A Digital Dataset of European Groundwater Resources at 1:500,000. (v. 1.0)

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Foreword

This document provides information on the derivation and use of the digital dataset of European Groundwater Resources version 1.0 digitised on behalf of the European Commission and the European Crop Protection Association in July 2002.

The document describes the published paper maps and reports, from which the dataset was derived, the digital dataset, its formats and attribute data and highlights a number of issues that should be taken into account when using the dataset, particularly if it is used in a Geographic Information System (GIS) with other European-level digital data.

The project was co-ordinated by the National Soil Resources Institute of Cranfield University and the digitisation was carried out by CDD (Cartographic Data Development) Ltd. Contact details for the project managers are as follows:

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1. INTRODUCTION AND BACKGROUND TO THE DATASET

In 1982, the European Commission published a set of 38 1:500,000 scale maps detailing Groundwater Resources across the 9 countries (Belgium, Denmark, France, Ireland, Italy, Luxembourg, Netherlands, United Kingdom, West Germany) which, at that time, comprised the European Community. The maps are accompanied by a short 'Synthetical Report' (CEC, 1982) and a set of explanatory reports for each country. The objective of the project was "….*to obtain a quantitative assessment of the groundwater resources of the Community using a regionalisation both hydrogeological and administrative of the Member States. Its aim is to provide water managers and planners at regional, national and Community levels with a true image of the available quantities and distribution of groundwater in the Community under present conditions of recharge and exploitation at such a scale as to allow a harmonization in the presentation and consistency of the results and to supply valuable comparisons between member States. It is also aimed to estimate the development potential, both with regard to the quantities of groundwater and to areas where such additional abstraction might be undertaken*……"

The report also recognises the potential of the maps to contribute to topic areas other than water resource management. It states "…*Furthermore,* (the results of the study) *should be introduced in the ecological mapping of the European Community territory in order to better evaluate potential and pressures of the medium concerning water supplies*…".

The study was co-ordinated by Professor J.J. Fried of the University Louis Pasteur, Strasbourg and carried out by 10 consultants or groups of consultants, one for each of the member States and one for cartographic problems. In order to ensure harmonisation of the information and its method of presentation, a project panel, comprising the co-ordinator and a representative from each of the consultants, developed an agreed methodology which was strictly applied by each of the consultants. Specific problems that arose during implementation of the methodology were considered by the project panel and solutions agreed. As stated in the report, "…*Trans-frontier problems were given special attention by the concerned consultants, especially for the harmonisation of the hydrogeological data along the borders of Member States*…"

This set of maps and reports remain the most comprehensive compilation of consistent information on the resources of the 9 European countries currently available. As a consequence, in December 2000, the European Crop Protection Association, commissioned a project to digitise the maps so that they could be used in Geographic Information Systems together with other European level environmental datasets describing soil, climate, weather, land use, topography, *etc*.

This document describes the resulting digital dataset, explains some implications of using the data in relation to pesticide fate and behaviour and highlights a number of issues that should be considered when using it.

1.1 Assessment of the published data and what to digitise.

The cartographic base for the maps is the World 1404, at the scale of 1:500,000, which was separated into 38 'Grids' to give a complete and coherent coverage of all the 9 countries included.

The published paper maps are extremely complex and the information on them is organised into four 'Themes':

1. An inventory of **Aquifers** in terms of their spatial distribution, geological and lithological features, as well as their types (phreatic or confined) and flow characteristics (interstitial, fissured or karstic). These are differentiated on the maps using different colours, patterns and symbols.
2. The **hydrogeological characteristics** of the aquifers, including contours of the piezometric surface of the groundwater (where available), arrows indicating the direction of groundwater flow and interactions between surface and groundwater and between individual aquifers. Also shown in this theme are the presence of saline groundwater areas and saline intrusions from sea waters.
3. **Abstraction** of groundwater, including the distribution of abstraction sources, the type of source (wells, springs or mine water) and the amount of abstraction classified into three ranges.
4. Potential **Additional Groundwater Resources**, including zones of possible surplus, equilibrium, overdevelopment and where no significant groundwater occurs.

Each Theme has a separate map, so there are potentially 152 separate map sheets. In practice, some of the areas with little or no significant groundwater resource do not have sufficient information to justify a separate sheet for Themes 2, 3 or 4.

Before digitisation commenced in this project, a number of basic decisions were made as to what data would be captured.

1.1.1. The Digital Topgraphic base

No digital version of the World 1404 map was available for use in this project. It was therefore necessary to select a digital topographic base to form the template for digitisation of the Groundwater data. As the objective of digitising the Groundwater resources data is to provide groundwater resource information suitable for supporting environmental resource and risk assessment within the European Union, an obvious base dataset to use is the digital boundaries of The Nomenclature of Territorial Units for Statistics (NUTS) provided in the GISCO database NUE1MV6. This dataset, established by the Statistical Office of the European Communities (Eurostat) comprises digital coastline and country boundaries at a scale of 1:1,000,000 derived from the Commune Boundaries dataset, which is a compilation of boundary data of various sources, all of a detail of 1:1,000,000 or better. Using this dataset as the topographic base for the Groundwater resources database has the following advantages:

- It is the official European Community dataset for administrative boundaries at the scale of 1:1,000,000 and is thus of direct use for European regulatory or planning purposes.
- The dataset can be used directly to derive information at the three different administrative unit levels used in the NUTS system.

- Because it uses the NUTS system, statistical information on cropping, land use, farming systems, transport, *etc*, collated by Eurostat, can be directly overlain on the groundwater resource dataset.

However, when digitisation of the Groundwater Resources maps began, it was quickly found that the 1:1,000,000 scale of the NUE1MV6 dataset gave too coarse a resolution of national and, in particular, coastline boundaries, compared to the 1:500,000 scale groundwater maps. This meant that some groundwater resource information at coastal boundaries could potentially be lost. An alternative source for the base topography was therefore sought.

One of the other important environmental datasets available for use at the European level, the Soil Geographic Database of Europe (v. 3.2), presents harmonised soil information at the 1:1,000,000 scale (Le Bas, *et al*, 1998). This dataset has a coastline coverage that is considerably more detailed than that in the NUE1MV6 dataset and also corresponds well with that on the published Groundwater Resources maps. As the European soil database is one of the key datasets likely to be used and overlain on the European Groundwater Resources database, it would be an advantage if the coastline boundaries for the soil dataset and the European Groundwater Resources dataset matched when overlain within a GIS. *It was therefore agreed to integrate the digital coastline from the soil database with the terrestrial country boundaries from the NUE1MV6 dataset*. The two datasets were combined to form one complete 'boundary dataset', which for ease of reference may be called **EUGWB dataset**. This was used for all boundaries not digitised from the paper maps.

Adoption of this solution meant that a number of other minor topographic boundary issues had to be resolved.

- The Groundwater Resources paper maps do not cover what was, at the time of their publication, the German Democratic Republic whereas the NUE1MV6 dataset has boundaries for the unified Germany. The former boundary between East and West Germany was therefore digitised from the Groundwater resources paper maps and included in the EUGWB dataset.

