EA-GV MAPS

# Guide to Groundwater Vulnerability Mapping in England and Wales


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NRA

National Rivers Authority

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**Statement of Use**
This document is to be used by the NRA as a basis for a guide to accompany the series of 1:100 000 scale groundwater vulnerability maps being produced for the NRA by SSLRC and BGS. The document will also inform NRA staff about the principles behind the maps and provide a clearer understanding of how to use the maps and the limitations of the information provided by the maps.

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# GLOSSARY

Adsorption
Process by which a thin layer of a substance accumulates on the surface of a solid substance.

Aerobic
In the presence of the atmosphere or free oxygen.

Aquifer
Permeable strata that can transmit and store water in significant quantities.

Attenuation
Breakdown or dilution of a contaminant in water.

Baseflow
That part of the flow in a watercourse made up of groundwater and discharges. It sustains the watercourse in dry weather.

Biodegradation
Microbial breakdown of a compound.

Bypass flow
Liquid flow through preferential routes in cracks, fractures etc. whereby flow is more rapid than within the soil or rock matrix.

Cation
Positively charged ion (see Cation Exchange and Cation Exchange Capacity)

Cation exchange
The interchange between cations in solution and cations on the surface of clay or organic colloids.

Cation exchange capacity
The sum total of exchangeable cations that a soil can adsorb.

Confined aquifer
Where permeable strata are covered by a substantial depth of impermeable strata such that the cover prevents infiltration.

Confining beds
Impermeable strata which prevent infiltration to underlying permeable strata.

Conservative pollutant
Pollutant which can move readily through the aquifer with little reaction with the rock matrix and which are unaffected by biodegradation (eg chloride).

Diffuse source pollutants
Pollution from widespread activities with no one discrete source

Diffusion
The process by which ions and molecules dissolved in water move from areas of higher concentration to areas of lower concentration.

Drift deposits
Term used to include all unconsolidated superficial deposits (eg. fluvioglacial, alluvium etc.) overlying solid rocks.

Ecosystem
A system involving the interactions between a community and its non-living environment.

Fractures/Fissures
Natural cracks in rocks that enhance rapid water movement.

Inorganic
Chemicals which are not carbon-based, such as salt, nitrate fertilizers etc.

Leaching
Removal of soluble substances by action of water percolating through soil, waste or rock.

Lithology
The general characteristics of a sedimentary rock including mineral composition and texture.

Organic
Chemicals which are carbon-based, such as pesticides, dry cleaning solvents etc.

Outcrop
Where strata are at the surface, even though they may be obscured by soil cover.

Permeability
measure of a soil or rock's capacity to transmit water.

pH
the degree of acidity (or alkalinity) of a solution or soil and expressed in terms of the pH scale.

Potentiometric surface
A surface that represents the level to which water will rise in tightly cased wells.

Primary Permeability
Permeability related to flow between grains within the aquifer.

Recharge
Water which percolates downwards from the surface into groundwater.

Secondary Permeability
Permeability related to groundwater flow within fissures rather than between grains (see Primary Permeability)

Septic tank
Small tank receiving and treating sewage by bacteria where effluent overflows.

Slowly permeable (soil)
A term used to describe subsurface layers which act as a significant barrier to water movement when the soil is saturated. They are generally dense and clay-rich.

Soakaway
System for allowing water or effluent to soak into the ground, commonly used in conjunction with septic tanks.

Temperate
Moderate, without extremes.

Unconfined aquifer
An aquifer in which the water surface is formed by the water table which is free to fluctuate under atmospheric pressure and can thus reflect changes in storage in response to abstraction and recharge.

Unsaturated zone
Zone of aquifer between soil and watertable which is partly saturated (ie that part of the aquifer above the water table.

Water table
Top surface of the saturated zone within the aquifer.

# EXECUTIVE SUMMARY

This guide, produced by the Soil Survey and Land Research Centre (SSLRC) and the British Geological Survey (BGS), is designed to be used with the series of 1:100 000 scale Groundwater Vulnerability Maps which form part of the National Rivers Authority (NRA) Groundwater Protection Policy. The generic information contained within this guide supplements the local information provided on each map legend so that the map user is provided with a clear understanding of the scope and limitations of the data presented.

To cater for the different levels of knowledge of map users, it is envisaged that those who only require sufficient guidance to use and interpret the maps will consult Chapters 1, 3 and 4. Those users requiring technical information on the principles used in the compilation of the maps and on the conceptual limitations of the maps should also consult Chapters 2 and 5. The five chapters are:

Chapter 1 identifies the aims of the guide and provides the background to groundwater vulnerability mapping within the context of European and national legislation. The physical factors affecting groundwater vulnerability are discussed and finally the role of the map series within local authority planning is described.

Chapter 2 describes the scientific principles used in the groundwater vulnerability assessment. The water cycle, hydrogeology, soil and the factors affecting pollutant movement are described.

Chapter 3 outlines the methodology and data sources used in the map production. The classification of solid geological units into Major Aquifers, Minor Aquifers and Non-Aquifers; drift geological units into Minor Aquifers and low permeability drift; and soil types into Leaching Potential classes are described.

Chapter 4 provides an overview of the information shown on the maps and gives examples of interpretations based on the maps for assessing potentially polluting activities on the land surface and within the soil zone.

Chapter 5 presents some of the limitations of the maps at the site-specific level and in terms of the reliability of the data used. This chapter stresses the need for the user to take into account the limitations inherent in this regional scale of map and for the necessity of site investigation at the site-specific level.

# KEY WORDS

Groundwater
Groundwater vulnerability
Soil
Soil leaching potential
Aquifer classification
Pollutant movement
Groundwater Protection Policy
Maps

# 1. INTRODUCTION

## 1.1 Aims of the guide

This guide is designed to be used with the series of 1:100 000 scale maps which form part of the National Rivers Authority (NRA) Policy and Practice for the Protection of Groundwater (abbreviated in this document to Groundwater Protection Policy- GPP), published in 1992. The maps depict groundwater vulnerability, a concept based on interpretations of geology and soil, and the series is being progressively published over a 4½ year period with full coverage of England and Wales expected by 1998. The programme is being carried out by the Soil Survey and Land Research Centre (SSLRC) and the British Geological Survey (BGS) to take advantage of the existing soil and geological databases of the two organizations.

The aims of this guide are to:

- give the background to the groundwater vulnerability mapping programme
- describe the groundwater, geology, soils and contaminant transport principles used in the classifications forming the basis of the maps
- describe the methodology and data sources used in the production of the maps
- provide an overview of how to use the maps through example interpretations
- discuss some limitations of groundwater vulnerability mapping in general and at 1:100 000 scale in particular.

This guide, together with the Source Protection Zone Guide, provides a complement and update to the GPP and is directed towards the following readership:

- NRA officers, and particularly non-specialists in groundwater protection
- developers and their agents
- planning, central government and other statutory authorities
- interest groups
- consultants.

Because of the likely different levels of technical knowledge between the many map user-groups this guide is aimed at the informed non-specialist lay person. However, as the guide provides both general and detailed background information, it is envisaged that it will be used in different ways by the various users of the Groundwater Vulnerability Maps.

Those who only require sufficient guidance to use and interpret the maps are advised to consult:

- Chapter 1- Introduction
- Chapter 3- Map production methodology and data sources
- Chapter 4- Use and interpretation of the maps.

Those users requiring specialist technical information on the principles used in the compilation of the maps and on the conceptual limitations of the maps should also consult:

- Chapter 2- Principles used in groundwater vulnerability mapping
- Chapter 5- Limitations of the Groundwater Vulnerability Maps

## 1.2 Background

### 1.2.1 The importance of groundwater

Groundwater is contained naturally within underground water-bearing strata (*aquifers*[1]) of various types across the country. It is present within all rocks but some contain more than others and are therefore more important for water resources.

The volume of water stored in the pores and *fractures* of aquifers vastly exceeds the volumes of fresh water in lakes and rivers in England and Wales. Many of the most productive aquifers, such as the Chalk or Triassic sandstones, occur in the densely populated relatively dry eastern and central parts of England and consequently, groundwater has a strategic significance in providing high quality water for public supply. It provides approximately 35 per cent of present national demand but in some southern and eastern regions more than 80 per cent.

Groundwater is also an important source for industry and agriculture as well as sustaining the *baseflow* of rivers. Rivers can dry up without sufficient volumes of groundwater inflow as occurred in Chalk streams during the drought of the early 1990's. Baseflow often provides the bulk of a river's flow in summer so that groundwater quality is crucial in maintaining surface water quality to the benefit of aquatic ecology, wetland habitats and recreational uses.

Groundwater is increasingly under threat. Pollution can arise from many activities carried out on, or near, the land surface. This may be at a particular place (a point source) or be widespread over large areas (a diffuse source). Examples of point source pollution include spillages of chemicals from industrial sites which give rise to intense but localised effects. In contrast, nitrate pollution from agriculture is a diffuse source which can build up over many years and affect significantly larger volumes of groundwater. The protection of groundwater quality is of critical importance for the following reasons:

- The degradation of a widespread high quality water resource, through contamination of an aquifer, might necessitate the development of more expensive water resources, if available, or expensive water treatment before use.

- Once polluted, groundwater is costly and difficult, if not impossible, to rehabilitate due to the inaccessibility of the strata, the slow rates of groundwater movement and the low levels of microbiological activity. Processes which take place in days or weeks in surface water systems are likely to take decades in groundwater systems.

It is better to prevent or reduce the risk of groundwater contamination than to deal with its consequences.

[1] Words shown in italics are defined in the glossary

### 1.2.2 Groundwater vulnerability within the legislative framework

In 1980 the European Commission introduced a Groundwater Directive (80/68/EEC) aimed largely at the control of discharges of a wide range of potentially toxic substances. These are grouped by the Directive into List I and List II substances (NRA 1992, Appendix 1). The Directive did not address either diffuse pollution arising from the use of agricultural fertilizers or the essential links to the management of abstraction.

At a Seminar on Groundwater held in the Hague in November 1991, EC Environment Ministers recognized the limitations of existing community-wide regulations and adopted an action programme for the future protection of groundwater. Groundwater is recognized as a finite, natural resource of great value which should be managed and protected on a sustainable basis. The subsequent declaration stressed that the objective of sustainability should be implemented through an integrated approach, which means that surface water and groundwater should be managed as a whole, paying equal attention to both quality and quantity aspects and taking into account all interactions with the soil and atmosphere.

The NRA (and the Environment Agency after April 1996) has a duty to monitor, maintain and protect groundwater resources from pollution with the aid of various legislative provisions. These provisions implement EC Directives including the 80/68/EEC on the Protection of Groundwater Against Pollution Caused by Certain Dangerous Substances, the Control of Pollution Act 1974, the Environment Protection Act 1990 and the Water Resources Act 1991. Together they control the storage and discharge of dangerous chemicals to groundwater, control the disposal of wastes, and control the handling of potential pollutants used in the agricultural industry.

At its time of creation in 1989, the NRA inherited various Groundwater Protection Policies from the former Water Authorities. In order to consolidate and standardise the existing policies and to take account of new duties imposed on the NRA, including the need to support the EC objective on sustainability of groundwater quality and quantity, the NRA has adopted a new policy framework for protecting groundwater that is outlined in the Groundwater Protection Policy. Groundwater Vulnerability Maps, and Source Protection Zones (which are being produced separately), are integral parts of the Groundwater Protection Policy. The maps deal with the areal zonation of land above aquifers according to the vulnerability to pollution of the groundwater contained in the underlying aquifer, whereas Source Protection Zones define areas immediately surrounding a groundwater source or group of sources according to the travel times for groundwater flow to the source.

## 1.3 Groundwater vulnerability

### 1.3.1 Factors which affect groundwater vulnerability

Many human activities present a potential hazard to groundwater quality and in most cases a significant element of the total hazard to quality depends on natural soil and geological conditions. The concept of groundwater vulnerability, that is the susceptibility of groundwater to contamination from surface or near-surface derived pollutants, recognizes that the risk of pollution from a given activity is greater in certain soil and hydrogeological situations than in others.

Groundwater vulnerability depends on the natural characteristics of a site and relates to the ease of vertical movement of pollutants. It is assessed on the physical, chemical and biological properties of the soils and rocks beneath the site as these control the ease with which a pollutant can migrate to the *water table*. The factors which together define the vulnerability of groundwater resources to a given pollutant or activity are:

- presence and nature of overlying soil
- presence and nature of *drift deposits*
- nature of solid geological strata in the *unsaturated zone*
- depth to groundwater.

It has also to be recognized that these intrinsic properties can be modified by man-made structures or excavations.

The key to groundwater vulnerability classification lies in the unsaturated zone - that volume of the soil, and unsaturated aquifer or *confining beds* situated above the water table or *potentiometric surface*, respectively. In the absence of *fissures* in the unsaturated zone, water movement is essentially slow and takes place within the interconnected pore spaces; the chemical environment is *aerobic* and generally alkaline. This provides the potential for:

- interception, *adsorption* and elimination of bacteria and viruses.
- *attenuation* of heavy metals, and other *inorganic* compounds.
- adsorption and *biodegradation* of *organic* compounds.

The presence of vertical fissure systems, however, may enable the rapid flow of pollutants from the land surface directly to the water table and the potential therefore for the above processes to take place will be greatly reduced.

There are many published methodologies for assessing groundwater vulnerability (IAH, 1994). A review of the available techniques (Adams and Foster, 1991) enabled the NRA (later followed by the Department of the Environment for Northern Ireland and also the Scottish Office Environment Department) to adopt the easily visualized approach described in this guide.

The NRA 1:100 000 scale Groundwater Vulnerability Maps have been prepared to reflect the different degrees of groundwater vulnerability according to a range of soil properties and geological criteria (Foster and Skinner, 1995). The main purpose of the maps is to communicate such scientifically derived land subdivisions to those whose knowledge of the earth sciences may be limited but who need to make land use and land management decisions based on the data portrayed in the maps.

### 1.3.2 Groundwater Vulnerability Maps within the Groundwater Protection Policy

A full vulnerability assessment of the risks posed to groundwater by potentially polluting activities on the land surface can only be achieved by local studies which, in many cases, will involve detailed soil and hydrogeological investigations. However, in the context of strategic land use planning the NRA (Environment Agency) is producing the series of Groundwater Vulnerability Maps to allow planners, developers and regulatory bodies to make informed judgements on the location of new developments.

The policy statements in the Groundwater Protection Policy and the information provided on the Groundwater Vulnerability Maps do not, of themselves, have a statutory status. However, they will enable the NRA to use its existing statutory powers in a consistent and uniform manner and they will guide it in its response to the various statutory and non-statutory consultations it has with other organisations whose decisions can affect groundwater.

### 1.3.3 Purpose of the Groundwater Vulnerability Maps

The Groundwater Vulnerability Maps are an aid both to developers planning new activities, and to Planners assessing new proposals or drawing up strategic planning documents (Local Plans/Structure Plans). They will allow better informed judgements to be made on the location of new developments. By consulting the maps, in conjunction with the policy statements and matrices in the Groundwater Protection Policy, land users and developers will know to avoid proposing potentially polluting activities in highly vulnerable areas, while favouring sites on Non-Aquifers or sites with soils of low *leaching* potential where a more permissive view is likely to be taken by the NRA. It is important to recognize this role as a 'first pass' screening tool in site assessment. Site specific studies will always be needed for detailed proposals.

The maps also have a use in the consideration of existing activities which may be giving rise to (presently undetected) pollution. They will allow owners of multiple sites to prioritise their investigative and subsequent remedial actions where historical practice may have given rise to land and groundwater contamination.

This is the first time this type of information has been published in England and Wales and it will prove an invaluable source of initial strategic information to local planning authorities, other regulatory bodies, developers, consultants and the general public.

