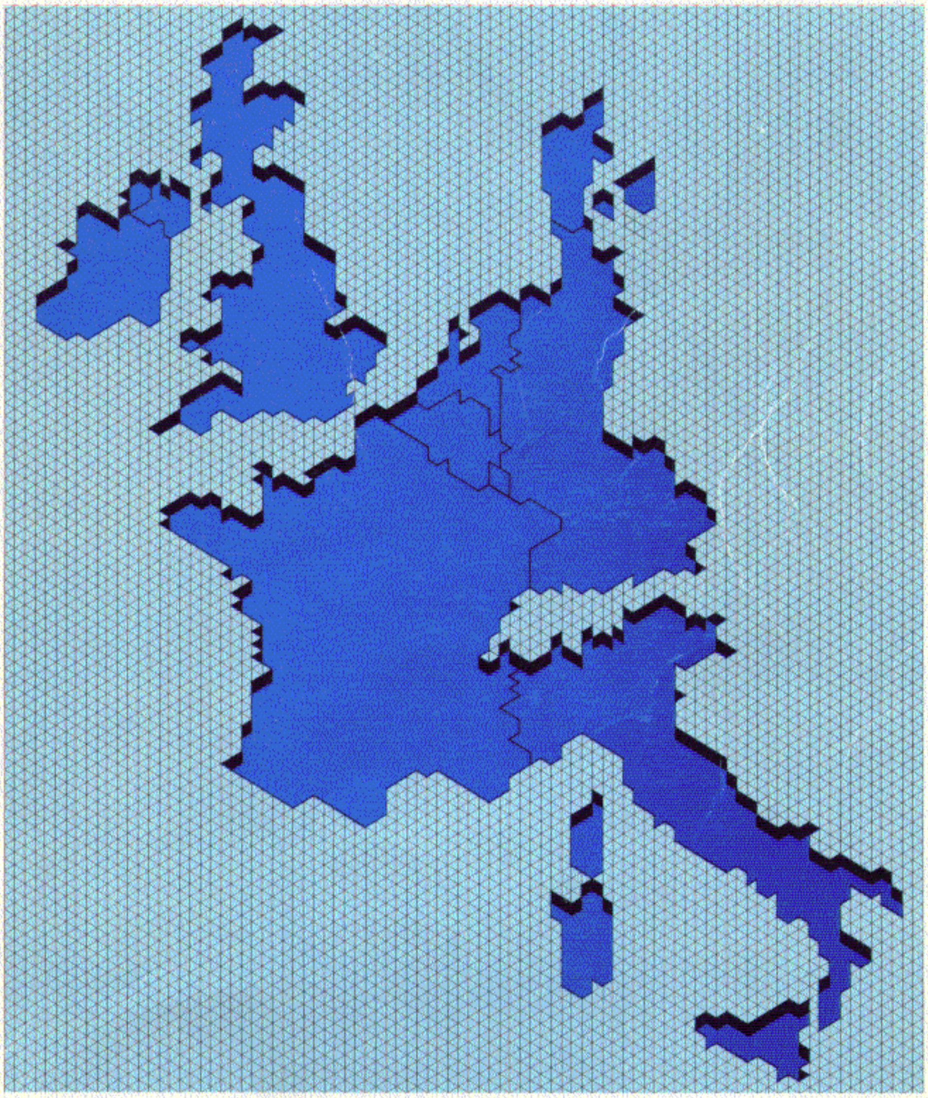
Commission of the European Communities

Groundwater Resources of the European Community Synthetical Report



Commission of the European Communities

Groundwater Resources of the European Community Synthetical Report

Directorate-general for the environment,
consumer protection and nuclear safety

Th. Schäfer GmbH · D-3000 Hannover 1

J. J. Fried, Professor at the University Louis Pasteur, Strasbourg.
Coordinator of the study.

EUR 7940 EN

Published and distributed by
Th. Schäfer Druckerei GmbH · Tivolistraße 4 · D-3000 Hannover 1
Telefon (05 11) 34 99-0 · Telex 9 23 846 (vinha)

Introduction

Dr. K.-H. Narjes

Member of the Commission
of the European Communities

responsible for the Environment, Consumer Protection
and Nuclear Safety

The balance of groundwater resources in the Community is an estimate of these resources designed primarily to be of use to water management and planning authorities and, more generally, to national and Community decision-makers. This study has been performed at a scale such as to allow the homogenization of the results and to ensure their consistency as well as meaningful comparisons between Member States. It provides a picture as complete as possible at Community scale of the distribution and availability of groundwater.