- Although most of the coastline from the EUGWB dataset has a reasonable agreement with most of the coastlines on the Groundwater Resources paper maps, there were significant mismatches in the region of Germany / Netherlands border. These appear to relate to coastal features shown on the Groundwater resources maps and assigned symbols, but not shown on the EUGWB boundary dataset. In order to present all the information as shown on the Groundwater Resources paper maps, the symbolised section of coastline on the paper maps was digitised and used as the polygon boundaries within the Groundwater resources digital dataset.

- A number of inland water features are shown on the paper maps but are not included in the EUGWB boundary dataset. The following procedure was adopted to deal with this situation:

  If the water feature did not form any part of any aquifer polygon boundary it was not digitised.

  If the any part of the water feature boundary forms any part of an aquifer polygon boundary then that part forming the aquifer boundary was digitised from the paper maps.

If an aquifer polygon boundary obviously crossed a water feature boundary on the paper maps, but was drawn as terminating on either side of the water feature then the 'missing' part of the aquifer polygon boundary was digitised.

1.1.2. The mapped information to be digitised

At the start of the project, it was decided that, with the exception of the final point in 1.1.1 above, all boundaries and information shown on the paper maps would be reproduced digitally without alteration, even where this resulted in trans-national or sheet boundary mismatches. This was an important decision as, despite the efforts of the correlation team, significant mismatches between aquifer polygon boundaries, aquifer attributes, and groundwater contours are present on the paper maps (see section Annex 1). These become obvious when all the separate maps are digitised and datasets representing individual sheets are joined together.

Some of the information on Theme 3 relates to water resource administrative units. This data, together with all of the 'Additional Resources' information on Theme 4 are based on data collected over 30 years ago and are now likely to be considerably out of date. This is much less true of the information in Themes 1 and 2 and the abstraction source 'point' information in Theme 3. It was therefore decided *not to digitise any data from theme 4*, whereas only the information on abstraction source location and type would be digitised from Theme 3. All information from Themes 1 and 2 would be captured.

The data relating to aquifer boundaries and attributes presented in theme 1 of the maps are complex with many layers of information. This is particularly the case with respect to Multiple aquifers – areas where two or more different geological strata in a vertical sequence contain distinct groundwater bodies. In such cases the paper map conveys information by striped patterns of colour with the colours of the stripes representing the aquifer attributes and the thickness of the stripes indicating whether the attributes apply to the top, middle or lower aquifer. This information was too complex to present digitally in a reasonable way and was thus simplified for use in the digital dataset. Where such Multiple Aquifers occur, their presence is indicated in the first of the aquifer attribute codes (the 'nature' of the aquifer). Subsequent aquifer attribute codes indicating their 'type' (confined, unconfined or complex), their layered nature (multi-layered or mono-layered), nature of water movement, complexity and geology, are indicated *only for the uppermost aquifer*.

Finally, Theme 2 of the maps includes a set of arrows indicating directions of water movement within groundwater bodies or interactions between groundwater bodies and surface waters. In some cases the arrows also indicate interactions between groundwater in different overlying aquifers. Because none of the attributes of any lower aquifers in multiple sequences were digitised, *none of the arrows showing interactions between multiple aquifers were digitised*.

1.2 Digitisation of the Published Data.

Polygon, line and point data were captured into separate coverages on Calcomp 9500 series digitisers using ARC/INFO software. These data were edited, cleaned and built and checked on-screen against the original at every stage. The required coverages have accurate intersections and do not contain undershoots or overshoots.

This methodology was carried out using a number of in-house macro routines that have been found to be very effective over a number of years. These routines highlighted disconnected lines and any gaps in the data, which were then corrected, and the data rechecked. The appropriate processes were then repeated until all the errors had been removed. When the coverage was error free it was built to form the required attribute tables and the attributes added.

The accuracy of the attribute data was maintained by a macro program that checked each new input against a definitive list of valid attribute values. Non valid entries were flagged immediately so that all polygons with no attributes were highlighted and these were then revisited and checked. Occasionally some of the polygons appeared as very small slithers or dead space between genuine polygons, these were also highlighted and subsequently all removed. As a final check the digital attribute data were symbolised in a way that matched the information on the paper maps. This helped to very easily identify attribute codes that appeared to be valid but were in the wrong polygon.

Each of the individual themes on each of the paper maps was digitised in this way and sent to NSRI cartographic staff for separate checking against a second copy of the paper maps, using a QA methodology developed for the purpose. Identified errors were noted and corrected by CDD Ltd. When this process was complete, the separate theme data for each individual map sheet were joined to form a single digital coverage for each of the three data themes, *Aquifers*, *Groundwater Hydrology* and *Groundwater Abstraction*.

During the digitisation process, a number of decisions were made to address some issues relating to scale differences between the EUGWB dataset and the Groundwater resources paper maps or to inconsistencies between aquifer boundaries and aquifer attributes on adjacent map sheets. These are described briefly in Annex 1.

2. THE DIGITAL DATASET

2.1 Introduction

The digitised version of the Groundwater Resources Map of Europe is available in ArcView 3.2 format. It provides valuable information on the hydrogeology of much of Europe in a relatively consistent framework. The value of this spatial data resource can be further increased by linking the map to detailed hydrogeological data via the geological attribute coding provided.

To assist users of the map who have a limited background knowledge of hydrogeology, the following sections aim to provide a short and clear explanation of the three themes and also of how they might be used within a pesticide fate assessment context. In addition, there are a number of online hydrogeological glossaries that may help users. At the time of writing, examples can be found at:

- Texas Environmental Centre's Encyclopaedia of Water Terms: http://www.tec.org/tec/tec/terms2.html
- Geotech.org's Dictionary of Geologic Terms: http://www.geotech.org/survey/geotech/dictiona.html
- Nevada Division of Water Planning's Water Words Dictionary: http://www.state.nv.us/cnr/ndwp/dict-1/waterwds.htm