### 1.3.4 Groundwater vulnerability mapping

All groundwaters are controlled waters and are afforded protection, regardless of whether, or how, they are currently used. However, for strategic land use planning it is convenient to subdivide permeable strata into the categories of Major Aquifers and Minor Aquifers. Due to relatively high *permeability*, Major Aquifers generally have less capacity for attenuating contaminated *recharge* entering at their surface than Minor Aquifers. This division is to a certain extent also coincident with their water resource potential. Low permeability strata are classified as Non-Aquifers although groundwater will be present and may be an important part of surface water baseflows.

A soil classification, based upon the physical and chemical properties of undisturbed soil, has been developed by SSLRC to assess the likelihood of pollutants moving down through the soil column. This classification can be applied to all soils, but only those soils overlying Major and Minor Aquifers have been classified on the maps.

Wherever geological investigations identify low permeability surface drift deposits overlying Major and Minor Aquifers their presence is indicated on the maps by a stipple ornament. A stipple is used to highlight the inherent variability in permeability of many drift deposits, both laterally and vertically, to emphasise the need for detailed site specific information to assess individual situations.

The Groundwater Vulnerability Maps therefore show the degree of risk of a pollutant, which originates at the surface, moving down into an underlying aquifer by assessing (Figure 1.1) the:

- soil type
- likely presence/absence of low permeability surface drift deposits
- permeability of aquifer material.

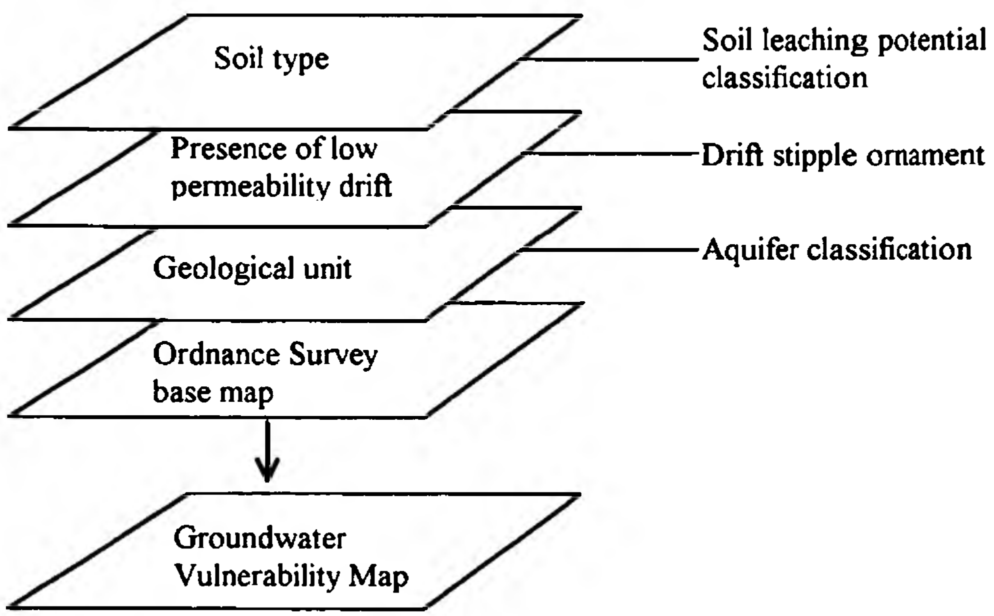



**Figure 1.1 Overview of information layers used to compile a Groundwater Vulnerability Map.**

# 2. PRINCIPLES USED IN GROUNDWATER VULNERABILITY MAPPING

## 2.1 Water cycle

The water cycle, depicted in Figure 2.1, has no beginning or end but it is convenient to describe it starting with the process of evaporation whereby water vapour enters the atmosphere. Evaporation is not restricted to open water bodies, such as oceans, lakes, streams and reservoirs. Precipitation (rain, hail, snow or mist) intercepted by leaves and other vegetative surfaces can also evaporate, as can soil moisture in the upper layers of the soil.

Water vapour is held in the atmosphere and transported by global weather systems until conditions cause the vapour to condense to form droplets which fall as precipitation. Precipitation which reaches the ground, without being intercepted, can follow a number of different pathways within the water cycle. Precipitation which drains across the ground surface is termed runoff, and can directly enter stream channels. A proportion, however, infiltrates into the ground, and drains downwards through the unsaturated zone by gravity at a rate dependant on the soil permeability, a function of the size of the pores and their degree of continuity. At some depth, the soil or rock is saturated with water. As the water moves through the unsaturated and saturated zones, its chemistry is changed by interactions with the surrounding soil and rock material.

Groundwater, although it often flows at a very slow rate, may not stay underground for ever. It can discharge as a spring or as slow seepage into stream, lake or ocean beds. Water flowing in a stream can therefore originate either from runoff or from groundwater that has seeped into the stream bed. The groundwater contribution is termed baseflow.

## 2.2 Hydrogeology

### 2.2.1 Introduction

The rocks that underlie England and Wales can be classified according to their age (see Appendix 1), according to their mode of formation or merely according to their type (sandstone, granites, limestones etc.). An aquifer contains useful quantities of groundwater within its interconnected pore spaces and cracks which can be abstracted. Classification of rocks according to their physical properties relating to the occurrence of groundwater is, therefore, most pertinent to any assessment of the vulnerability of groundwater to pollution.

Groundwater is the water contained within a rock system both within the unsaturated zone as well as below the water table in the saturated zone (Fig. 2.1).

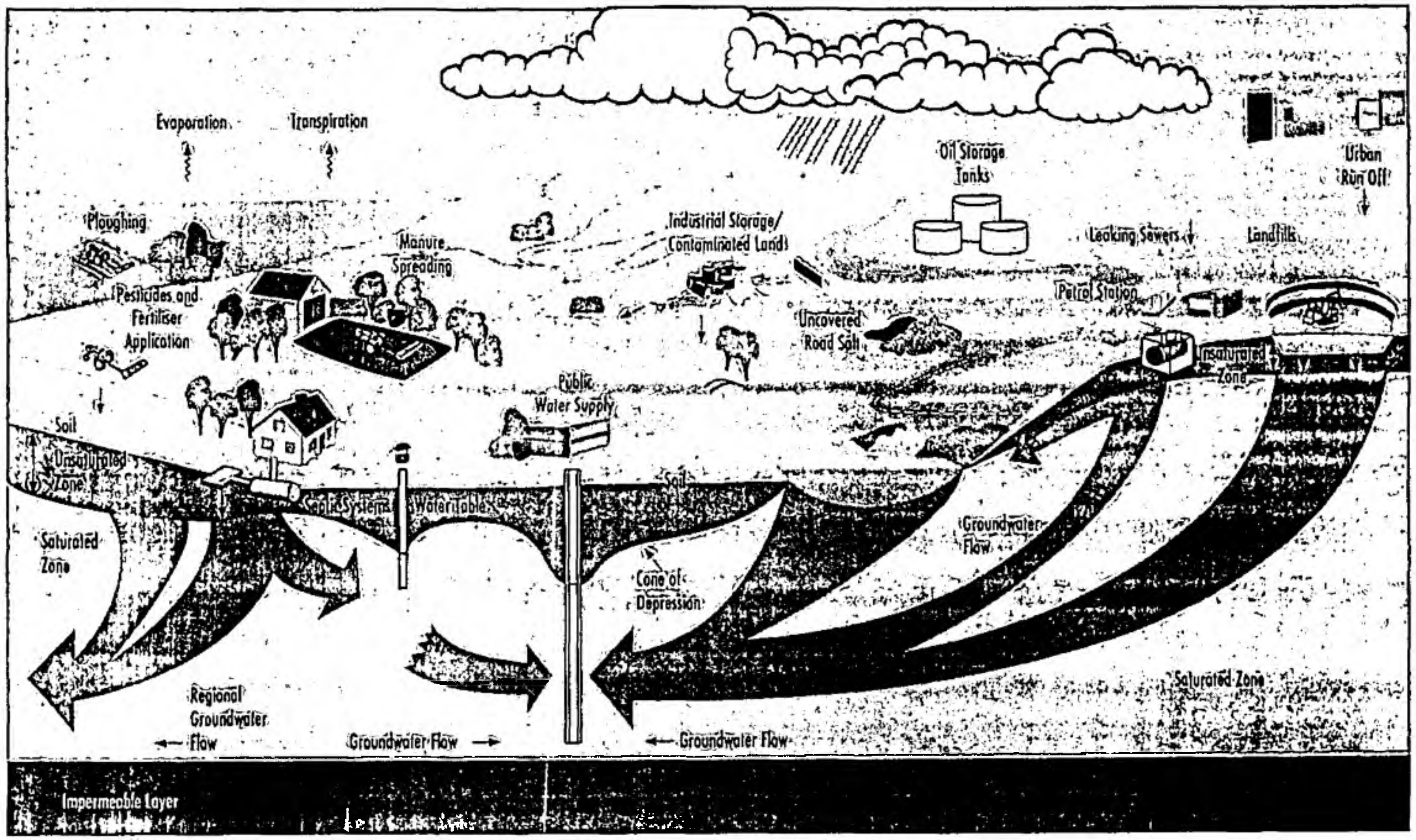



**Figure 2.1 Diagrammatic representation of the water cycle showing groundwater and surface water relationships and groundwater pollution risks**

### 2.2.2 Importance of the unsaturated zone

Above the water table, *unconfined aquifers* have an unsaturated zone, which may include unconsolidated drift deposits and, above these, the biologically active soil zone. The nature of any drift cover is important with regard to the downward percolation of pollutants through the unsaturated zone. A cover of uniform clay grade material, such as clay till, will provide a hydraulic barrier, whereas sand and gravel as in glacial outwash deposits will readily allow the downward passage of pollutants.

In the case of mobile *conservative pollutants* (e.g. road salt) the unsaturated zone merely introduces a time lag before the arrival of the pollutant at the water table without significant attenuation.

In other cases (e.g. degradable organic compounds) the degree of attenuation is highly dependent upon the unsaturated zone but is difficult to predict. It will depend on the:

- physical and chemical characteristics of the pollutant
- geochemical environment
- time taken to travel from surface to water table (Robins et al., 1994), which depends upon the intensity of application of the pollutant, the prevailing rainfall, the presence or absence of by-pass fissures or low permeability horizons (e.g. marl bands) and the thickness and *primary permeability* of the unsaturated zone.

For *diffuse source pollutants*, transit time in the unsaturated zone can be assessed from average annual infiltration rates and the moisture retention properties of the soil. In practice, saturated flows only occur for short periods of time under field conditions, but in most strata (other than fine-grained unconsolidated sediments) maximum pollution risk occurs wherever the unsaturated zone is thinnest. The *lithology* of the unsaturated zone, its degree of consolidation and the presence of fracturing in, are the key factors beneath the soil zone in assessing the vulnerability of groundwater to pollution.

### 2.2.4 Role of the saturated zone

Groundwater flow is induced from areas where the water table is highest, which are, therefore the main areas of recharge, to areas where the water table is at its lowest elevation, again by definition the areas where groundwater discharge (springs or baseflow to rivers) is at its greatest.

Rocks which are less able to transmit groundwater may form a hydraulic barrier, or a confining layer to deeper, more permeable strata. Such is the case in the London Basin, where London Clay confines groundwater in the underlying Palaeogene sands and the Chalk. The latter forms a *confined aquifer* beneath parts of London, but are unconfined where they *outcrop* beyond the London Clay cover to form the Chalk downlands (Figure 2.2). A confined aquifer whose recharge area may be distant, is better protected from direct percolation of pollutants. In the London Basin, the Chalk remains susceptible to surface pollution at outcrop beneath the Chalk downlands north and south of the London Clay cover, but not in the confined area beneath the London Clay.

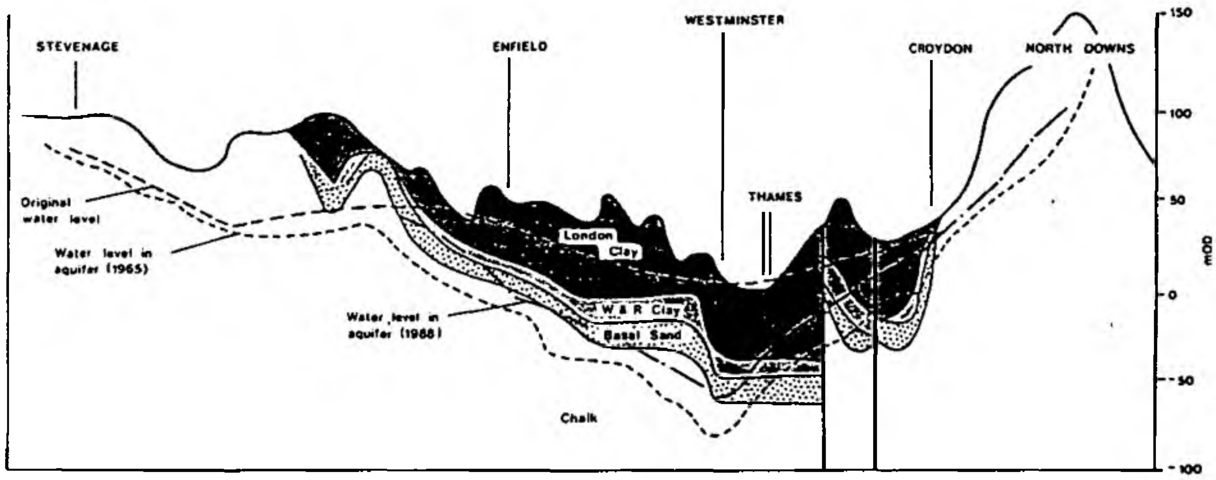



**Figure 2.2 A diagrammatic geological cross section of the London Basin**

The Groundwater Vulnerability Maps only classify aquifers which outcrop at surface or beneath drift cover; these tend to be unconfined aquifers. Aquifers that are confined by bedrock, which are concealed and protected from pollution by their confining cover, are not shown.

Groundwater in many aquifers such as the Chalk or the Permian and Triassic sandstones is contained both in intergranular pore spaces and in the many cracks which characterize these rocks. Although storage of water in the intergranular pore spaces is usually more significant than that in the cracks, it is the cracks which are likely to be the main route for groundwater flow. These are termed fractured aquifers. However, the dimensions, and importance of fractures for groundwater flow vary greatly from aquifer to aquifer.

There are three key physical properties which all rocks, both aquifers and non-aquifers possess. These are:

- permeability (which is based on the size and connectivity of the pores and other voids within a given rock unit) which controls the ease with which groundwater can flow
- porosity, or volume of void space (water and air filled) relative to the unit volume of aquifer
- amount of groundwater that may be released from the aquifer (storage coefficient).

Clearly aquifers with high permeabilities and large storage coefficients are likely to be most susceptible to pollution from the surface simply because water can move relatively rapidly through their interconnected pore spaces, cracks and fractures in the unsaturated and saturated zones.

There is no consideration of the processes taking place in the saturated zone within this assessment of groundwater vulnerability because once a pollutant has arrived at the water table the groundwater is assumed to be contaminated. However, the prevailing groundwater flow direction (hydraulic gradient) and physical properties of the aquifer will dictate the direction, speed of movement, *diffusion* and possible further attenuation of the pollutant within the groundwater body.

## 2.3 Soil

### 2.3.1 Introduction to soils

Soil is the upper layer of the earth's crust and is the product of complex interactions, which are most intense near the surface, between climate, living organisms, parent material and relief. Soils develop through the accumulation of unconsolidated mineral grains from the physical and chemical weathering of rock fragments and the addition of organic material (humus) from vegetation. For the purposes of assessing pollutant movement, soil is here considered to be the upper weathered parts of the earth which are affected by living organisms, and which undergo seasonal changes in moisture content, temperature and gaseous composition. In the UK, as in most other *temperate* countries, the soil zone extends to about 2 m depth.

A vertical section through soil, as seen in the face of a pit or excavation is known as a soil profile (Fig. 2.3). A soil profile usually contains a number of distinct horizons, or layers, which are the product of various soil forming processes taking place within it. There is usually a complex assembly of horizons within a soil profile but a simple three-fold division is discussed below. From the surface downwards these are:

- **Topsoil-** This is usually dark brown in colour due to the incorporation of decomposed plant residues. It is relatively organic- and nutrient-rich and is the zone of maximum biological activity. It is also subject to the greatest changes in temperature and moisture. Most roots, plant and animal life, from moles to earthworms, to microscopic bacteria and fungi are found here.

- **Subsoil-** This is the altered parent material where soil forming processes are active; minerals are actively broken down and altered, plant nutrients are released and considerable reorganization of soil material occurs, involving the binding of soil particles to form aggregates. Organic material is restricted to living and dead plant roots and is much less abundant than in the topsoil.

- **Parent material-** This is the relatively unaltered material at the base of the soil profile in which the soil is developed. This zone is least affected by soil forming processes and the original rock structure can usually be seen. The depth to parent material within the soil depends on its resistance to weathering and the length of time the weathering processes have been active.

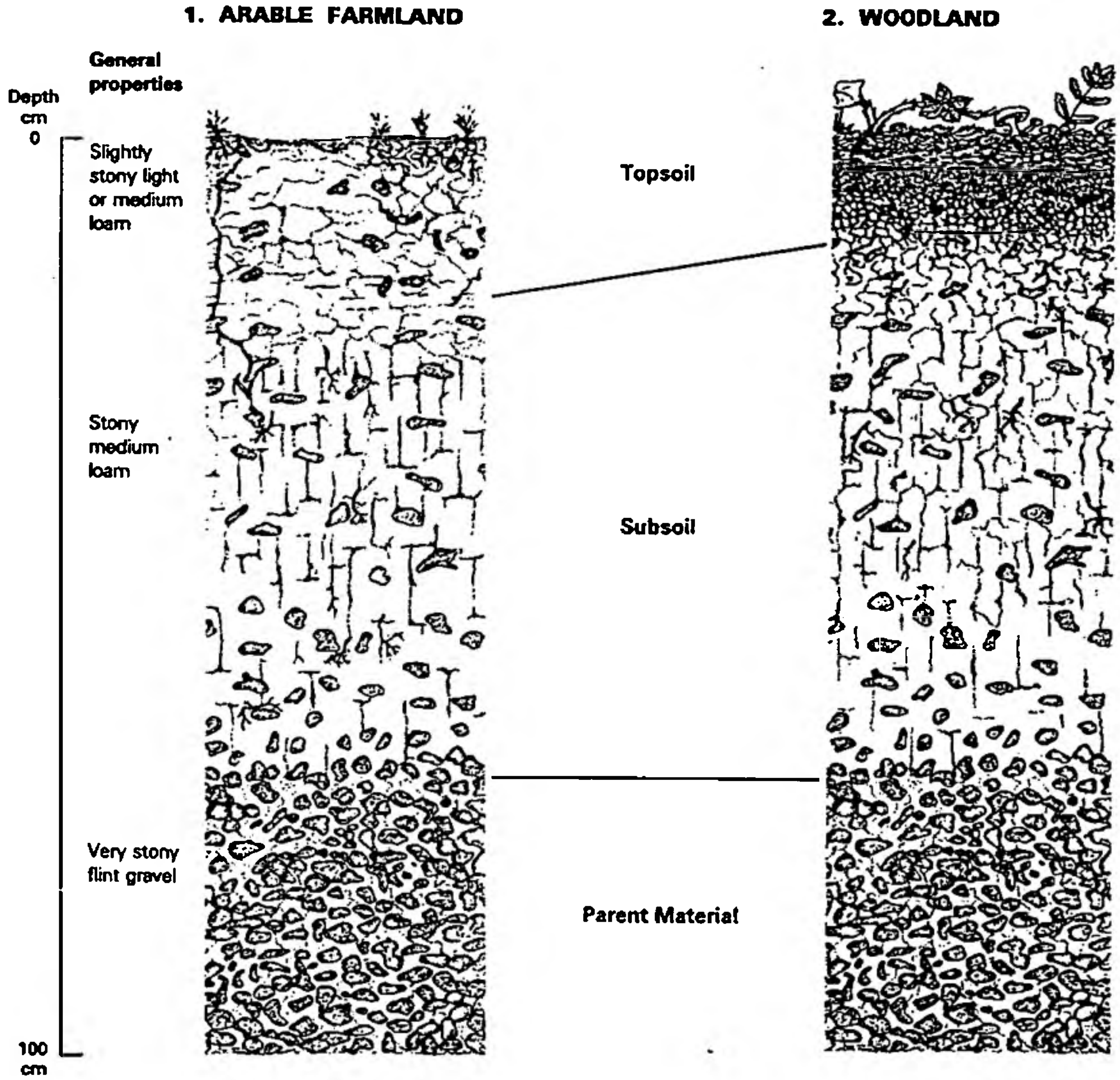



**Figure 2.3 Diagrammatic representation of a soil profile showing the three main horizons (or layers).**

### 2.3.2 Soil classification in England and Wales

The characteristics of the soil at any particular location depend on five main groups of factors. These are:

- the physical and chemical constitution of the parent material
- past and present climate
- relief and hydrology
- length of time during which soil forming processes have been acting
- *ecosystem*, including the extensive modifying effects of man's activities.

In order to provide a consistent and systematic basis for differentiating the characteristics, properties and relationships of soils in England and Wales, a *hierarchical* soil classification has been developed (Avery, 1980). This classification, adopted for use throughout England and Wales, groups soils that behave in a similar and therefore predictable way.

The lowest category in the system (Clayden and Hollis, 1984), and the unit shown on detailed soil maps, is the soil series, of which there are over 700 established. Soil series are named after the place where they were first described or are extensive. For example, the Aberford series was first described near the village of Aberford in North Yorkshire during the early stages of the soil survey of the Leeds district (Crompton and Matthews, 1970).

Each soil series has a limited and defined range of diagnostic properties that distinguish it and allow its consistent national recognition, so that soils belonging to the Aberford series are recognised throughout the areas of Jurassic and Magnesian Limestone in eastern and southern England. A useful definition is given by Robinson (1943)- "a group of soils similar in character and arrangement of horizons of the profile, and developed under similar conditions from one type of parent material".

The diagnostic properties used to differentiate soil series are the relatively permanent properties which determine soil behaviour, but which are not easily changed by land management practices. Several important diagnostic properties used to define soil series also influence the movement of pollutants in soil:

- depth and duration of waterlogging. This is associated with either high groundwater levels or precipitation. A high soil water table may indicate a limited unsaturated zone.
- texture. This is based on the relative proportions of sand, silt and clay-sized particles in a soil (particle size distribution) and is closely related to permeability.
- parent material type and depth. This identifies where aquifers are very close to the land surface.
- organic matter content. This is related to the ability to adsorb pollutants.

For example using the above criteria, the Aberford series is defined as a well drained, fine loamy textured soil developed in hard or shattered limestone bedrock within 80 cm depth.

The spatial distribution of soil series within the landscape is very complex and, locally, can be difficult to show on a map even at 1:10 000 scale. For maps at a scale of 1:100 000 or smaller, amalgamations of soil series into soil complexes or soil associations are usually made. Soil complexes contain two or more soil series which are intricately mixed in the landscape such that they cannot be mapped separately. A soil association is a grouping of soil series that occur together, often in predictable patterns, on the same geological parent material and which differ in characteristics related to local variations in texture, relief and hydrologic conditions. They are generally characterised and named after the most frequently occurring component soil series (termed the lead series), although the other soil series may have different soil leaching potentials to the lead series.

For example in a typical area mapped as Aberford association, it is predicted that approximately 55 % of the soils consist of Aberford series (H3 soil leaching potential), 30 %

Elmton series (H1 soil leaching potential- a very shallow soil over limestone), 10 % Dullingham series (I1 soil leaching potential- a deep soil found in narrow valley bottoms and formed in accumulated weathered limestone debris) and 5 % other undefined soil series. For explanation of soil leaching potential classes see Inset on page 26.

## 2.4 Factors affecting pollutant movement in soil

### 2.4.1 Introduction

Factors which influence how likely a pollutant applied at the soil surface will move through the soil profile include:

- characteristics of the potential contaminants
- physical and chemical characteristics of the soil including
  - -characteristics which encourage lateral pollutant movement
  - -characteristics which affect the speed of pollutant movement
  - -influence of soil texture on pollutant mobility
  - -characteristics affecting the degradation or attenuation of potential contaminants.

### 2.4.2 Characteristics of the potential contaminants

The Groundwater Vulnerability Maps consider the ability of the soil and unsaturated zones to attenuate three types of pollutant:

- liquids (e.g. from slurries, manures, waste water irrigation and large spillages)
- diffuse pollutants which under certain circumstances can be adsorbed (or retained) in the soil layers (e.g. pesticides, certain other organic compounds and some metal-based inorganic compounds)
- diffuse pollutants which are soluble and can readily pass through the soil layers without being adsorbed (e.g. nitrate).

**Liquids**

The rate of pollutant movement through the soil resulting from liquid discharges is much faster than the movement associated with diffuse pollutants derived from either agrochemicals or the redevelopment of contaminated land.

In the case of liquid discharges, the large volumes often involved produce saturated conditions at or near the surface for at least a short period. The rate of pollutant movement through the soil will then be dependant upon the vertical or sub-vertical saturated soil permeability. Potential pollutants may therefore move rapidly (several meters per day) out of the upper soil layers and hence bypass the zone of maximum microbiological activity, and consequent degradation.

**Diffuse pollutants**

Diffuse source pollutants, compared with liquid discharges, are characterized by much lower rates of application and therefore lower concentrations of pollutant are present in the soil water. Unsaturated soil conditions usually predominate in which soil permeability is generally several orders of magnitude lower than when the soil is saturated. Potential diffuse source pollutants therefore remain in the upper soil layers significantly longer than most pollutants derived from a liquid discharge. Where pollutants have physico-chemical characteristics which allow attenuation by degradation and adsorption, these processes lead to a reduction in the volume and concentration of pollutant leaching from the soil. For diffuse source pollutants, the leaching potential of many soils to non- or weakly adsorbed compounds will be greater than their leaching potential to more strongly adsorbed ones.

### 2.4.3 Physical and chemical characteristics of soil

The physical and chemical characteristics of soil which influence the soil leaching potential classification are summarized in an Inset on page 26.

**Characteristics which encourage lateral pollutant movement**

Subsoil horizons which are dense, coarsely structured, clay-rich and act as significant barriers to water movement are termed slowly permeable. Soil layers above a slowly permeable horizon suffer seasonal waterlogging and water movement in these layers is lateral where slopes allow.

Where slowly permeable subsoils extend below 1m depth the downward movement of pollutants is strictly limited and it is unlikely that any pollutant applied at or near the surface will penetrate below 2 m depth. Such soils are classified as Low Leaching potential.

Locally, especially on sloping ground, soil characteristics indicate the occurrence of only slight seasonal waterlogging above the slowly permeable layer. Here excess water may be readily shed laterally downslope or the slowly permeable layer may not be laterally continuous and hence allow some downward percolation. In these situations the soils are placed in the Intermediate (I1) Leaching potential class.

In upland sites, a combination of high rainfall and low permeability bedrock or drift can lead to the development of permanently wet peaty topsoils. These blanket peats readily shed excess rainfall laterally and are classified as Low Leaching potential.

**Characteristics which affect the speed of pollutant movement**

Pollutants can pass rapidly to groundwater or through the soil zone either where the soils suffer from a seasonally high water table caused by fluctuating groundwater or where the soils are shallow over bedrock, rock-rubble or gravel.

In many lowland soils, seasonal waterlogging is caused by fluctuating groundwater within the soil profile. Even when underdrainage is installed it is likely that during the wettest parts of the year, there will be groundwater at relatively shallow depth within the soil. In such circumstances, even relatively short-lived pollutants, such as biodegradable pesticides and herbicides, which enter the soil are likely to reach groundwater. Such soils are classified as High (H1) Leaching potential.

Raw lowland peat soils that are saturated for most of the year are also classified as High (H1) Leaching potential. They occur in undrained sites under semi-natural bog or fen vegetation, usually where peat is still accumulating.

Where hard bedrock, rock-rubble or gravel occurs immediately beneath the topsoil layer or where only a thin subsoil is present, potential contaminants at the soil surface are likely to reach the underlying geological material very quickly. Because the ability of unweathered geological material to attenuate potential pollutants is far less than that of soil material, little additional attenuation of the contaminant is likely to occur. Such soils are classified as High (H1) Leaching potential.

The thicker the subsoil overlying rock, rock-rubble or gravel the greater is the potential to attenuate diffuse source pollutants due to the increased time the pollutant is subject to degradation and adsorption in the soil zone. Therefore soils with a greater thickness of subsoil above the parent material, while still considered to be High Leaching potential are given a lower H3 subclass.

**Influence of soil texture on pollutant mobility**

When a pollutant enters the soil it partitions, or separates, into three phases. Some of the pollutant will adsorb onto clay particles and organic matter within the soil matrix, some will volatilize, or evaporate, into the gaseous phase and the remainder will remain as a liquid. After partitioning, the concentration of pollutant in the soil is determined by the relative volume of pollutant and water retained within the soil. Only a proportion of this retained liquid, that is the mobile fraction, which varies between soil types, is likely to move downwards through the soil, taking pollutants with it. Any potential pollutant within the remaining non-mobile liquid fraction, which resides in very small pores, will leach only very slowly by the process of diffusion into the mobile water.

For a conservative pollutant such as road salt, that does not degrade and cannot be metabolized by plants or micro-organisms, the entire volume of pollutant held within the non-mobile phase will eventually diffuse out and leave the soil profile. However, for non-conservative pollutants, this period of diffusion allows the pollutant to be degraded by microbial activity such that less of the pollutant originally retained in the non-mobile phase may be able to pollute groundwater.

In sandy soils, the volume of water retained by the soil is relatively small and most of the retained water is in the mobile phase. In these soils, therefore, the concentrations of any dissolved pollutant can be relatively high and a large proportion is likely to leach quickly out of the soil profile. Sandy soils thus have significantly less potential than other soils to attenuate potential pollutants through the processes of dilution, retardation and degradation. A subclass (H2) is therefore established in the High Leaching potential class to cater for sandy soils.

Conversely, peat soils and soils with a high silt and/or clay content are all able to retain significantly larger amounts of water, most of which is held tightly in the non-mobile phase. In such soils, therefore, the concentrations of any dissolved pollutant are likely to be lower than in sandy soils and, because a large proportion will be retained in the non-mobile phase, most will leach only slowly, giving more time for degradation to occur. These soils are grouped as Intermediate Leaching potential and a subclass I2 established for peat soils.

**Soil characteristics affecting degradation or attenuation of potential pollutants**

In broad terms, the ability of a soil to adsorb pollutants depends upon its *cation exchange capacity* which, under temperate soil forming conditions, depends mainly on organic matter and clay content, although *pH* can be an important modifier. Thus, the lower the soil organic matter and clay contents, the lower the ability of the soil profile to attenuate potential pollutants. Based on a statistical analysis of 6 500 soil samples by SSLRC, it has been possible to group soils into 4 broad classes of adsorption potential according to their overall clay and average topsoil organic matter contents under a range of land uses.

Soils with a low adsorption potential comprise well drained sandy or near-sandy soils with low clay and high sand contents throughout and a low average topsoil organic matter content. These soils are classified as High (H2) Leaching potential.