2.2 Theme 1, Aquifers

2.2.1 The Aquifers data

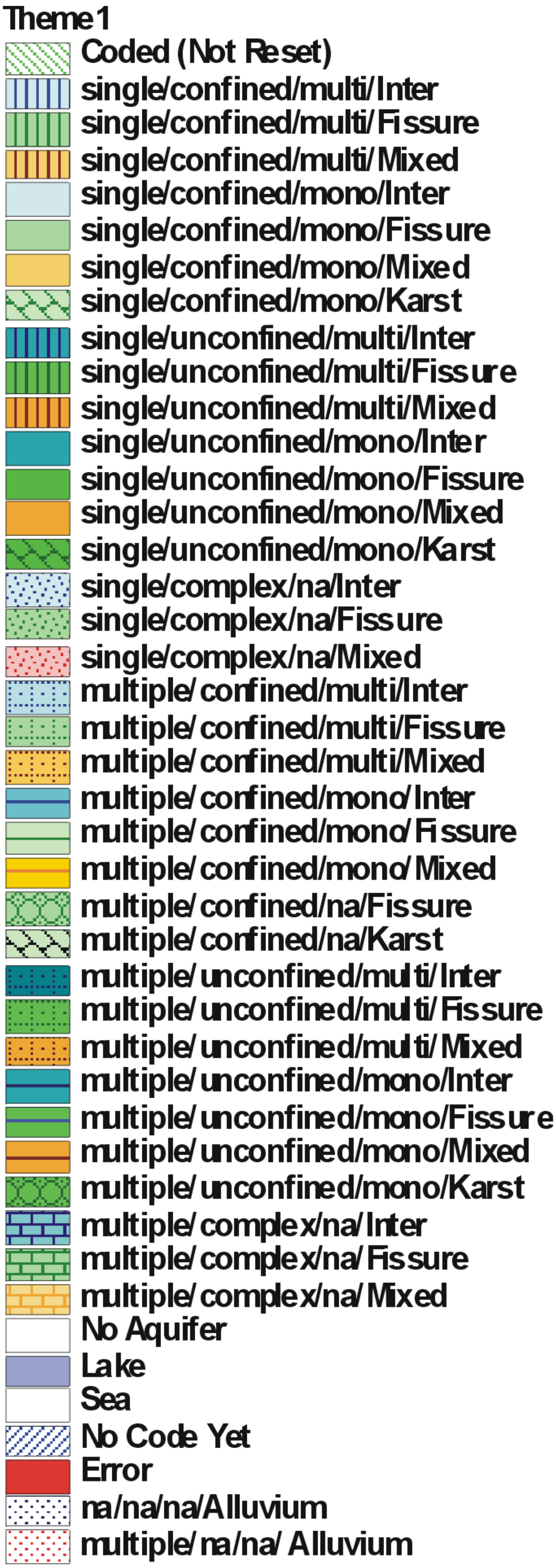
Theme 1 presents four sets of information regarding the properties of the aquifers:

1. The type of aquifer - unconfined, confined or complex;
2. The nature of water movement - intergranular, fissure, mixed or karstic ;
3. The complexity of the vertical sequence of aquifers- single aquifer or multiple aquifers;
4. Special cases.

The coding that appears on the legend when theme 1 is used in Arcview 3.2 is shown in Table 1.

Table 1 Codes (indicated in red) used in the map legend .avl file to characterise aquifer attributes

Nature	Level	Multi (vertical stripes)	Geology	Dom_Lith	Sec_Lith
Single 1 (no stripes)	Confined 1	Y/N 1 (Y)	Inter 1	Attribute	Attribute
	Unconfined 2	Y/N 2 (N)			
	Complex 3	N/a 9			
	Confined 1	Y/N 1 (Y)	Fissure 2	Attribute	Attribute
	Unconfined 2	Y/N 2 (N)			
	Complex 3	N/a 9			
	Confined 1	Y/N 1 (Y)	Mixed 3	Attribute	Attribute
	Unconfined 2	Y/N 2 (N)			
	Complex 3	N/a 9			
	Confined 1	Y/N 1 (Y)	Karst 4	Attribute	Attribute
	Unconfined 2	Y/N 2 (N)			
	Complex 3	N/a 9			
Multiple 2 (horizontal stripes)	Confined 1	Y/N 1 (Y)	Inter 1	Attribute	Attribute
	Unconfined 2	Y/N 2 (N)			
	Complex 3	N/a 9			
	Confined 1	Y/N 1 (Y)	Fissure 2	Attribute	Attribute
	Unconfined 2	Y/N 2 (N)			
	Complex 3	N/a 9			
	Confined 1	Y/N 1 (Y)	Mixed 3	Attribute	Attribute
	Unconfined 2	Y/N 2 (N)			
	Complex 3	N/a 9			
	Confined 1	Y/N 1 (Y)	Karst 4	Attribute	Attribute
	Unconfined 2	Y/N 2 (N)			
	Complex 3	N/a 9			
	These attributes are defined from the characteristics of the thickest horizontal stripes				
Multiple 2	N/a 9	N/a 9	Alluvium 5		
N/a 9	N/a 9	N/a 9	Alluvium 5	Attribute	Attribute
Nil (Non-Aq) 4	N/a 9	N/a 9	N/a 9		
Sea 6	N/a 9	N/a 9	N/a 9		


Theme1
Coded (Not Reset)
single/confined/multi/Inter
single/confined/multi/Fissure
single/confined/multi/Mixed
single/confined/mono/Inter
single/confined/mono/Fissure
single/confined/mono/Mixed
single/confined/mono/Karst
single/unconfined/multi/Inter
single/unconfined/multi/Fissure
single/unconfined/multi/Mixed
single/unconfined/mono/Inter
single/unconfined/mono/Fissure
single/unconfined/mono/Mixed
single/unconfined/mono/Karst
single/complex/na/Inter
single/complex/na/Fissure
single/complex/na/Mixed
multiple/confined/multi/Inter
multiple/confined/multi/Fissure
multiple/confined/multi/Mixed
multiple/confined/mono/Inter
multiple/confined/mono/Fissure
multiple/confined/mono/Mixed
multiple/confined/na/Fissure
multiple/confined/na/Karst
multiple/unconfined/multi/Inter
multiple/unconfined/multi/Fissure
multiple/unconfined/multi/Mixed
multiple/unconfined/mono/Inter
multiple/unconfined/mono/Fissure
multiple/unconfined/mono/Mixed
multiple/unconfined/mono/Karst
multiple/complex/na/Inter
multiple/complex/na/Fissure
multiple/complex/na/Mixed
No Aquifer
Lake
Sea
No Code Yet
Error
na/na/na/Alluvium
multiple/na/na/Alluvium

2.2.2. Using the aquifers data

It is important to recognise that the maps only depict information on geological deposits that were considered to be important as aquifers, whether locally or nationally, and which could be depicted at the scale of the map. Otherwise, the map is left uncoloured. The presence of an uncoloured area (or an area with no attribution on the digital version) does not imply that there is no groundwater present, or that there are no groundwater abstractions providing private supplies.

On the paper maps, the aquifers are bounded by either real limits based upon hydrogeological considerations, or artificial limits when it proved necessary to stop the depiction of the aquifer. The artificial limits, which usually represent the limit of exploitation of the aquifer due to depth or salinity, are indicated on the original paper maps by the cessation of the colouring without a line. It has not been possible to indicate this on the digital maps, but such artificial limits can normally be recognised by the artificial degree of straightness of the digitised boundary.

The type of the aquifer

The map depicts three main types of aquifer:

Unconfined aquifer- an unconfined aquifer has a watertable, or phreatic surface, which is defined as the surface of atmospheric pressure and appears as the level at which water stands in a well penetrating the aquifer. Unconfined aquifers can potentially receive recharge across their entire area, although they may be partly overlain by low permeability material such as till which will reduce recharge. An unconfined area of an aquifer can form the recharge area for the confined portion of the same aquifer.