Soils with a moderate adsorption potential comprise well drained sandy or near-sandy soils with low clay and high sand contents throughout and a moderate average topsoil organic matter content. These soils are classified as High (H3) Leaching potential.

Deep, moderately permeable loamy and clayey soils with a low or moderate adsorption potential and which do not suffer marked seasonal waterlogging are classified as Intermediate (I1) Leaching potential.

Soils with a high adsorption potential comprise soils with organic mineral or peaty textures in some part. Due to their high organic matter content these soils are classified as Intermediate (I2) Leaching potential.

# 3. MAP PRODUCTION METHODOLOGY AND DATA SOURCES

## 3.1 Overview

The production of each Groundwater Vulnerability Map (Fig. 3.1) involves five main stages, with a consultation period for Quality Assurance checks after each of the first four stages. These ensure that potential errors are found and corrected before they are compounded in subsequent stages. Discrepancies and local NRA requirements are discussed as early as possible in the process. The five stages are as follows and the numbers correspond to those in Figure 3.1.

1. Preparation of an aquifer classification which places all geological units present in a map sheet area into the categories of Major Aquifer, Minor Aquifer, Non-Aquifer (Section 3.2.2). Low permeability drift deposits (Section 3.4) are also identified at this stage.
2. Preparation of Ordnance Survey (OS) film bases showing the extent of the various aquifer classes and of the low permeability drift deposits
3. Overlaying soil leaching potential classes (Section 3.3.2) onto areas of Major and Minor Aquifers
4. Production of a four colour 'cromalin' final proof map
5. Production of final artwork from which the printers make the printing plates.

## 3.2 Geology

### 3.2.1 Sources of Geological Data

The Groundwater Vulnerability Maps are compiled from the most recent BGS 1:50 000 or 1:63 360 scale geological maps. Generally, modern geological mapping is published at 1:50 000 scale but coverage is not yet complete (Fig. 3.2). Mostly these are published maps, but in a few cases compilations of recent, as yet unpublished, mapping are made available. Where there is no map coverage at these scales suitable 1:25 000, 1:10 000 or 1:10 560 scale maps have been used. The few remaining gaps have been filled with Old Series 1:63 360 scale maps and locally 1:250 000 and 1:625 000 scale maps have been used for the solid and drift deposits respectively where no other mapping is available. The source material has been photographically adjusted to 1:100 000 scale in order that the pertinent boundaries can be extracted.

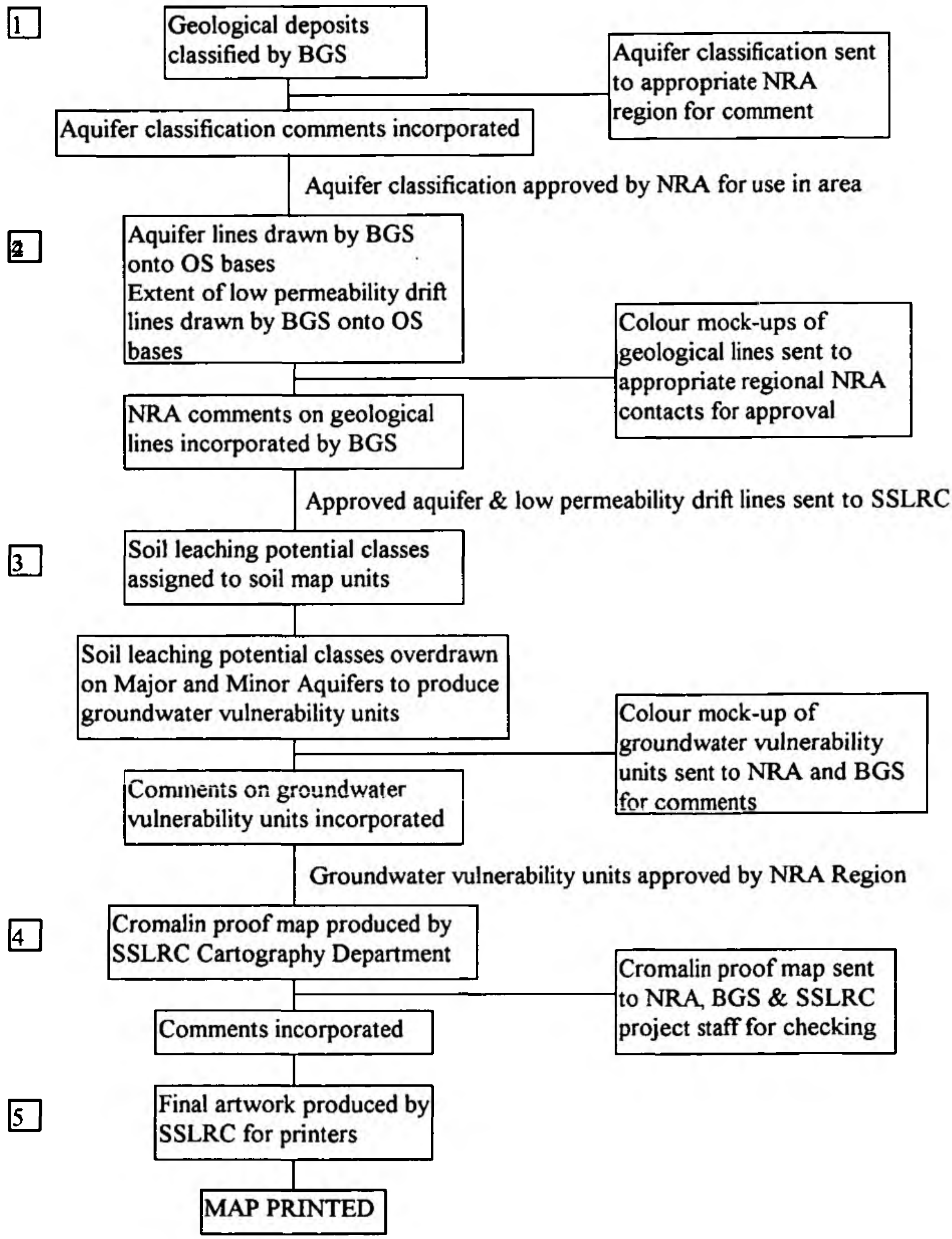



**Figure 3.1 Stages in producing Groundwater Vulnerability Maps.**

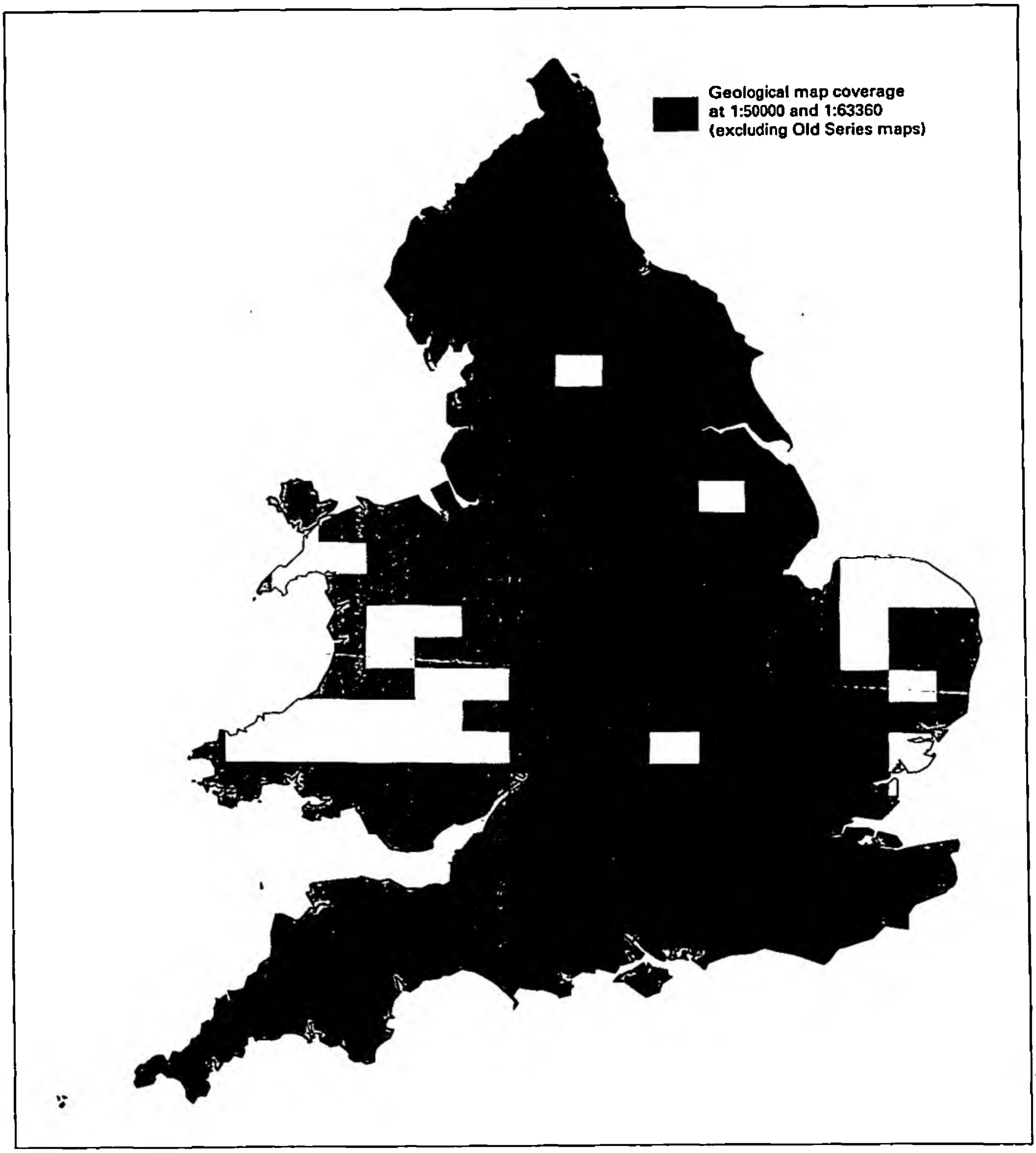



**Figure 3.2 Geological map coverage at 1:50 000 and 1:63 360 scale (excluding Old Series Maps) used in the compilation of the Groundwater Vulnerability Maps.**

### 3.2.2 Geological Classification

The legend to each vulnerability map includes a description of the geological classification which begins with the following statement:

> Geological strata which contain groundwater in exploitable quantities are termed aquifers, whereas rocks which are largely impermeable and do not readily transmit water are termed non-aquifers. Aquifers vary in their general and hydraulic properties and can be classified as fractured, fracture-intergranular and intergranular and it is these properties, particularly in the upper unsaturated zones, which form the basis of the groundwater vulnerability assessment.

The three basic geological classes are Major Aquifers (Highly permeable), Minor Aquifers (Variably permeable) and Non-Aquifers (Negligibly permeable) (Table 3.1). It is important not to confuse the use of these classification on the Groundwater Vulnerability Maps with groundwater resource potential, because the descriptors relate specifically to the vulnerability of the unsaturated zone and not necessarily to the saturated zone resource potential. Information on resource potential is available on hydrogeological maps (Fig. 3.3).

The three classes are broadly described as follows:

**Major Aquifer (Highly permeable)**: Highly permeable formations usually with a known or probable presence of significant fracturing. This class includes the *outcrop* areas of the three regionally most significant aquifers: the Chalk, the Permian and Triassic sandstones and the Jurassic limestones (the latter largely a confined aquifer). Full lists of these aquifers are given in Appendix 1.

**Minor Aquifers (Variably permeabie)**: Fractured or potentially fractured rocks, which do not have a high *primary permeability* (e.g. Millstone Grit), or other formations of variable permeability (e.g. alluvium) including unconsolidated deposits, such as the Crag, or permeable drift deposits (e.g. glacial sands and gravels). Full lists of these aquifers are given in Appendix 1.

**Non-Aquifers (Negligibly permeable)**: These are formations which are generally regarded as containing insignificant quantities of groundwater, although some may yield water in sufficient quantities for domestic use. Full lists of these aquifers are given in Appendix 1.

All permeable drift deposits are mapped as Minor Aquifers; although wherever they overlie a Major Aquifer this takes precedence. All permeable drift deposits are mapped regardless of whether they contain groundwater (potentially an aquifer) or are dry (the base of the deposit is situated above the water table) as this may vary from season to season. Drift deposits can vary greatly in composition vertically and horizontally, so that their hydraulic properties which are used in the aquifer classification may change over very short distances.

**Table 3.1 Generalized Classification of Types of Strata (refining Appendix 3 in NRA, 1992)**

| Major Aquifers (highly permeable) | Minor Aquifers (variably permeable) | Non-Aquifers (negligibly permeable) |
|---|---|---|
| Chalk | blown sand | Palaeogene clays |
| Upper Greensand | alluvium | Gault and other Lower Cretaceous clays |
| Lower Greensand | dry valley deposits | Jurassic clays |
| Spilsby Sandstone | river terrace deposits | Penarth Group |
| Jurassic limestones | glaciofluvial sand and gravel deposits | Mercia Mudstone Group |
| Upper Lias Sands | Crag | Permian marls |
| Dolomitic Conglomerate | Pliocene gravels | Silurian (except limestones) |
| Sherwood Sandstone Group | Palaeogene sands | Ordovician |
| Permian sandstones | Lower Cretaceous sands (except greensands and Spilsby Sandstone) | Cambrian |
| Magnesian limestones | Jurassic limestones, sandstones and ironstones (except where Major Aquifers) | Precambrian |
| Carboniferous Limestone | Permian breccias and conglomerates (SW England) | intrusive igneous rocks |
| | Coal Measures | |
| | Millstone Grit | |
| | Lower Carboniferous limestones and shales | |
| | Old Red Sandstone | |
| | Silurian limestones | |
| | volcanic rocks | |

See Appendix 1 for detailed classification and regional variations.

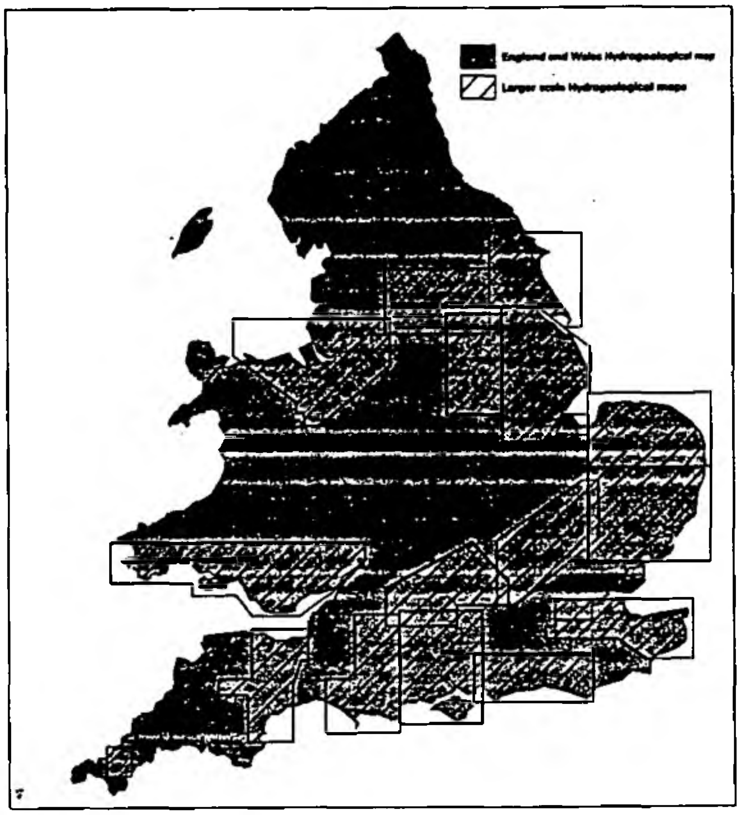



**Figure 3.3 Availability of hydrogeology maps for England and Wales**

## 3.3 Soil

### 3.3.1 SSLRC soil maps

The soil information used in the Groundwater Vulnerability Maps is based upon maps and reports produced since 1939 by the Soil Survey and Land Research Centre, formerly the Soil Survey of England and Wales. Both published and unpublished information, at a variety of scales ranging from 1:25 000 to 1:250 000, have been used. Approximately one-third of England and Wales is mapped at detailed scales of 1:63 360 or greater (Figure 3.4) while the whole of England and Wales is covered by the National Soil Map at a scale of 1:250 000 (Soil Survey Staff, 1983).