Confined aquifer- confined aquifers occur where groundwater is confined under a pressure greater than atmospheric pressure by overlying relatively impermeable strata. In a well penetrating such as aquifer, the water level will rise above the bottom of the confining bed to the level of the potentiometric or piezometric surface. Confined aquifers may receive recharge from underlying aquifers, or by leakage through the overlying confining bed, but will typically receive most of their recharge from unconfined portions of the aquifer.

Complex aquifers- no definition of a complex aquifer has been found, although the map legend mentions "poor or complex local aquifers of restricted extent".

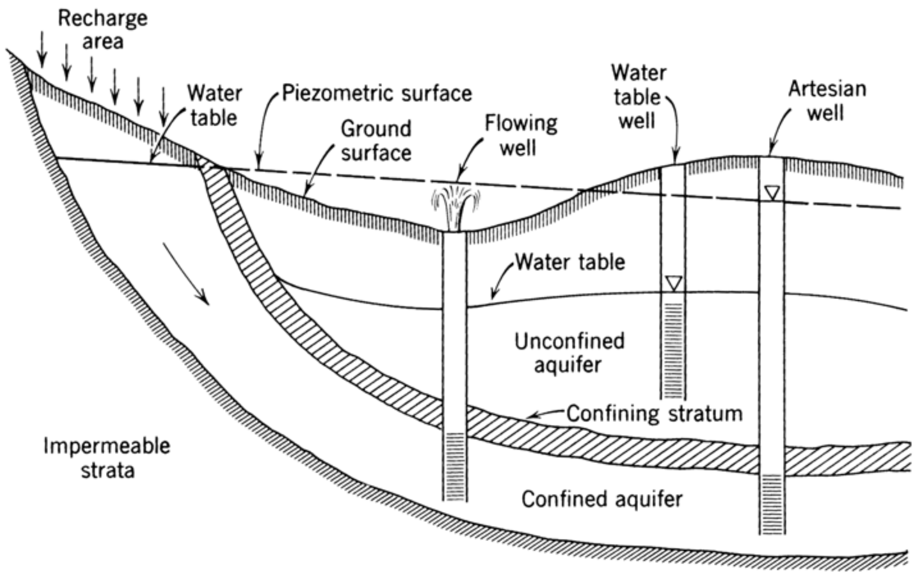


Figure 1 Schematic cross section illustrating unconfined and confined aquifers (from Todd, 1980)

Relevance to pesticide fate assessment:

- An *unconfined aquifer* can potentially receive recharge over the whole of its area, while a *confined aquifer* will tend to have a proportionally smaller recharge area, which will itself be unconfined;
- *Unconfined aquifers*, or the *outcrop / recharge areas of largely confined aquifers* may be vulnerable to pesticide leaching, dependent upon the nature of overlying deposits and the thickness of the unsaturated zone;
- *Confined aquifers* are afforded significant protection by the overlying confining bed (which is not depicted on the map), and pesticide degradation may be enhanced by chemically-reducing conditions which are common in extensive confined aquifers.
- *complex aquifers*- studies in these areas would benefit from more detailed geological mapping in order to more accurately ascertain the extent and lithological heterogeneity of such aquifers.

The nature of water movement

The nature of water movement through the aquifers depicted on the maps has been separated into four classes:

- **Intergranular**- flow occurs through the pore spaces between individual grains. Intergranular permeability can also be referred to as *primary permeability*. Most examples of material in which intergranular flow is the dominant flow mechanism are unconsolidated deposits such as sands and gravels. According to Volume 1, these aquifers usually have a low rate of flow and a high storage content due to the volume of pore spaces- *however, flow rates may be higher depending upon the permeability, for example in gravels*;
- **Fissure**- flow occurs through fissures (although no definition of fissure size appears to be given), which can be referred to as *secondary permeability*.

Examples of material with fissure flow are chalk, some limestones and hard rocks which have been designated as aquifers. According to Volume 1, these aquifers usually have a high rate of flow and a low storage content- *however, flow rates may be lower (i.e. moderate) depending upon the degree of development of fissuring, and the storage may be higher depending on the volume and continuity of pores;*

- **Mixed**- aquifers having both fissures and a high storage capacity in the interstices: for example cemented sandstones (See below). Most flow will occur through the fissures;
- **Karst**- karst flow usually occurs in calcareous deposits, such as limestone, where solutional enlargement of fractures and fissures leads to the development of large solution channels. Aquifers with a karstic flow have been defined as water soluble formations, chemically weathered, with a secondary permeability of fissures, able to produce large and irregular flow rates with respect to regional mean flow rates. Karstic aquifers are normally unconfined, but in a very few cases, karst flow can be confined, for example in southern Belgium.

Relevance to pesticide fate assessment:

- *Intergranular flow*- water moves along tortuous flow paths, which provides both time and the potential for significant interaction with the aquifer matrix;
- *Fissure flow*- fractures and fissures allow for fast flow rates with limited contact with aquifer media. The aquifer matrix may be calcareous or non-calcareous. Localised karst flow may occur in some portions of the aquifer;
- *Mixed*- the combination of the characteristics of both intergranular and fissure flow allows for fast flow rates together with a large intergranular storage, into which pollutants may diffuse from the fissures. While flow will be dominantly through the fissures, the groundwater resource comes mainly from groundwater released from intergranular storage by falling groundwater levels.
- *Karst flow*- the large solution channels associated with karstic terrain allow for very fast flow rates (of the order of kilometres per day) with limited contact with aquifer media, but probably in a high pH environment.
- *Karst flow*- rates can be high enough to generate turbulent flow, allowing the movement of particulate and colloidal material through the groundwater system.
- Normal unconfined *karstic aquifers* are often associated with a karst terrain, characterised by solution channels, closed depressions, sinkholes and caves. These allow very rapid movement of surface water and recharge in to the groundwater system. Karst aquifers can be very vulnerable to pollutants entering from the surface water system.

It appears that there were perceived difficulties in applying the above criteria to mixed aquifers across Europe, because the criteria for fissure (high rate of flow and a low storage content) and mixed (high rate of flow due to fissuring and a high storage content) form a continuum, and it became necessary to list the mixed aquifers:

- Belgium- Cretaceous chalk; Permian conglomerates; Jurassic sandy limestones, sandstones and sands
- Denmark- Paleocene limestone
- Germany- alternate Cretaceous layers of sandstone and sand, with clay marls and limestone lenses (at the border with Belgium); fissured sandstones and sandstones

with conglomerates (at the border with Luxembourg); fissured sandstones with some conglomerates (at the border with France);
- France and Italy- some conglomerate sandstones; some granites, intrusive rocks at the scale of the map; extrusive rocks, basic; alternation of lava with fissured permeability and pouzzolanes with intergranular permeability; some marly-sandy flysch containing sandstones and sands.
- Ireland- some Triassic sandstones
- Luxembourg- sandstones with calcareous cements
- United Kingdom- cemented sandstones; fissured sandstones in shales.

The complexity of the vertical sequence of aquifers

The original paper maps contained information on the vertical sequence of aquifers. However, protection of groundwater from contamination by surface-applied compounds needs to be focussed on minimising transport to the uppermost aquifer. Therefore the information provided about the vertical sequence of aquifers beneath the uppermost aquifer is not provided on the digital map version.

Instead a column within the attribute table indicates:
- Whether an aquifer is mono-layered (single) or multi-layered;
- Whether there are multiple contrasting aquifers (intergranular versus fissure flow; or confined versus unconfined etc.).

The depiction of a multi-layered aquifer on the map is likely to represent a number of different situations, in which the dominant flow mechanisms are likely to be the same:
- A single aquifer which consists of alternating sequences of contrasting lithology;
- Two distinct aquifers that are locally adjacent and exchange water, as for example in Belgium;
- Where there are several superimposed aquifers that exchange water and cannot be easily differentiated at the scale of the map, the whole system is assumed to be a multi-layer aquifer, for example much of the Netherlands.

Special cases

Two special cases are described on the maps. These are:
- Discontinuous aquifers
- Alluvial aquifers

Discontinuous aquifers- these are only shown in the Republic of Ireland, partly because of the low level of geological information in this country at the time of map production.

Alluvial aquifers- these have been treated as a special case on the map and depicted separately, even though they are characterised by intergranular flow. Although their dimensions are often small, their importance to water resources / supply is disproportionately high because of their interactions with the surface water network. Abstraction of groundwater from these alluvial aquifers can induce artificial recharge of river water into the alluvial aquifer providing a far larger groundwater resource than suggested by the normal recharge over their surface area. This may particularly be the case in south western France where there are multiple alluvial aquifers.

Relevance to pesticide fate assessment:

- *Alluvial aquifers* are disproportionately important for water supply purposes;
- *Alluvial aquifers* are vulnerable to contamination from the induced infiltration of contaminated surface water;
- *Discontinuous aquifers*- studies in these areas would benefit from more detailed geological mapping in order to ascertain more accurately the extent and lithological heterogeneity of these aquifers.

Geological information

Some limited quantitative data are given in the various national reports accompanying the original paper maps, and in the national overview tables in the Synthetical *(sic)* Report. These provide some information as to the hydrogeological properties of the aquifers shown. However, these values are no more than indicative as hydrogeological properties such as transmissivitiy, storativity *etc*. vary greatly at scales much smaller than that of the maps.

To provide a means of linking the aquifers depicted on the maps to local published data in journals, reports *etc*., geological information describing each polygon has been included in two columns of the aquifer (Theme 1) attribute table. One column contains the geological information, which is described below, for the geological deposit which is estimated to be the spatially dominant component of the uppermost aquifer. The second column contains the geological information for all other deposits which make up the polygon of the uppermost aquifer.

The attribute data give the:

- geological age of the deposit, using the symbols of the International Geological Map of Europe (Figure r and Table w);
- mode of origin (for Quaternary deposits), given in Table x
- dominant aquifer lithology (Table y).

For example, c2Lh = Upper Cretaceous (c2) chalk
qp'mSg = Pleistocene (qp) sands and gravels (Sg) of marine origin ('m)

Relevance to pesticide fate assessment:

- The geological attribute coding allows detailed quantified hydrogeological information, available from geological memoirs, journal papers etc. such as transmissivity, hydraulic conductivity, specific yield etc. to be linked to the digital map.

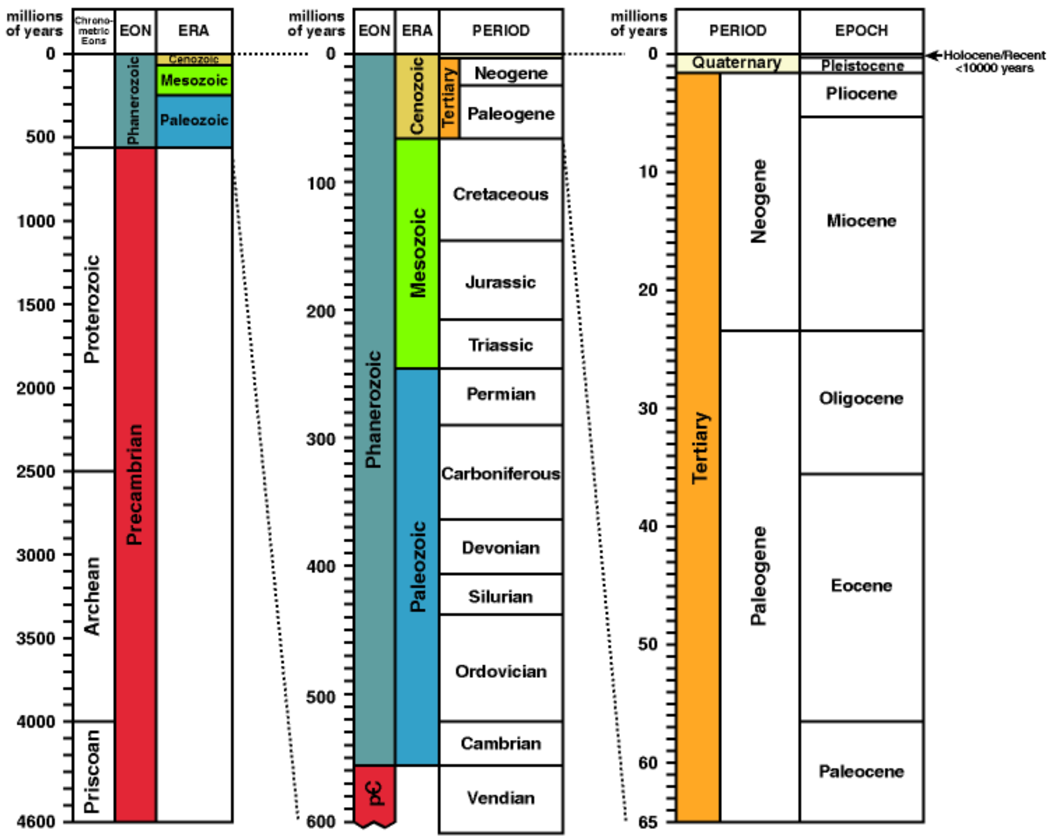


Figure 2 Geological timescale (from http://www.geo.ucalgary.ca/~macrae/timescale/timescale.html)

Table 2 Explanation of the geological timescale codes used on the map

Era	**Period**		**Epoch**	**Map code**
Cenozoic	Quaternary		Holocene	qh
			Pleistocene	qp
	Tertiary	Neogene		ng
			Pliocene	m4
			Miocene	m3
		Palaeogene		pg
			Oligocene	m2
			Eocene & Palaeocene	m1
Mesozoic				ms
	Cretaceous	Upper Cretaceous		c2
		Lower Cretaceous		c1
	Jurassic	Upper Jurassic		j3
		Middle Jurassic		j2
		Lower Jurassic		j1
	Triassic	Upper Triassic		t3
		Middle Triassic		t2
		Lower Triassic		t1
		Permo-Triassic		t+p