In general, individual soil types (known as soil series) are shown on the more detailed soil maps, while soil associations (or groupings of soil series of similar character) are mapped on the National Soil Map. Soil series and soil associations have been discussed in greater detail in Section 2.3.2.

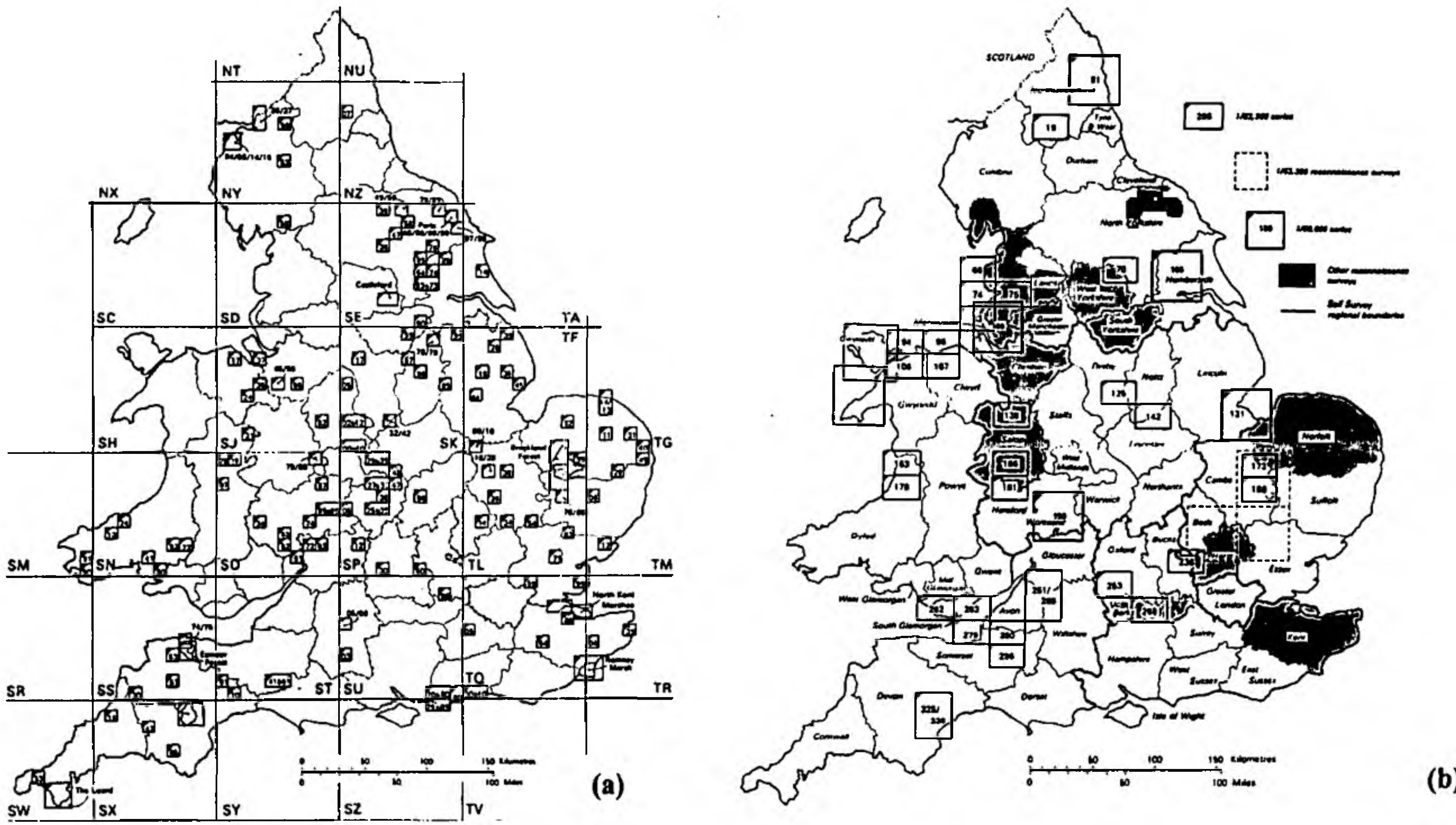



**Figure 3.4 Areas of detailed published soil maps produced by SSLRC at (a) 1:25 000 scale and (b) 1:50 000 or 1:63 360 scale used in the production of the maps.**

### 3.3.2 Soil leaching potential classification

A methodology for classifying of soils into three leaching potential classes has been devised by SSLRC for use in the Groundwater Vulnerability Maps. This classification embraces all soil series in past and current use on detailed soil maps; and all the soil associations of the National Soil Map. With regard to the soil associations, the individual soil series are classified according to their leaching potential and the leaching class found to be the most widespread is then used to define the association.

As described in Section 2.4, the maps aim to illustrate the ability of the soil to attenuate three types of pollutants:

- liquids
- diffuse source pollutants which under certain circumstances can be adsorbed in the soil layers
- diffuse source pollutants which are soluble and can readily pass through the soil layers without being adsorbed.

However, due to the widely differing chemical properties of these types of pollutants, the soil leaching potential classification devised by SSLRC is of necessity generalized. In order to produce a single map that illustrates the vulnerability of groundwater to these differing pollutants, the properties of a 'representative' pollutant was used. This 'representative' pollutant is:

- soluble in water, so that it moves through the soil column in solution
- able to adsorb (or stick) onto clay particles and organic matter.

It is recognized that some pollutants which pose a threat to groundwater quality do not have these properties. For these pollutants, the leaching potential may be higher or lower than that shown on the maps. The use of the maps in assessing groundwater vulnerability to some of these pollutants is discussed in Sections 4.1.2 and 5.6.3.

The classification groups all soils into one of three soil leaching potential classes (High, Intermediate and Low) and six subclasses (H1, H2, H3, I1, I2 and HU-Urban). See inset and Appendix 2. The classification is applied to soils overlying Major and Minor Aquifers but not to those overlying Non-Aquifers.

### 3.3.4 Urban or Disturbed Soils

Soil information relating to urban areas is often limited and soil maps are locally less reliable than for rural areas. This is often also the case for disturbed sites such as restored mineral workings where it may be impossible to give reliable soil leaching potential classes without detailed site investigation. For example, imported topsoil and subsoil materials used in restoration schemes can differ markedly in permeability and thickness to the original natural soil. Extensive urban areas and large restored mineral workings are therefore assumed to have

## Soil Leaching Potential Classes

The classification defines 3 main categories of leaching potential ranging from High to Low.

### High Soil Leaching Potential

The High category is subdivided into 4 subclasses with soils in the HI subclass having a greater soil leaching potential than H2 and H2 soils a greater potential than H3.

H1 Soils with groundwater at shallow depth.
Soils with rock, rock-rubble or gravel at shallow depth.
Undrained lowland peat soils with permanently wet topsoils.

H2 Sandy soils with a low topsoil organic matter content.

H3 Sandy soils with a moderate topsoil organic matter content.
Soils with rock, rock-rubble or gravel at relatively shallow depth within the soil profile.

HU Soils in urban areas and areas of restored mineral workings.

### Intermediate Soil Leaching Potential

The Intermediate category is subdivided into 2 subclasses; mineral soils are placed in I1 and peat soils in I2.

I1 Deep loamy and clayey soils unaffected by marked seasonal waterlogging, with a topsoil of low or moderate organic matter content.

I2 Lowland peat soils which have been drained for agricultural use.

### Low Soil Leaching Potential

There is no subdivision of the Low category of soil leaching potential.

L Soils with a dense subsoil which restricts downward water movement.
Upland soils with a permanently wet peaty topsoil.

High leaching potential, until proved otherwise, but are designated uniquely by the HU subclass.

Locally, because of the small 1:100 000 scale of the Groundwater Vulnerability Maps, the age of some of the OS base maps and the lack of site specific information, a High (HU) leaching potential designation may not be shown in some relatively small built up areas or in areas of active or recently restored mineral workings. However, it should not be assumed that the soil is everywhere undisturbed in these areas but it should be borne in mind that the leaching potential is always based on an undisturbed soil profile.

## 3.4 Low permeability drift deposits

Variable, but generally low permeability drift deposits are difficult to classify in terms of the likelihood of pollutant movement through them. Clearly where there is 10 m or more thickness of clay-rich till (boulder clay) overlying an aquifer, that aquifer is likely to be well protected from surface pollutants. On the other hand a 3 m thickness of silty till containing sand and gravel lenses and vertical fractures may offer little, if any, protection to an underlying aquifer. Wherever there is no site specific detailed information on drift deposits there is uncertainty about their composition and thickness. They are therefore treated everywhere as a special case in this groundwater vulnerability assessment.

Generally, wherever low permeability drift deposits occur at the surface and overlie (directly or indirectly) Major Aquifers or Minor Aquifers they are interpreted separately from the aquifer classification and depicted on the map by a black stipple ornament. The presence of the stipple ornament indicates that a drift deposit of generally low permeability (such as till or peat) is known to be present, but that the degree of protection afforded to the underlying aquifer is uncertain. However, the aquifer is probably better protected than if low permeability drift was absent. In these areas, local site specific enquiries will be required and, if need be, exploratory boreholes drilled in order to establish the nature, thickness and integrity of the low permeability drift cover.

Locally, where the low permeability drift deposits are considered to be sufficiently thick (greater than 5 m) to afford complete protection to underlying Major or Minor Aquifers from surface derived pollutants those aquifers are not shown. The special cases where this has been carried out are discussed in Section 4.3

# 4. USE AND INTERPRETATION OF THE MAPS

## 4.1 Overview of information provided by the maps

The maps incorporate three layers of information, which from the surface downwards are:

- soil leaching potential classes (High/Intermediate/Low) and subclasses
- presence, where applicable, of low permeability drift deposits at the surface above aquifers by stipple ornament
- permeability of the geological deposits (Major/Minor/Non-Aquifers).

Together these layers of information produce 27 different vulnerability combinations which are shown on the maps.

In order to use the maps to their full potential it is necessary:

- to appreciate the potential complexity of the possible combinations of aquifer types and drift deposits which are represented by the restricted number of simple classes shown on the maps (fig. 4.1)
- to understand the relevance of the soil leaching potential classification to individual pollutant groups
- to interpret the relationship between soil leaching potential classes and presence or absence of low permeability drift deposits at the surface.

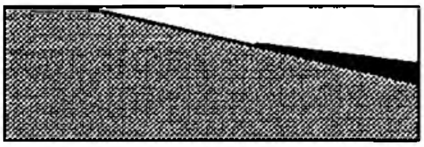
### 4.1.1 Combinations of aquifer types and drift deposits

Any site in England and Wales will be underlain by one or more of the following types of geological unit; permeable drift deposits; low permeability drift deposits; Major Aquifers; Minor Aquifers; or Non-Aquifers. However, for any vertical sequence of such deposits the Groundwater Vulnerability Maps reduce the natural complexity to show only 5 combinations based upon permeability characteristics. These are:

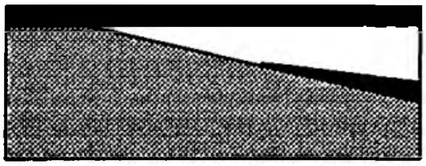
- Major Aquifer
- Major Aquifer with drift stipple
- Minor Aquifer
- Minor Aquifer with drift stipple
- Non-Aquifer.

The simplification of the many geological sequences to arrive at one of these 5 combinations is achieved by only classifying strata down to the first solid deposit and by restricting the classification of drift to the surface deposit. Geological units occurring beneath the uppermost solid strata are never considered in the aquifer classification, even if they may potentially be Major or Minor Aquifers. It is considered they are unlikely to be vulnerable to surface-derived contamination in this position. Figure 4.1 shows schematically the range of strata that have been encompassed by each of the five combinations.

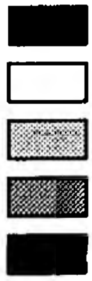
Major Aquifer without stipple



Major Aquifer with stipple



**Key**



Low permeability drift

Permeable drift (Minor Aquifer)

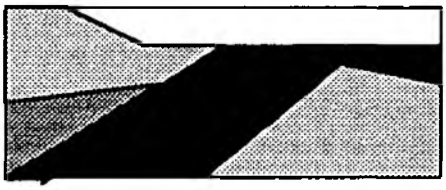
Solid Minor Aquifer

Major Aquifer

Non-Aquifer

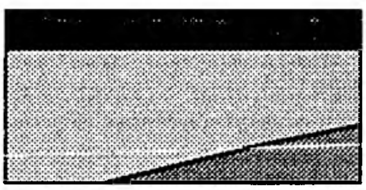
**N.B.** Vertical scale exaggerated

Minor Aquifer without stipple



Low permeability drift >5 m thick*

Minor Aquifer with stipple



Non-Aquifer

Low permeability drift >5 m thick**

* The treatment of thick deposits of low permeability drift in parts of Northumbria and Yorkshire and North West NRA Regions. See Section 4.3.2 for further detail.

** The treatment of thick deposits of low permeability drift in parts of Northumbria and Yorkshire NRA Region. However, in North West NRA Region the Major Aquifer is shown as Major Aquifer with stipple ornament. See Section 4.3.2 for further detail.

**Figure 4.1 The range of geological sequences encompassed in the combinations used on the maps.**

### 4.1.2 Treatment of different pollutant types

It is recognized that many types of pollutant with differing chemical and physical properties pose a threat to groundwater quality. Table 4.1 below indicates the relative vulnerability of groundwater to pollution from 3 broad groups of pollutants applied to soils with leaching potential classes given in the key to the maps. Non-adsorbed diffuse pollutants are those which are applied across wide areas and which do not bind onto the soil (e.g. nitrates from agricultural use) while adsorbed diffuse pollutants can include chemicals such as pesticides and herbicides.

**Table 4.1 A provisional assessment of the relative vulnerability of groundwater to pollution from certain pollutant types applied to soils with different leaching potential**

| | Pollutant type | | |
|---|---|---|---|
| Soil leaching potential class | Liquid discharges | Non-adsorbed diffuse pollutants | Adsorbed diffuse pollutants |
| H1 | ✓✓✓ | ✓✓ | ✓ |
| H2 | ✓✓ | ✓✓ | ✓✓ |
| H3 | ✓✓ | ✓✓ | ✓ |
| I1 | ✓ | ✓ | ✓ |
| I2 | ✓ | ✓ | × |
| L | × | × | × |

✓ The larger the number, the greater the risk of pollutant moving towards groundwater.

× Negligible risk of pollutant moving towards groundwater.

### 4.1.3 Combinations of soil leaching potential classes and the presence or absence of drift stipple

All groundwaters are controlled waters, and are therefore protected by both European and national legislation against pollution so that for most types of land use and many activities which present a threat to groundwater quality, the most relevant information provided by the maps will be the assessment of the protection afforded to groundwater by the soil and unsaturated zones.

In order to fully utilise the information on the maps it is necessary to understand and interpret the relationship between the various combinations of the presence or absence of low permeability drift deposits (stipple ornament) and the soil leaching potential classes given in Table 4.2. A schematic ranking is given to each combination according to the vulnerability of groundwater in underlying aquifers ranging from 11 (lowest) to 1 (highest). In those combinations which suggest there is a discrepancy between the soil and drift geology classification, the soil classification has, for convenience, been assumed to be correct. However, there will be some localities where the geological mapping is more detailed and/or more recent than the soil maps and here the geological mapping may take precedence.