Paleozoic	Upper Paleozoic		pl2
	Lower Paleozoic		pl1
	Permian	Upper Permian	p2
		Lower Permian	p1
	Carboniferous	Upper Carboniferous	h2
		Lower Carboniferous	h1
	Devonian	Upper Devonian	d3
		Middle Devonian	d2
		Lower Devonian	d1
	Silurian		s
	Ordovician		o
	Cambrian		cb
Precambrian			pr

NB Where a geological map code appears without a corresponding number e.g. 'd', the age of the geological unit is undifferentiated *ie*.Devonian

Table 3 Map codes used to discriminate the mode of origin of Quaternary deposits

Map code	Origin
'm	Marine
'g	Glacial
'fg	Fluvioglacial
'f	Fluviatile
'e	Eolian
't	Bogs
'r	Mud flats, salt flats

Table 4 Codes used to indicate the lithological classes

Lithology	Map code
Alluvium (sands, pebbles, gravels, loam)	A
Sands	S
Alternate strata sands and clay	Sc
Alternate strata alluvia and clay	Ac
Sands and gravels	Sg
Sandstones or calcarenites (sandstones with calcareous cement)	G
Conglomerates	C
Sandstones with conglomerates	Gc
Limestones	L
Chalk	Lh
Marly limestone	Lm
Karst limestone	Lk
Dolomitic limestone	Ld
Dolomites	D
Calcareous sinters	T
Intrusive rocks	I
Extrusive rocks	V
Acid extrusive rocks	Va
Basic extrusive rocks	Vb
Metamorphic rocks	M
Evaporates (sodic, potassic salts, gypsum)	E
Marly-sandstone flysch (alternate marly, sandstones, sand strata)	Fm
Alternate sandstones and shales	Ga
Marl	M
Pierres vertes	p.v.

2.3 Theme 2, Groundwater Hydrology

2.3.1 The Groundwater hydrology data

Theme 2 provides a variety of information concerning the dynamics of groundwater movement within the aquifers depicted in Theme 1. For purposes of data storage within the GIS files, the information has been sub-divided into:

- Arrows- directions of groundwater flow and of water transfers;
- Contours- contours of the watertable or the potentiometric surface;
- Points- springs;
- Polygons- areas of seawater intrusion or saline groundwater;

The coding that appears on the legend when theme 2 is used in Arcview 3.2 is shown in Table 5.

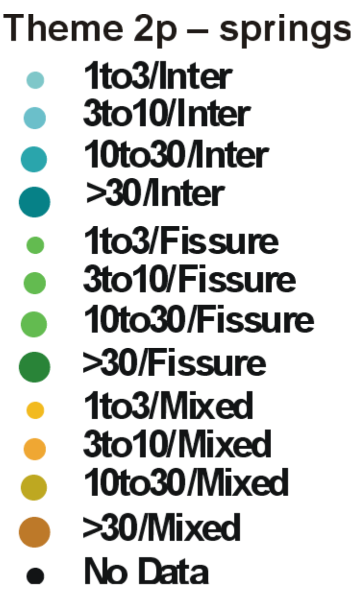
Table 5. Codes (indicated in red) used in the map legend .avl file to characterise Groundwater hydrology attributes

Contours (lines)

Geology	**Level**	**Value**
	Upper 1	Attribute
	Middle 2	Attribute
Inter 1	Lower 3	Attribute
	Upper 1	Attribute
	Middle 2	Attribute
Fissure 2	Lower 3	Attribute
	Upper 1	Attribute
	Middle 2	Attribute
Mixed 3	Lower 3	Attribute

Springs (points)

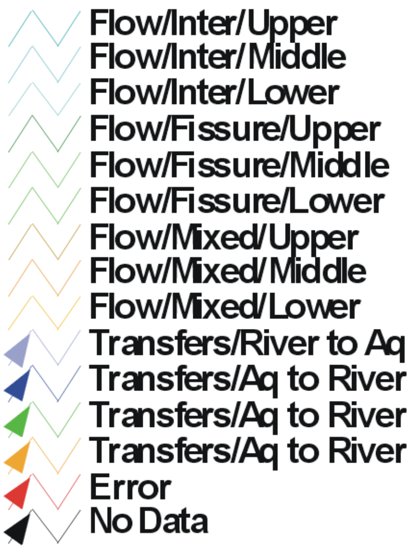
		Geology		Rate		Nature	
Springs	1	Normal (filled circle symbol)	3	1 to 3	1	Inter (blue)	1
				3 to 10	2		
				10 to 30	3		
				> 30	4		
				1 to 3	1	Fissure (green)	2
				3 to 10	2		
				10 to 30	3		
				> 30	4		
				1 to 3	1	Mixed (orange)	3
				3 to 10	2		
				10 to 30	3		
				> 30	4		



Flow and Transfers (arrows)

Type	Geology	Level	Direction
Flow 1	Inter (blue) 1	Upper 1	N/a 9
		Middle 2	N/a 9
		Lower 3	N/a 9
	Fissure (green) 2	Upper 1	N/a 9
		Middle 2	N/a 9
		Lower 3	N/a 9
	Mixed (orange) 3	Upper 1	N/a 9
		Middle 2	N/a 9
		Lower 3	N/a 9
Transfers 2	Inter (blue) 1	N/a 9	river to aquifer 1
		N/a 9	aquifer to river 2
	Fissure (green) 2	N/a 9	river to aquifer 1
		N/a 9	aquifer to river 2
	Mixed (orange) 3	N/a 9	river to aquifer 1
		N/a 9	aquifer to river 2

Theme 2a – arrows



2.3.2 Using the Groundwater Hydrology data

Directions of groundwater flow

The general movement of water within an aquifer is qualitatively shown in many aquifers, even those without piezometric contours, by an estimate of the flow direction of the aquifer. This has been obtained from more detailed piezometric maps or from known direct evaluation. Arrows, which differentiate between aquifer permeability type and aquifer (lower, middle or upper), are used to visualise these movements.

Where arrows are not given to indicate groundwater flow directions, they can be estimated based on the locations of recharge areas and discharge areas. Groundwater will flow from the former towards the latter. The recharge area of relevance to pesticide fate assessment can often be readily identified from the maps as the outcrop (unconfined) area of the aquifer, but the discharge areas can be more difficult to identify. They may be natural surface discharge areas (rivers, springs etc.), a hydraulic connection to other aquifers or be induced by man's activities (boreholes, adits etc.).

Relevance to pesticide fate assessment:

- The direction of groundwater flow can be used to assess in which direction groundwater may move from areas where pesticide leaching risk is high;
- The direction of groundwater flow can be used to assess where the source of areas of sensitive receptors (important wetlands, springs etc.) may be.

Contours of the water table or the potentiometric surface

Contours are given for some of the main aquifers showing typical elevations of the water table (in unconfined aquifers) or potentiometric surface (confined aquifers) and, "when significant", the yearly fluctuations. The contour information is intended, when combined with aquifer hydraulic properties, to allow an estimate of the mean yearly movement of groundwater.

Although the form of the contours distinguishes the permeability type (intergranular, fissure *etc.*) and the level (upper, middle or lower), the labelling does not distinguish between confined and unconfined aquifers. The contours in this Theme must, therefore, be examined in conjunction with the aquifer type in Theme 1 to ascertain if they refer to the water table or a potentiometric surface.