**Table 4.2 A schematic ranking of the relative vulnerability of groundwater in underlying aquifers represented by the range of combinations of soil leaching potential classes and presence or absence of low permeability surface drift deposits (stipple ornament).**

| Soil Leaching Potential class | Presence/absence of drift stipple | Relative vulnerability of groundwater in underlying aquifers* | Provisional interpretation |
|---|---|---|---|
| Low (L) | Present | 11 | High degree of protection is afforded to any underlying groundwater. |
| Low (L) | Absent | 10 | Soil data suggesting high degree of protection present. |
| Intermediate (I2) | Present | 9 | Groundwater quality within peat is at risk but a significant degree of protection is likely to be afforded to groundwater within underlying solid formations due to low permeability of peat. |
| Intermediate (I2) | Absent | 9 | Groundwater quality within peat is at risk but a significant degree of protection is likely to be afforded to groundwater within underlying solid formations due to low permeability of peat. |
| Intermediate (I1) | Present | 8 | If drift deposits are of low permeability, excess water is likely to be shed laterally within the soil zone so that there is a moderately high degree of protection afforded to any underlying groundwater. |
| Intermediate (I1) | Absent | 7 | Moderate degree of protection is likely to be afforded to groundwater by deep loamy and/or clayey soils. |

* 11 Lowest vulnerability
1 Highest vulnerability

**Table 4.2 Contd.**

| Soil Leaching Potential class | Presence/absence of drift stipple | Relative vulnerability of groundwater in underlying aquifers* | Provisional interpretation |
|---|---|---|---|
| High (H3) | Present | 6 | The low permeability drift deposit will be thin but will afford some limited protection to groundwater. |
| High (H3) | Absent | 5 | Very limited protection is likely to be afforded to groundwater due to the shallow depth or very permeable nature of the soils overlying aquifer material. |
| High (H2) | Present | 4/3 | Mismatch between datasets suggested- soils are deep and sandy (permeable), geology indicates low permeability drift at surface. |
| High (H2) | Absent | 3 | Only limited protection is likely to be afforded to groundwater due to the highly permeable nature of these soils. |
| High (H1) | Present | 2 | The low permeability drift will afford only very limited protection to groundwater due to the very shallow depth to aquifer material or groundwater. |
| High (H1) | Absent | 1 | Only extremely limited protection is likely to be afforded to groundwater due to the shallow depth to aquifer material or groundwater. |

* 11 Lowest vulnerability
1 Highest vulnerability

## 4.2 Example interpretations

### 4.2.1 Application for disposal of liquid waste within the soil zone

Waste may be disposed of beneath the topsoil, but within the soil zone, through a number of activities, such as:

- near-surface *soakaways*
- *septic tank* discharges
- injection of farm or sewage sludges.

In addition, in areas where the topsoil has been removed but the remainder of the soil profile is undisturbed, the application of potential contaminants and the spillage of chemicals will be equivalent to disposal beneath the topsoil.

At first glance, the Groundwater Vulnerability Maps may not appear to be directly suited to provide an interpretation on such issues, as the point of entry of the pollutants into the soil-rock column is beneath the surface. However, by re-interpreting the leaching potential classes (Table 4.3) it is possible for the maps to provide some guidance in such cases.

However, there are a number of cautionary points which need to be borne in mind when considering such activities:

- soil types which make excellent soakaway material, such as sandy soils, have high soil leaching potentials (H2 and H3)
- soils with Low leaching potential which provide significant protection to groundwater generally make poor soakaway material
- depending upon local topography and the proximity of surface water features, lateral downslope movement of pollutants within the relatively permeable upper horizons of soils classified as Low leaching potential may pose a threat to surface water quality. In addition, the downslope movement within the soil may lead to the contaminated water recharging nearby aquifers by lateral movement into and through more permeable soil types.
- In soils which suffer seasonal waterlogging, either associated with high groundwater levels (some H1 soils) or poor infiltration of precipitation (L and some I1 soils), underdrainage may be installed to alleviate soil wetness. The drains then provide the potential for the rapid movement of applied liquids, such as slurry, out of the soil profile and into nearby surface water courses.

Using the information provided in Table 4.3 it may be recommended, in conjunction with the Acceptability Matrices in the GPP, that soil zone disposal does not take place in areas classified on the maps as High (H1, H2 & H3) leaching potential or in areas of shallow

**Table 4.3 A provisional modification of soil leaching potential classes for the disposal of potential pollutants within the soil zone, taking into account the nature of the surface drift deposits.**

| SSLRC Soil leaching potential class | Presence /absence of drift stipple | Provisional revised soil leaching potential class |
|---|---|---|
| L | Present<br>Absent* | High degree of protection likely. |
| I2 | Present | If peat is deeply drained, may stay as I2. Otherwise should be treated as H1 due to the proximity of the water table though some shallow peats may be best treated as I1. |
| | Absent | These probably include areas of peat soils too shallow to be identified by geological maps. Generally these soils should be treated as H1 or, more rarely as I1 or H2 depending on the depth to groundwater or presence of sandy subsoil textures respectively. |
| I1 | Present | Where the soils contain *slowly permeable* horizons, they remain as I1 or, depending upon the degree of waterlogging become L. |
| | Absent | Where the soils are moderately permeable, they remain as I1, but may become H1 or H3 (if aquifer material or a water table is present at relatively shallow depth). |
| H3 | Present* | |
| | Absent | Sandy soils become H2 or locally I1 where the sands overlie loamy or clayey material. Shallow soils over aquifer material and soils containing groundwater at relatively shallow depth may become H1. |
| H2 | Present* | |
| | Absent | Most soils remain as H2 but if groundwater is at relatively shallow depth these soils may become H1. Where aquifer material is at relatively shallow depth these soils become H3 and where the sands overlie loamy or clayey material they become I1. |
| H1 | Present* | |
| | Absent | All soils remain as H1, but the risk of groundwater contamination is increased. |

* The occurrence of these combinations require further investigation before modifications can be proposed.

peat soils of Intermediate (I2) leaching potential. If an aquifer is known to be present within less than about 2 m below ground surface, then care should be taken in disposing of any liquids in areas classified as Intermediate (I1) leaching potential. This information should be considered in addition to the determination of the type of aquifer present (Major or Minor Aquifer).

## 4.3 Regional differences in low permeability drift interpretation

### 4.3.1 Introduction

The range in permeability of deposits classified as generally of low permeability has necessitated the use of regional special cases. The cases made so far are described below.

### 4.3.2 Treatment of thick low permeability drift cover

In and around the Vale of York and on Holderness in Northumbria and Yorkshire Region; wherever thick clayey drift deposits (>5 m thick) overlie potential solid Major and Minor Aquifers, those potential aquifers are considered to be protected from surface-derived pollutants. Where spatial data is available delineating areas with this type of thick clayey drift cover the aquifer classification has been used to zone the surface drift deposits (permeable deposits are shown as Minor Aquifers and low permeability deposits as Non-Aquifers). Potential Major and Minor Aquifers have so far been taken out of the classification system in this manner on Maps 8, 9, 12, 13.

In the North West Region (Vulnerability Map 16) along the River Mersey, the Sherwood Sandstone Group is known to be locally overlain by more than 5 m of clay within the drift sequence. In these areas where permeable drift deposits are present at the surface the Sherwood Sandstone is shown as a Minor Aquifer but where low permeability drift deposits are at the surface, the sandstone is portrayed as a Major Aquifer with low permeability drift stipple ornament.

### 4.3.3 Peat

On a few of the early vulnerability maps (Sheets 18, 24 and 25, mainly in East Anglia) drained lowland peats were considered to offer only partial protection to underlying aquifers and were therefore not classified as low permeability drift. However, subsequently all peat deposits shown on geological maps whether drained or undrained, are classified as low permeability drift deposits similar to the treatment of upland peats.

### 4.3.4 Brickearth

Brickearth varies considerably in composition. In Sussex, on Sheets 45 and 46 where it is relatively permeable, it is shown as a Minor Aquifer but further east and west along the south coast (Sheets 44, 47 and 52) it is classified as a low permeability drift and where applicable indicated by a stipple ornament. On Sheet 33, the older (glacial) brickearths are shown as low permeability drift, while the post-glacial brickearths are classified as Minor Aquifers.

# 5. LIMITATIONS OF THE GROUNDWATER VULNERABILITY MAPS

## 5.1 Introduction

Although the methodology of producing the Groundwater Vulnerability Maps incorporates various Quality Assurance checks, there are a number of unavoidable limitations and necessary compromises associated with the data and methodology that need to be borne in mind when using the maps. These include:

- attempting to portray the 3-dimensional continua of the soil and geological columns in 2-dimensions
- mismatches resulting from the overlaying of information of differing scales
- attempting to sub-divide a continuum of soil, geological and contaminant properties into a number of discrete classes
- limitations resulting from overlaying data from different sources with different base maps.

Limitations manifest in the geological, soil and drift data, together with limitations in a site-specific context are discussed in the following sections. However, it should be remembered that this series of maps are intended as a first-pass assessment of the likely vulnerability of groundwater in England and Wales. Many of the limitations highlighted in this chapter are intrinsic to any groundwater vulnerability assessment not dealing with site specific information.

## 5.2 Geological data limitations

### 5.2.1 Introduction

General limitations imposed by the quality of geological mapping may be due to:

- lack of data on the variability of mapped units
- inadequate description of drift deposits
- presence of bypass features
- difficulties of portraying multi- and sequential aquifer systems as a single aquifer.

### 5.2.2 Lack of data on the variability of mapped units

Generalizations may have to be made in compiling the geological classes because of insufficient data on the variability of mapped units. A single mapped unit on a geological map relates to a lithological and stratigraphical nomenclature, not to a given rock type. For example, the Coal Measures comprise sandstone, shale, seat-earth and coal, each with very different hydrogeological properties but which are shown collectively as one unit, except for significant sandstones and coals which may be mapped separately. On the Groundwater Vulnerability Maps the Coal Measures are classified collectively as a Minor Aquifer, even though the shales, seat-earth and coal strata have the properties of Non-Aquifers.

The aquifer classification depends on mapped geological units corresponding to aquifer units. This is generally satisfactory, as both are based on *lithology*. However, locally important aquifer units may be too thin to map and may be undifferentiated from Non-Aquifers.

In addition litho-stratigraphical units may change in lithology and hydrogeological character from place to place, for example the Upper Greensand. Locally, permeability characteristics change gradually but sufficiently for the unit to change aquifer types, in these circumstances, wherever possible the boundary has been drawn at the margin of a map sheet to ease compilation.

### 5.2.3 Inadequate description of drift deposits

Drift deposits are widespread in England and Wales yet drift geology maps are not as universally available as those for solid bedrock geology. For some areas drift mapping is incomplete (showing only river terrace deposits and alluvium) and some older maps do not show even the most rudimentary subdivisions of the glacial deposits such as sand and gravel from till. It is likely therefore that, in some areas of England and Wales, permeable drift deposits qualifying as Minor Aquifers will be more extensive than shown on the Groundwater Vulnerability Maps.

Poor understanding of lithology, thickness and variability of drift deposits has resulted in the use of a stipple ornament on this map series to represent low permeability drift at the surface. This is because it is often not possible to characterize drift sufficiently accurately to incorporate them into a consistently defensible aquifer classification system. However, where the deposits are known to contain permeable horizons, they are generally classified as Minor Aquifers, rather than Non-Aquifers (e.g. some brickearths, morainic drift). In this way the maps therefore represent a worst case scenario in relation to drift deposits.

The identification of geological boundaries beneath significant thicknesses of superficial drift deposits is inevitably less reliable than for boundaries occurring at the surface.

### 5.2.4 Presence of bypass features

More specific limitations arise from the uncertainty of geology itself. Regardless of bedrock geology and drift deposit cover, bypass features may be present that allow the rapid passage of percolating rainwater from the land surface to the water table. These features may enable the moderating effects of the unsaturated zone below the soil zone to be ineffective. They include cracks, joints and other features offering *secondary permeability* such as in limestones, sandstones and the Chalk, and topographic depressions in which recharge potential is enhanced. They also include sink holes in karst limestone rocks and man-made features such as soakaways and other excavations which allow the whole of the unsaturated zone to be by-passed. These typical bypass features may turn an apparently secure non-vulnerable aquifer into one at risk.

### 5.2.5 Portrayal of multi- and sequential aquifer systems

It is a convention, except for some areas of North West and Northumbria and Yorkshire Regions discussed in Section 4.3, that where the uppermost solid geological unit is a Major or Minor Aquifer, the extent of that unit is shown on the map regardless of the properties of any overlying drift deposits. As a result, the aquifers delineated on the Groundwater Vulnerability Maps do not necessarily correspond to the geological parent material of the overlying soil.

Ground-water Gley Soils is one of the 10 Major Soil Groups recognised by SSLRC in the national soil classification system. This group of soils is developed within or over permeable materials and suffers likely periodic seasonal waterlogging associated with fluctuating groundwater levels. Due to the shallow depth of groundwater during a considerable part of the year, they are classified as High (H1) soil leaching potential. However, the soil water table may not be in hydraulic continuity with the groundwater body in the underlying mapped aquifer. It is therefore necessary to take account of local topography and geology in order to ascertain whether the high groundwater levels in the soil are related to the aquifer beneath or are in fact perched some distance above it.

For example, on Groundwater Vulnerability Sheet 13 (Humber Estuary), a large part of the southern shore of the Humber estuary is mapped as Major Aquifer with an H1 leaching potential (Fig. 5.1). The high groundwater levels which give the soils their high leaching potential occur within the more permeable layers of the marine alluvium. The Chalk, which constitutes the Major Aquifer, is confined beneath a thick sequence of impermeable glacial drift deposits which in turn underlie the marine alluvium. The Chalk is therefore likely to be protected from any pollutants that may be within the alluvial groundwater body, and the H1 leaching potential classification is overly pessimistic in relation to Chalk but highly pertinent to groundwater bodies in the marine alluvium.

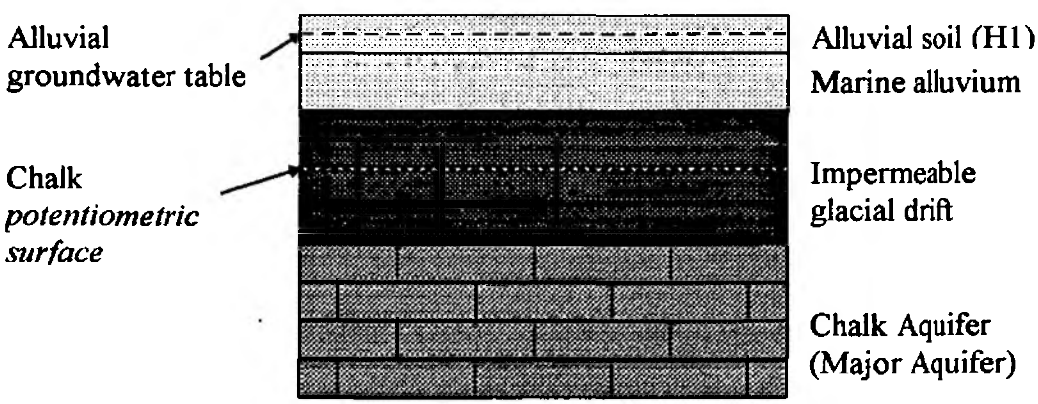



**Figure 5.1 Diagrammatic cross section of the possible misrepresentation of the groundwater vulnerability of some confined aquifers.**

It is therefore locally important that the Groundwater Vulnerability Maps are interpreted in conjunction with the soil and geological information on which they are based. There are many cases where drift Minor Aquifers support soils whose leaching potential is classified on the maps, but which overlie older Major or solid Minor Aquifers which are the strata classified on the map. If low permeability drift deposits occur between the zoned Minor or Major Aquifer and the permeable drift deposit at the surface, there is the potential for overstating the vulnerability of the zoned aquifer.