Relevance to pesticide fate assessment:

- Contours of water table elevation can be used to provide an indication of the depth of the water table below groundwater;
- Contours of the elevation of the potentiometric surface CANNOT be used to provide an indication of the depth of groundwater below the land surface (see Figure 1);
- All contours are likely to be given relative to a NATIONAL ordnance datum (OD) which may differ between countries. Caution must be exercised if these contours are used with a GLOBAL ordnance datum;

- The contours can be used to predict general groundwater flow directions- from high elevation to low elevation;
- When combined with aquifer transmissivity (hydraulic conductivity multiplied by aquifer thickness), the hydraulic gradient calculated from the map can be used to assess bulk groundwater flow rates;
- Where there are no values given for the yearly fluctuations, it should not be assumed that they are insignificant;
- All other things being equal, the yearly fluctuations of the potentiometric surface of a confined aquifer will be greater than those of the water table in an unconfined aquifer.

Springs

Springs are an important water supply source in some European countries. According to Volume 1, they provide 81.7% of all groundwater in Luxembourg, 27.5% in Italy, 10-15 % in France and 10 % of the groundwater used for public water supply in the former West Germany. Only springs with flow rates of greater than 30 l/s (equivalent to about $1x10^6$ m^3/a) are depicted on the map, and are separated into:

- Normal springs;
- Mineral springs;
- Thermal springs.

However, neither mineral springs, nor thermal springs appear to be depicted on the maps and thus only ‘normal’ springs are included in the dataset.

For each spring, its discharge (or 'size of spring' as given on the map legend) is rated as 1-3 $x10^6$ m^3/a, 3-10 $x10^6$ m^3/a, 10-30 $x10^6$ m^3/a and >30 $x10^6$ m^3/a, and the nature of the permeability from which it issues classified (intergranular, fissure or mixed). It would be anticipated that the highest discharges will typically be associated with fissure flow (and karst which has probably been included within the fissure class), with the lowest discharges more typical in intergranular aquifers. There will of course be exceptions to this.

Springs or springlines generally occur in sloping land, where geological features such as faults, dips, slope, rock unconformities and outcrops cause the watertable to intersect the land surface. The most common situation is at the point of outcrop between permeable and underlying impermeable strata where water issues out on the surface at the junction, giving rise to springs, which are probably those referred to as *'normal'* springs.

Relevance to pesticide fate assessment:

- *Normal springs*- likely to be important water supply sources;
- *Normal springs*- these may represent the discharge of local groundwater bodies, so that flowpaths and residence times may be relatively short;
- Springs in *karstic* areas can, due to the very rapid rates of groundwater flow (kilometres per day) have distant source areas;
- The very high (but variable) flow rates of *karstic* aquifers, which can make them important water supply points, makes them vulnerable to contamination by solutes or particulates.

Areas of seawater intrusion or saline groundwater

Areas of saline groundwater are depicted on the map, and the origin of the salinity is differentiated between areas of:

- Salt water intrusion;
- 'Natural' saline groundwater.

In coastal areas where there is a hydraulic connection between the sea and the aquifer, seawater may naturally intrude into the aquifer (because of the greater density of seawater compared to normal groundwater) even when the watertable / potentiometric surface is higher than sea level. The resulting seawater intrusion will be wedge-shaped, with the foot of the seawater intrusion being furthest inland. Seawater, or salt water, intrusion is greatly exacerbated when over abstraction of groundwater results in the watertable being lowered below sea level so that the hydraulic gradient is reversed.

Areas of saline groundwater can also be found inland, away from the coast. In these cases, there can be several sources of the salinity. The groundwater can be ancient, or connate, saline groundwater from when sea levels were much different or from when the geological material was deposited which has not been flushed out, deep saline groundwater which has risen up due to over abstraction of groundwater or due to proximity to salt (halide) deposits.

Relevance to pesticide fate assessment*:*

- *saltwater intrusion* and *saline groundwater*- unlikely to be used for potable water supply;
- *saltwater intrusion* and *saline groundwater* - may be used for industrial water supply, especially in the Netherlands.

Water transfers

The maps provide information on water transfers between aquifers and surface water systems, or vice versa. Transfers from an aquifer to the river ('gaining' river) are a natural consequence of groundwater levels being higher than the river level and a hydraulic connection existing. Transfers from a river to the aquifer ('losing' river) can be either a natural consequence of groundwater levels being lower than the river level and a hydraulic connection existing, or because of groundwater abstraction in the alluvial/river terrace deposits inducing river water to infiltrate into the aquifer.

The relationship between an alluvial aquifer and a river are complex, and depend upon the degree of clogging of the river bank and bed and various hydrological factors like the water levels in the river or the distribution and pumping rates of the boreholes. The transfers are therefore qualitatively classed as good, medium or weak aquifer-river exchanges.

Relevance to pesticide fate assessment:

- *Aquifer* to *river exchange*- indicates the location of a groundwater discharge zone, which may be useful in inferring flow directions;
- *River* to *aquifer exchange*- may indicate location of important groundwater abstraction site utilising induced bank infiltration;

- *River* to *aquifer exchange*- may indicate location where an aquifer is vulnerable to contamination from polluted surface waters.

2.4 Theme 3, Groundwater abstraction

2.4.1 The Abstraction data

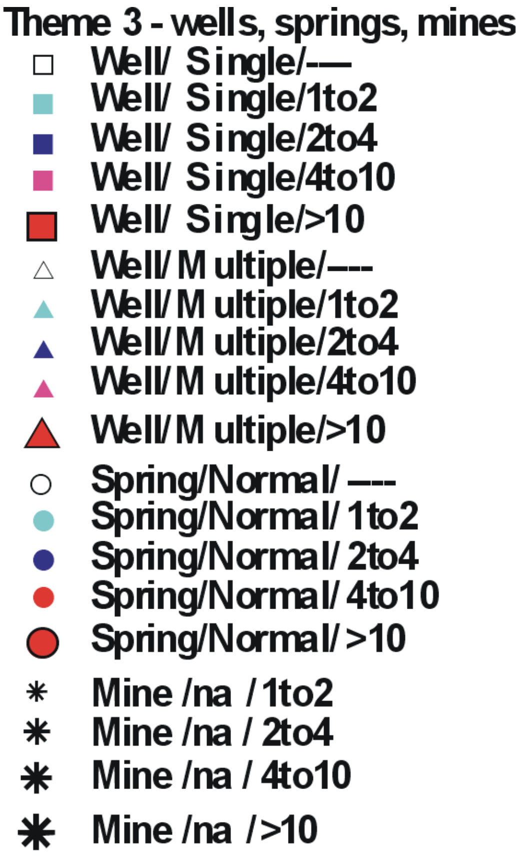
The most common types of groundwater abstraction are wells, springs, mine drainage and drainage galleries (adits). Three sets of information are provided in this theme:

- Wells;
- Springs;
- Mine drainage.

The coding that appears on the legend when theme 3 is used in Arcview 3.2 is shown in Table 6.