## 5.3 Soil data limitations

### 5.3.1 Variability within soil mapping units

General purpose soil maps produced by SSLRC show the distribution of soils by the use of three types of map unit, according to the scale of the final map. These are:

- Soil series
- Soil complexes
- Soil associations.

The way in which the soil leaching potential classification is assigned differs according to the type of map unit.

**Soil series**

In general, if a block of land is shown on a detailed soil map to be uniformly one soil series, it contains at least 70 % of that named series. The remaining 30 % may include several other, often unnamed, series. Although these are usually similar to the named series, due to the natural heterogeneity of soil, occasional contrasting soils may be found.

The soil leaching potential class given to this block of land is that of the named series. There are, therefore, small patches within the mapped area of the soil series (maybe up to 30 %) which may be of lower or higher soil leaching potential.

**Soil complexes**

When two or more soil series are intricately mixed such that they cannot be mapped separately, even on detailed soil maps, map units called soil complexes are defined. When assigning a leaching potential class to these units it is based on the soil series included within the complex with the highest leaching potential class, unless this series is described to be of very limited extent. It is likely therefore that significant proportions of soil complexes may be of lower leaching potential than that assigned, although discrete areas will be of limited lateral extent.

**Soil associations**

Soil series and soil complexes are used on detailed soil maps which are available for about one-third of England and Wales. Elsewhere, the leaching potential classes are based on the soil associations of the National Soil Map. In all but 39 of these, the series providing the name of the soil association (the lead series) forms an extensive and often dominant component of most delineations. Therefore the soil leaching potential class given to the association is that of the lead series, although there will inevitably be areas within the association (generally 30-60 %) where soils may have either a higher or lower leaching potential.

The remaining 39 soil associations are more variable in composition, having a number of inextensive and dissimilar soils and are named after the soil series which characterises them best. Each of these associations is given the leaching potential class which occurs most widely among its constituent soil series. For example, the Holidays Hill association is assigned an I1 leaching potential class as it contains 30 % Holidays Hill series (I1), 20 % Shirrel Heath series (H3), 20 % Kings Newton series (L), 10 % Isleham series (I2), 10 % Rapley series (I1) and 10 % unspecified soil series.

The reliability of the leaching potential estimates given on the vulnerability maps therefore depends on the scale of soil map and the type of soil map units used (Table 5.1), which in turn relates back to the mapping quality of the original source soil map (Figure 3.4).

**Table 5.1 The basis and reliability of soil leaching potential estimates for each type of soil map unit.**

| Map scale | Mapping Unit | Basis of leaching potential estimation | Reliability of leaching potential estimate |
|---|---|---|---|
| 1:10 000<br>1:25 000<br>1:50 000<br>1:63 360 | Soil Series | Named soil series | Very good but may include small areas of different leaching potential |
| | Soil complex | Soil series with highest leaching potential | Good but possibly includes large areas of lower leaching potential, although individual patches of limited extent |
| 1:100 000<br>1:250 000 | +Soil Association | Lead soil series | Regionally good but likely to include restricted areas of lower & higher leaching potential |
| | *Variable Soil Association | Most extensive leaching potential class | Regionally satisfactory but may include substantial areas of lower & higher leaching potential |

+ Name of Soil Association given in capitals on the legend for the 1:250 000 scale Soil Map of England and Wales
* Name of Soil Association given in mixed case type on the legend for the 1:250 000 scale Soil Map of England and Wales

## 5.4 Drift data limitations

### 5.4.1 Mismatch with soil information

There are certain combinations of soil leaching potential classes and low permeability drift stipple ornament which may occur when there is a difference in interpretation between soil and drift geological mapping. These are:

- Low leaching potential without drift stipple
- High (H2 and sandy H3) leaching potential with stipple
- Intermediate (I2) leaching potential without drift stipple
- High (H1 and shallow H3) leaching potential with stipple.

These differences can result from:

- the availability of more detailed soil mapping than geological mapping, or vice versa
- inadequate mapping of drift deposits on many early geological maps
- disagreement in the definition of a drift aquifer
- a lack of understanding or information on the texture of some drift aquifers.

The individual cases outlined above are discussed in the following sections.

**Low leaching potential without drift stipple**

Soils are routinely examined to a depth of 1-1.2 m during a soil survey and the leaching potential class is assigned based upon the properties of the soil to 1 m depth. For a soil to be classified as Low leaching potential it must have physical properties preventing the movement of water (and pollutants) down through the soil profile to 1 m depth. It is implicit in this soil classification that a permeable deposit must extend below 1 m depth to qualify as an aquifer.

However, it is only in the last two decades that field geologists have closely examined surface drift deposits (to 1-1.5 m depth) with hand augers. In older geological surveys, therefore, the characterization of drift deposits was less comprehensive and both low permeability and permeable drift deposits may have been omitted from geological maps which would now be shown. In other areas the permeable topsoil and shallow subsoil of some Low leaching potential soils (with dense slowly permeable subsoils) were mapped as permeable drift deposits and have been shown on the Groundwater Vulnerability Maps as Minor Aquifers. In these cases, the Low leaching potential class refers to the whole soil profile to 1 m depth which includes the aquifer material as defined by BGS and the underlying slowly permeable layer. If these very shallow permeable layers are the object of protection policy decisions at a local level, the vulnerability of groundwater will be higher than that shown on the map.

### High (H2 and sandy H3) leaching potential with stipple

Soils within the High (H2) or those sandy soils classed as High (H3) leaching potential are sandy to below 80 cm depth by definition. The occurrence of a sandy soil developed in till may reflect the nature of the till. Not all till is clay (in texture), much is silty or sandy clay and there may also be sand and gravel horizons within it. Therefore, the presence of a low permeability drift stipple ornament on sandy soils, whilst appearing to suggest a data mismatch, may be providing additional information on the local lithology of the till.

### Intermediate (I2) leaching potential without stipple

Soils with Intermediate (I2) leaching potential have peaty topsoils and peat can extend to depths of 100+ cm. Peat develops at the surface of these soils in response to high groundwater levels within the soil profile. While all groundwaters are protected according to the Groundwater Protection Policy peat is insufficiently permeable to yield groundwater in exploitable quantities and has therefore been classified by the BGS as a low permeability drift deposit. Many geology maps only indicate the presence of peat if it is greater than 1 m in thickness.

Soil maps occasionally identify surface peat deposits up to 1 metre thick which are not shown on geology maps. In these situations Intermediate (I2) leaching potential soils without stipple indicate where permeable drift deposits or solid Minor Aquifers or Major Aquifers underlie the peat. Groundwater in these deposits is likely to be afforded significant protection by soil horizons of high organic carbon content.

However, as discussed in Section 4.3.3, peat is treated in a different manner on Sheets 18, 24 and 25 around the Wash. Here, peat is considered permeable where soil survey evidence shows the soils to be deeply drained and under arable cultivation. Underdrainage lowers the groundwater levels, resulting in oxidation and shrinkage of the peat which increases its permeability. Therefore, on these 3 maps peat is classified as a permeable drift deposit but is <u>not</u> depicted as an aquifer.

In coastal areas soils developed in marine alluvium with thin peat topsoils over clayey mineral subsoils are classified as Intermediate (I2) leaching potential. Often these areas receive a stipple ornament because of the low permeability of the marine alluvium. In this case the classification of an Intermediate (I2) leaching potential class with stipple should not be interpreted as indicating the presence of thick peat.

### High (H1 and shallow H3) leaching potential with stipple

Soils classified as High (H1 and shallow H3) leaching potential because aquifer material is found at relatively shallow depth within the soil profile are unlikely to contain a sufficient thickness of clay to be recognised by geologists as a low permeability drift deposit. In those small areas where drift stipple is shown on such soils it is likely to result from a mismatch between soil and geological mapping. In certain cases, the pattern of the drift stipple ornament on the vulnerability maps and a lower soil leaching class is broadly similar but not coincident. These slight discrepancies may be caused by the different scales and objectives of the original surveys. An example relates to the clay-with-flints deposits over the Chalk in Kent (Sheet 47), where the extent of the Intermediate (I1) leaching potential soils representing the soils developed in clay-with-flints are broadly similar to, but do not exactly match the drift stipple so that the stipple occasionally overlaps onto the shallow High (H1 and H3) leaching potential soils developed in the Chalk.

Alluvium can vary in texture from sandy to clayey, yet geological maps seldom give any indication of this. Locally, where such geological information is available, areas of clayey alluvium are classified by BGS as low permeability drift and so are given a stipple ornament. However, soil information often indicates that these deposits are sufficiently permeable, at least in their upper parts, for the principal source of waterlogging within the soil profile to be due to groundwater. An alluvial soil of High (H1) leaching potential shown on the map with a low permeability stipple ornament therefore indicates a difference of interpretation of permeability between the soil scientist and geologist.

## 5.5 Site specific limitations

### 5.5.1 The Ordnance Survey National Grid

The vulnerability maps are produced by overlaying information taken from soil and geology maps, at a range of scales from 1:10 000 to 1:250 000, onto an Ordnance Survey 1:100 000 scale national grid base map. Compromises in accuracy result from this approach for the following reasons:

- Prior to overlaying, most soil and geology maps have to be either photo-enlarged or reduced to exactly 1:100 000 scale. When photo-enlarging small scale maps to 1:100 000 scale, the National Grid lines rarely coincide with those on the OS published film bases, even though all maps are precisely 1:100 000 in scale. Overlaying has routinely been carried out using fixed features such as rivers and railways, rather than the National Grid. Whilst this ensures an accurate fit adjacent to water courses, it cannot be guaranteed that the overlays are perfect fits. It must be borne in mind that a misalignment in any of the maps of only 1 mm is equivalent to 100 m on the ground. In most areas of the maps, the misalignment of soil and geological boundaries are likely to be less than 1-1.5 mm. It is possible that, in some areas of 1:250 000 scale mapping with few fixed features, misalignment of soil boundaries of up to 2-3 mm may occur. However, most boundaries between soil series or soil associations in the field are gradational, rather than abrupt, so that any misalignment is likely to be less serious than might first appear.

- Some of the older geology maps published by the BGS date back to the turn of the century, before the National Grid was routinely placed on all base maps produced by the OS. Fixed features have to be used in aligning the overlay of these publications. Due to the errors inherent in these old maps and their use of uncertain cartographic projections, there may be a misalignment of boundaries of up to 2-3 mm in some areas.

### 5.5.2 The incompatibility between natural complexity and map scale

The natural variability of soil and geological properties is extremely complex. Even the most detailed maps (1:10 000 scale) are approximations to the actual distribution of soil types and geological units.

Further to these limitations in source maps, some geological simplification has, of necessity, been carried out in parts of recently published geological maps. Outcrops of less than 15 hectares in area have generally been omitted. This equates to areas on the maps of 3 mm by 5 mm or 1 mm by 15 mm. In the Jurassic rocks of the Cotswolds, for example, very thin bands of sands and clays (Minor Aquifers) have been separated from the Major Aquifer limestones on the dip slopes. Where the sands and clays outcrop on scarp slopes, they are much too narrow to show at 1:100 000 scale. Inevitably, amalgamation and simplification of some units has therefore been carried out. Outcrops which are continuous are therefore occasionally omitted where they are thinnest, and a potential ribbon-like pattern is broken up. The result is an exaggeration of Minor Aquifers at the expense of Non-Aquifers and of Major Aquifers at the expense of Minor Aquifers and/or Non-Aquifers.

The vulnerability maps incorporate soil information collated from maps ranging in scale from 1:25 000 to 1:250 000 while geological information is derived from 1:10 000 to 1:250 000 scale maps. Features mapped at a scale of 1:25 000 are sixteen times smaller in area when reduced to a scale of 1:100 000, while features at 1:10 000 are 100 times smaller in area when reduced to 1:100 000 scale. As a result, a great deal of simplification has had to be carried out to ensure an acceptable compromise between the representation of natural complexity and the ease of use of the maps.

These unavoidable compromises place strict limitations on the resolution and precision of map information. Detailed 1:25 000 scale soil and geology maps often have map separates of between 1 and 5 hectares in extent. These are clearly too small to show at 1:100 000 scale. An enlargement or magnification of the published 1:100 000 scale vulnerability map will, in these instances, not necessarily provide the best available information for a specific site.

In the case of this map series, the variety of soils, geological strata and potential contaminants that are covered is wide, and the classifications used are, of necessity, generalized. As a result, individual sites and circumstances will always require further and more detailed assessments to determine the specific impact of potentially polluting activities on groundwater resources.

### 5.5.3 Range of pollutants

The simple 3-fold leaching potential classification (High, Intermediate and Low) has been devised for soluble pollutants and liquid discharges, either of which may or may not adsorb onto soil particles. The sub-classes of the High and Intermediate classes explain something of the likely speed of movement of pollutants through the soil and take into account the adsorptive capacity of the soil.

The movement of insoluble pollutants depends on their individual properties such as density and viscosity. The leaching potential classification cannot be used directly for these pollutants and requires refining by amalgamating certain sub-classes and perhaps setting up new sub-classes before these specific pollutants could be catered for.

# 6. REFERENCES

Adams, B. and Foster, S.S.D. (1991) National groundwater protection policy: Hydrogeological criteria for division of the land surface area. NRA R&D Note 6.

Avery, B.W. (1980) Soil classification for England and Wales. (Higher categories). Soil Survey Technical Monograph No. 14.

Clayden, B. and Hollis, J.M. (1984) Criteria for differentiating soil series. Soil Survey Technical Monograph No. 17.

Crompton, A. and Matthews, B. (1970) Soils of the Leeds District. Memoir of the Soil Survey of Great Britain.

Duff, P.McL.D. and Smith, A.J. (Ed) (1992) Geology of England and Wales. Geological Society, London.

Foster, S.S.D. and Skinner, A.C. (1995) Groundwater Protection: the science and practice of land surface zoning. In Proceedings of the International Association of Hydrological Sciences conference (Groundwater Quality; Remediation and Protection, Prague 1995).

International Association of Hydrogeologists (1994) Guidebook on mapping groundwater vulnerability, Editors J Vrba and A Zaporozec. International Contributions to Hydrogeology Vol. 16.

National Rivers Authority (1992) Policy and practice in the protection of groundwater. NRA, Bristol.

Robins, N.S., Adams, B., Foster, S.S.D. and Palmer, R.C. (1994) Groundwater vulnerability mapping: the British perspective. Hydrogeologie, **3**, 35-42.

Robinson, G.W. (1943) Mapping the soil of Britain. Discovery, **4**, 118-121.

Soil Survey Staff (1983) The National Soil Map of England and Wales, 1:250,000 scale (in six sheets). Soil Survey of England and Wales, Harpenden.

# APPENDIX 1 STRATIGRAPHIC COLUMN AND STRATA IN AQUIFER CLASSES

**Table A1.1 Stratigraphic Column (based on Duff and Smith, 1992).** No time correlations are implied.

**Recent** aeolian, organic, fluvial, lacustrine and marine deposits
**Pleistocene** glacial deposits

| | East Anglia | London Basin | Hampshire Basin and IoW | Dorset | S.W. England |
|---|---|---|---|---|---|
| Neogene | Norwich Crag | | | | |
| | Red Crag | Netley Heath Beds | | | |
| | Coralline Crag | | | | St Erth Beds |
| | | Lenham Beds | | | |
| | | | | | Bovey Formation ↓ |
| | | | Hamstead Beds | | |
| Palaeogene | | | Bembridge Beds | | |
| | | | Osborne Beds | | |
| | | | Headon Beds | | |
| | | | Barton Group | Hengistbury Beds<br>Boscombe Sand | |
| | | | Selsey Sand )<br>Marsh Farm Fm ) Bracklesham<br>Earnley Sand ) Group<br>Wittering Fm ) | ( Branksome<br>( Sand<br><br>( Poole<br>(Formation | |
| | | Bagshot Formation | | | |
| | ← London Clay Formation → | | | | Haldon Gravels |
| | | Claygate Member<br>Blackheath and<br>Oldhaven Beds/<br>Harwich Formation | | | |
| | ← Woolwich Formation and Reading Formation / Lambeth Group → | | | | |
| | | Thanet Sand Fm | | | |

| | Yorkshire | Lincolnshire | North Norfolk | Bedfordshire | Weald | IoW |
|---|---|---|---|---|---|---|
| Cretaceous | ← Chalk Group → | | | | | |
| | | | | | Upper Greensand | |
| | Hunstanton Formation | | | ← Gault Clay Formation → | | |
| | Speeton | Carstone Formation | | | | Carstone ) |
| | Clay | | | Woburn | Folkestone Beds) L | Sandrock ) Lower |
| | Formation | Sutterby Marl | | Sands | Sandgate Beds ) G | Ferruginous ) Greensand |
| | ↓ | | | Formation | Hythe Beds ) S | Sands ) [LGS] |
| | | Skegness Clay | | | Atherfield Clay | |
| | | Roach Formation | | | Weald | Vectis ) |
| | | Tealby Clay Fm | Dersingham | | Clay | Formation ) |
| | | | Formation | | Formation | Wessex ) |
| | | Claxby Formation | | | | Formation ) Wealden |
| | | | Sandringham | | Tunbridge Wells Sands | ↓ ) |
| | | Spilsby Formation | Formation | | Wadhurst Clay | ) |
| | | | | | Ashdown Beds | ) |
| | | | | | Purbeck | |

| | Dorset | Cotswolds | East Midlands | Yorkshire |
|---|---|---|---|---|
| Jurassic | Purbeck Group<br>Portland Group | | | |
| | ← Kimmeridge Clay Formation → | | | |
| | | | Ampthill Clay Formation | |
| | Corallian Group | | West Walton Formation | Brantingham Fm |
| | ← Oxford Clay Formation → | | | |
| | ← Kellaways Formation → | | | |
| | ← Cornbrash Formation → | | | |
| | Forest Marble Formation | | Blisworth Clay | ↑ |
| | Great Oolite | White Lst Fm | Blisworth Limestone | |
| | Fuller's Earth | Hampen Fm | | |
| | | Taynton Lst Fm | Rutland Formation | |
| | | Sharp's Hill Fm | | |
| | | Chipping Norton Lst Fm | | Ravenscar Group |
| | | | Lincolnshire Limestone Formation | |
| | ← Inferior Oolite Group → | | Grantham Formation | |
| | | | Northampton Sand Formation | ↓ |
| | | | | Dogger Formation |
| LIAS GROUP | Bridport Sand Fm. | Cotteswold Sand | | |
| | Downcliff Clay | | Upper Lias | Whitby Mudstone Fm |
| | Junction Bed | | | |
| | Thorncombe Sand | | Marlstone Rock Formation | Cleveland Ironstone Fm |
| | Eype clay | | Middle Lias | Staithes Sandstone Fm |
| | Green Ammonite Beds | | | |
| | Belemnite Marls | | Lower Lias clays ) | Redcar Mudstone Fm |
| | Black Ven Marls | | ) Lower Lias | |
| | Shales with Beef | | ) | |
| | Blue Lias | | Hydraulic lsts ) | |

**Triassic**

Penarth Group
Mercia Mudstone Group
Sherwood Sandstone Group
Aylesbeare Mudstone Group (S.W. England)

| | Cumbria | Durham | Yorkshire | S.W. England |
| --- | --- | --- | --- | --- |
| **Permian** | St Bees Sandstone | Upper Permian Marl/Roxby Formation | Upper Permian Marl/Roxby Formation | |
| | Eden Shales/St Bees Shales and Evaporites | Upper Magnesian Lst/Seaham Formation | Upper Magnesian Lst/ Brotherton Formation | |
| | | Middle Permian Marl/Edlington Formation | Middle Permian Marl/Edlington Formation | |
| | | Middle Magnesian Lst/Ford Formation<br>Lower Magnesian Lst/Raisby Formation | Lower Magnesian Lst/Cadeby Fm. | |
| | | Lower Permian Marl | Lower Permian Marl | |
| | Penrith Sandstone | Basal Permian Sands and Breccias | Basal Permian Sands and Breccias | |
| | | | | Luccombe Breccia<br>Exeter Group<br>Vexford Breccia<br>Wiveliscombe Sandstones |

**Carboniferous**

( Coal Measures
( Millstone Grit
( Carboniferous Limestone

| | |
| --- | --- |
| **Devonian** | Old Red Sandstone |
| **Silurian** | shales with subordinate limestones |
| **Ordovician** | predominantly shales |
| **Cambrian** | predominantly shales |
| **Precambrian** | |

**Table A1.2 Major Aquifers (highly permeable)**

| |
|---|
| river gravels (Middle Thames valley) |
| Chalk |
| Red Chalk/Hunstanton Formation |
| Upper Greensand (except east of Hog's Back) |
| Carstone (Norfolk) |
| Lower Greensand (undifferentiated and Folkestone and Hythe Beds) |
| Dersingham Formation (sands) |
| Spilsby Sandstone |
| Sandringham Formation |
| Portland Stone |
| Corallian/Brantingham Formation (Yorkshire) and Osmington Oolite (Dorset) |
| Cornbrash Formation (where in hydraulic continuity with underlying limestones) |
| Forest Marble and Great Oolite limestones (south of Oxford) |
| Inferior Oolite/Lincolnshire Limestone |
| Upper Lias (Cotteswold, Midford, Yeovil) sands |
| Junction Bed (Dorset) |
| Dolomitic Conglomerate |
| Sherwood Sandstone Group |
| Permian sandstones (e.g. Dawlish Sandstone Formation, Collyhurst Sandstone, Bridgnorth Sandstone, St Bees Sandstone, Penrith Sandstone |
| Upper Magnesian Limestone/Brotherton and Seaham Formations |
| Middle Magnesian Limestone/Ford Formation |
| Lower Magnesian Limestone/Cadeby and Raisby Formations |
| Carboniferous Limestone (limestones except in northern England) |

**Table A1.3 Minor Aquifers (variably permeable)**

| |
|---|
| made ground |
| landslip |
| head (sandy) |
| coombe deposits |
| blown sand |
| brickearth (sandy) |
| calcareous tufa |
| alluvium |
| dry valley deposits |
| alluvial fan deposits |
| river terrace deposits (except Middle Thames) |
| storm beach deposits |
| raised beach deposits |
| glaciofluvial sand and gravel deposits |
| undifferentiated glacial drift (morainic drift, buried channel deposits) |
| sand and gravel of unknown age/origin |
| disturbed Blackheath Beds |
| Crag (Norwich, Red and Coralline Crags) |
| Pliocene gravels (e.g. Netley Heath Beds, Lenham Beds and St Erth Beds) |
| Hamstead Beds |
| Bembridge Limestone |
| Osborn Beds |
| Headon Beds |
| Bovey Formation |
| Barton Group (sands) |
| Bracklesham Group (sands) |
| Bagshot Formation |
| London Clay Formation (sands) |
| Claygate Member |
| Blackheath and Oldhaven Beds/Harwich Formation |
| Woolwich Formation and Reading Formation/Lambeth Group |
| Thanet Sand Formation |
| Haldon Gravels |
| Upper Greensand (east of Hog's Back) |
| Carstone (except Norfolk) |
| Whitchurch Sands Formation |
| Sandgate Beds |
| Roach Formation |
| Weald Clay (sandstones and limestones) |
| Tealby Limestone |
| Claxby Formation |
| Tunbridge Wells Sands |
| Spilsby Formation |
| Wealden Beds (sands) |
| Wadhurst Clay Formation (sands) |
| Ashdown Beds (except clay) |
| Purbeck (sands) |
| Portland Sands |
| Corallian Group (except Yorkshire and Osmington Oolite) |
| West Walton Formation (limestone) |
| Kellaways Sand/Osgodby Formation |
| Cornbrash Formation |

**Table A1.3 Contd.**

| |
|---|
| Ravenscar Group |
| Blisworth Limestone |
| Glentham Formation (limestones) |
| Fuller's Earth Rock |
| Northampton Sand |
| Upper Lias (Yeovil/Bridport) sands |
| Junction Bed (not Dorset) |
| Marlstone Rock Formation |
| Pennard Sands |
| Dyrham Siltstone Formation |
| Lower Lias (limestones) |
| Blue Lias |
| White Lias/Langport Member |
| Sandstones in Mercia Mudstone Group (e.g. Sneinton and Woodthorpe Formations) |
| Permian breccias and conglomerates (S.W. England) |
| Basal Permian Sands |
| Coal Measures (including "Barren Measures") |
| Millstone Grit |
| Culm |
| Carboniferous Limestone (limestones in northern England, Yoredales, Limestone Shales) |
| Old Red Sandstone/Devonian |
| Silurian limestones |
| volcanic rocks |

**Table A1.4 Non-Aquifers (negligibly permeable)**

| | |
|---|---|
| Norwich Crag (clays) | |
| Bembridge Marls | |
| Barton Group (clays) | |
| Bracklesham Group (clays) | |
| London Clay Formation | |
| Gault Clay Formation | |
| Speeton Clay Formation | |
| Sutterby Marl | |
| Skegness Clay | |
| Atherfield Clay | |
| Weald Clay Formation (clays) | |
| Snettisham Clay | |
| Tealby Clay Formation | |
| Grinstead Clay Formation | |
| Wealden Beds (clays) | |
| Wadhurst Clay | |
| Hundleby Clay | |
| Ashdown Beds (clays) | |
| Purbeck (clays) | |
| Kimmeridge Clay Formation | ) |
| Ampthill Clay Formation | ) |
| West Walton Formation (clays) | ) Ancholme Clay Group |
| Oxford Clay Formation | ) |
| Kellaways Clay Member | ) |
| Blisworth Clay | |
| Glentham Formation (clays) | |
| Fuller's Earth clays | |
| Grantham Formation | |
| Upper Lias (clays)/Whitby Mudstone Formation | |
| Downcliff Clay | |
| Middle Lias (clays) | |
| Eype clays | |
| Green Ammonite Beds | |
| Lower Lias (clays)/Redcar Mudstone Formation | |
| Belemnite Marls | |
| Black Ven Marls | |
| Shales with Beef | |
| Penarth Group (except Langport Member) | |
| Mercia Mudstone Group (except Dolomitic Conglomerate and sandstones) | |
| Manchester Marl | |
| Upper Permian Marl/Roxby Formation | |
| Middle Permian Marl/Edlington Formation | |
| Wetherby Member | |
| Lower Permian Marl | |
| St Bees Evaporites and shales/Eden Shales | |
| Silurian (except limestones) | |
| Ordovician | |
| Cambrian | |
| Precambrian | |
| intrusive igneous rocks | |

**Table A1.5 Low permeability drift deposits**

| |
|---|
| head (clayey) |
| clay-with-flints |
| loess |
| brickearth (except where sandy) |
| peat (except on maps 18, 24 and 25) |
| shell marl |
| lacustrine deposits |
| tidal flat deposits |
| saltmarsh deposits |
| marine and estuarine alluvium |
| glaciolacustrine deposits |
| till |

# APPENDIX 2 COMMONLY OCCURING SOIL SERIES WITHIN SOIL LEACHING POTENTIAL CLASSES

**Table A2.1 Soils with High leaching potential**

| H1 | H2 | H3 |
|---|---|---|
| Andover | Bearsted | Aberford |
| Blackwood | Bridgnorth | Anglezarke |
| Elmton | Bromsgrove | Badsey |
| Fladbury | Cuckney | Eardiston |
| Longmoss | Newport | Munslow |
| Newchurch | Wick | Neath |
| Sherborne | | Panholes |
| Wallasea | | Rivington |
| Wisbech | | Shirrell Heath |
| | | Sollom |
| | | Sonning |
| | | Swaffham Prior |
| | | Waltham |

**Table A2.2 Soils with Intermediate leaching potential**

| I1 | I2 |
|---|---|
| Batcombe | Adventurers' |
| Blacktoft | Altcar |
| Bromyard | |
| Burlingham | |
| Carstens | |
| Coombe | |
| Curtisden | |
| Denbigh | |
| East Keswick | |
| Evesham | |
| Fyfield | |
| Halstow | |
| Hanslope | |
| Ludford | |
| Manod | |
| Milford | |
| Whimple | |
| Worcester | |

**Table A2.3 Soils with Low leaching potential**

| |
|---|
| Beccles |
| Brickfield |
| Cegin |
| Clifton |
| Denchworth |
| Dunkeswick |
| Foggathorpe |
| Hafren |
| Ragdale |
| Salop |
| Wickham |
| Wilcocks |
| Windsor |
| Winter Hill |

# APPENDIX 3 KEY SHEET FOR UNDERSTANDING THE NRA GROUNDWATER VULNERABILITY MAPS

The degree to which groundwater is vulnerable to contamination from pollutants applied or discharged on the land surface is shown by the various shades and colours on the map. 3 types of information are used in compiling the maps:

- Soil -the ease with which pollutants move down through soil is indicated by the intensity of purple and brown colours- the denser the colour, the faster the movement.
- Low permeability surface drift deposits- indicated, where present, by a stipple ornament.
- Aquifer types- purples (Major Aquifer); browns (Minor Aquifer) and green (Non Aquifer).

**Soils**

Soils overlying Major and Minor Aquifers (see below) are ranked High (dark purple or dark brown), Intermediate (mid purple or mid brown) or Low (pale purple or pale brown) according to their Soil Leaching Potential, a measure of the relative speed of pollutant migration through the soil zone.

<u>High (H1, H2, H3) Soil Leaching Potential</u>: these soils have very little ability to prevent pollutants entering groundwater due to either:

- Groundwater present at very shallow depth within the soil zone
- Very shallow soils over aquifer forming rocks
- Physical properties that allow pollutants to move quickly through the soil.

Soils in built-up areas and areas of past or present mineral extraction are uniformly classified as High (HU) Soil Leaching Potential until demonstrated otherwise by more detailed desk assessment or site-specific investigation.

<u>Intermediate (I1, I2) Soil Leaching Potential</u>: these soils have some ability to prevent pollutants entering groundwater due to either:

- Physical properties that enable pollutants to bind onto soil particles
- Physical properties that limit the speed of pollutant movement through the soil
- Considerable thickness of soil.

<u>Low (L) Soil Leaching Potential</u>: these soils prevent pollutants entering groundwater due to either:

- Physical properties that prevent pollutants moving downwards through the soil
- Impermeable strata beneath the soil.

**Low permeability drift deposits**

A stipple ornament is used to indicate where geological maps suggest <u>low permeabilty drift deposits</u> to be present at the surface which may help to impede the downward movement of pollutants. The thickness and vertical consistency of the drift deposits (which is often very variable) and whether they are underlain by permeable drift are not considered.

**Aquifer types**

Geological deposits are divided into <u>Major, Minor and Non-Aquifers</u> (potentially water bearing rocks). Major Aquifers are used extensively for public water supply (and hence the protection of groundwater quality is of major concern) while Minor Aquifers are largely used for private supply but may support some public abstractions. Although Non-Aquifers have little importance for groundwater supplies they may, due to their impermeable nature, promote lateral movement of pollutants within the soil zone towards Major or Minor Aquifers.