Table 6. Codes (indicated in red) used in the map legend .avl file to characterise Groundwater abstraction attributes

Type	Nature	Rate
Well 1	Single 1	1to2 1
		2to4 2
		4to10 3
		>10 4
	Multiple 2	1to2 1
		2to4 2
		4to10 3
		>10 4
Spring 2	Normal 5	1to2 1
		2to4 2
		4to10 3
		>10 4
Mine 3	N/a 9	1to2 1
		2to4 2
		4to10 3
		>10 4



2.4.2 Using the Abstraction data

Volume 1 notes that drainage galleries exist in Italy (on Etna, in Calabria and near Napoli), where they are accounted for as springs, in north eastern Belgium where they are very large (about 21 $x10^6$ m^3/a) and in the chalk of the London Basin where they occur in large number. There is no indication as to how the latter two cases are accounted for on the maps and, in Belgium, only one very large abstraction well is shown.

Wells

Wells, which will include boreholes, represent the most frequent type of abstraction. In Theme 3, wells are subdivided according to the size of abstraction (1-2 $x10^6$ m^3/a, 2-4 $x10^6$ m^3/a, 4-10 $x10^6$ m^3/a and >10 $x10^6$ m^3/a) and whether the source area of the well/borehole is within a single aquifer or a multiple aquifer.

Relevance to pesticide fate assessment:

- The size of abstraction from *wells/boreholes* provides a measure of the importance of the aquifer to local and regional water supply;
- The size of abstraction from *wells/boreholes* provides a measure of the likely size of its source area.

Springs

In Theme 3, the springs shown on the map are again only characterised as ‘normal’, despite the paper map legend inclusion of thermal and mineral types. Springs are not further subdivided based upon permeability but the sub-division on 'average discharge' is based upon classes of 1-2 x10^6 m^3/a, 2-4 x10^6 m^3/a, 4-10 x10^6 m^3/a and >10 x10^6 m^3/a. As this differs from the classes used in Theme 2 of 'size of spring' it cannot be deduced as to whether these two themes are indicating different characteristics of the spring discharge, or are merely sub-dividing the same parameter with different classes.

Relevance to pesticide fate assessment:
- See notes for Theme 2 springs.

Mine drainage

Mine drainage contributes to groundwater abstraction in several countries, but the water obtained in this manner is usually unsuitable for public supply. According to Volume 1, recorded mine drainage accounts for about 2.5% of the total abstracted groundwater in the United Kingdom (Northwest, Yorkshire and Welsh water authorities), about 5% in France (Agences de Bassin Artois-Picardie, Loire Bretagne, Rhône, Mediterranée Corse and Rhin Meuse, the latter accounting for 94% of the total mine drainage), about 0.4% in Italy (Sardinia). Some mine drainage exists in Belgium (Limbourg) and in West Germany.

'Average discharge' from mine drainage is based upon classes of 1-2 x10^6 m^3/a, 2-4 x10^6 m^3/a, 4-10 x10^6 m^3/a and >10 x10^6 m^3/a.

Relevance to pesticide fate assessment:
- The presence of *mine drainage* indicates that there may be significant human alterations to groundwater flow systems in the area, in terms of lowering of groundwater levels due to pumping, changes in natural flow directions, development of hydraulic connections between aquifer and changes to flow paths (due to zones of subsidence, subsurface adits etc.);
- Surface water quality may be poor in areas of *mine drainage.*

REFERENCES

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Le Bas, C., King, D., Jamagne, M. & Daroussin, J. (1998). The European Soil Information System. In: Land Information Systems: Developments for planning the sustainable use of land resources. H.J. Heineke, W. Ecklemann, A.J. Thomasson, R.J.A. Jones, L. Montanarella & B. Buckley (Eds.). European Soil Bureau Research Report No. 4, EUR 17729 EN, 33-42. Office for Official Publications of the European Communities, Luxembourg.

ANNEX 1.

INCOMPATIBILITIES OF SCALE AND MAP SHEET BOUNDARIES AND SOLUTIONS IMPLEMENTED

During the digitising process, some minor incompatibilities between the paper maps and the EUGWB dataset and between information on some adjacent map sheets required a decision with respect to the amount of mapped information that would be digitised.

Problems that have been encountered by CDD whilst digitising to date.

There are 'edge-matching' problems between individual sheets of the paper Groundwater Resource maps and across country boundaries within individual sheets. These problems will not, however, be fully realized until such time as each individual paper map has been completed with regards to data capture. The edge matching should be commenced during January 2001 when the true magnitude of this problem will be discovered. These relate to offset polygon boundaries or lines in going from one sheet to the next and to different attributes attached to adjacent polygons on adjoining sheets or in adjoining countries.

The NUTS country boundaries will be used in the Groundwater Resources database. There appears to have been an error in the minutes of Meeting No.1, Section 2 para 8. namely "Where there is a mismatch between the NUTS country boundary and the **country** boundary shown on the paper maps, the Groundwater Resource data as shown on the map will always be captured, EXCEPT where the country boundary represents a boundary between a country with groundwater resource data and one with no data and the NUTS boundary falls within the country that has data. In such cases the groundwater resource data will only be digitised up to the NUTS country boundary". The bold **country** should read **aquifer.**

The coastline from the EUGB dataset, which has a reasonable agreement with most of the coastlines, differed greatly round the German/ Holland border. It was agreed that CDD digitise the coastline from the paper maps and use this as the coastline for the section of coastline in question.

There have been a number of inland water features not shown on the EUGB dataset and CDD queried what should be done with regards to these. The following was agreed :-

If the water feature does not form any part of any boundary it should not be digitised.

If the water feature boundary forms an aquifer boundary the relevant part should be digitised from the paper maps.

If an aquifer boundary obviously crosses the water feature but is drawn as terminating at both sides then CDD will join up the missing boundary. Unfortunately no hard and fast rule can cover the many unknowns that arise and many digitising decisions are made on the spot adhering to the above wherever as much as possible.

There are many instances where the contours do not have a value or two values. In these cases no values have been given to the contour unless it is obvious what its value is by the contour sequence.

The two points resulting from the test dataset discussed at Meeting No1 have been implemented following the agreed format between SSLRC (now NSRI) and CDD Ltd.

RGOB's stuff

The **international boundary** situation is of more concern and polygons are taking on curtailed or extended shapes by placement of the boundaries some distance from their paper base map representation.

Of more concern is the situation of the **coastline**, particularly on sheets 12 and 13 in southern England where the digital version is offset by 1–2 mm from the paper version. There is the **'Isle of Wight Syndrome'** where important aquifer information is truncated by the digital coastline and no adjustment is made by 'fitting' the map units to the coast rather than the edges of the map sheets. This situation is particularly obvious around Poole Harbour, Torquay and the Exe estuary and in all cases seems to distort reality. More rarely there is the **'Portland Bill Syndrome'**, where, because of the narrow promontory of land, some 'fitting' has had to be made or the map units would not fall on the land. It would be very time-consuming to rectify the former situation if a solution were decided upon.