One of the first international studies of its kind, it is original on several accounts:

- From the viewpoint of the results, the study provides the necessary elements for national and community groundwater management, especially by collecting and analyzing – in many cases for the first time – data which are usually dispersed; it also identifies gaps which should be filled for rational management of this important resource.
- From the technical viewpoint, the study, by introducing a regionalization both scientific and administrative, has displayed the problems of managing groundwater, within a framework which can also be used for political decision making.
- From the methodological viewpoint, the fact that the study has been carried out by nine teams, one from each Member State, under a project leader has made it possible to compare and harmonize approaches and methods used in the Member States.

The results and methodology should be of widespread interest.

Introduction

A. Andreopoulos
Director-General
Environment, Consumer Protection and Nuclear Safety

The Commission of the European Communities presents the balance of groundwater resources in the Community.

For the first time, a picture as comprehensive as possible at Community scale is given of the aquifers and their availabilities. The study deals with four main themes. Each is illustrated by 38 (1 : 500 000) maps together covering the entire Community (i.e. a total of 152 maps, about 50 × 80 cm on average) and is explained in detail in 10 reports, one for each Member State and a general survey.

Greece joined the European Community on 1 January 1981, when the studies for the nine other Member States had already been made.

It is for this reason that Greece is not included in this report. Work on Greek underground waters started in 1982 and the information for this Member State will be integrated subsequently into the complete report.

The themes are:

- Inventory of aquifers: location; geometric, lithological and stratigraphical characteristics; type (unconfined or confined); permeability (interstitial of fissures and karst);
- Hydrogeology of aquifers: transmissivities, direction of flow, water exchange between rivers and groundwater, and specific problems such as the intrusion of seawater;
- Groundwater abstraction: abstraction densities, large pumping stations;
- Potential additional groundwater resources: factors such as replenishment, use and water management imperatives are all taken into account in a geographical classification of the areas in which there is a possible surplus, areas in which there is a balance, areas in which resources are now known to be over-used under present abstraction policies and finally areas lacking adequate groundwater resources.

For several Member States this inventory is the first complete cataloging on their own national water resources. The study collates as far as possible all data which would otherwise be dispersed and, in many cases processes them for the first time.

This inventory is not only an essential instrument of Community groundwater management. It will also be extremely useful for the knowledge and management of groundwater resources, thanks to the original evaluation method, which combines both a hydrogeological and administrative regionalization on a network adapted to national administrative units. This makes it very easy to use for management and modelling taking into account administrative and political features.

Special symbology has been devised to ensure uniform mapping of the results throughout the Community. This makes the information more accessible to the layman without sacrificing any of the technical quality of the information.

Table of contents

List of Tables

Summary

This report is a synthesis of the main data concerning the evaluation of the groundwater resources of the Community. It stresses the significant features of this groundwater balance at Community scale. The evaluation is based upon four themes, the inventory of the aquifers, the hydrogeology, the exploitation, the additional resources ; a chapter is devoted to each theme consisting of a comparative study of the Member States allowing a better approach of the problems at Community level and, completed by detailed explanations about the cartography, a better global understanding of the thematic maps. For instance, the aquifers are listed for each Member State, classified by age and size, immediately stressing the important aquifers ; also given are tables of groundwater uses by region and Member State. General information, like the uses, the exploitation trends, the water industry in the Member States are provided in specific chapters. This report is completed by an introductory chapter briefly presenting the study and its aims, the methodology, the cartographic principles and the consultants.

Chapter 0

GENERAL INFORMATION ABOUT THE STUDY

0.1. PURPOSE OF THE STUDY

Preliminary studies undertaken by the Commission of European Communities on the availability of water resources in the Community have shown that these resources are globally adequate to cover the expected needs of all users up to the year 2000.

It is an interesting indication, involving that the water problems in the Community are management problems and not really resources problems. Of course, such global evaluations are not sufficient because they do not show what are the management problems and where they are located in the Community : for instance, they tell us that Italy has larger water resources than France without stressing the fact that these resources are localized mainly in Northern Italy while French resources are more homogeneously distributed ; or they neglect the fact that main users often are located in regions where local resources are not sufficient.

Availabilities of water resources vary with time and space. It is thus necessary to obtain an image of the regionalized distribution of water resources, taking into account both the quantities of water and their distribution in time and space, as a basis for their management.

The major part of the freshwater resources of the Community being made up of groundwater* and, furthermore, the drought of 1975-1976 having displayed the vulnerability of the water supply systems in Member States and showed the advantage in using groundwater as a supply not too dependent on climatic variations, the Commission of European Communities has emphasized the actions of protection and management of groundwater resources by recommending a priority use of groundwater, considered as generally being of good quality, for human

---

* A rough estimate of the percentage of groundwater versus total drinking water in 1976 has yielded : 98 % in Denmark, 93 % in Italy, 71 % in the German Federal Republic and Belgium, 70 % in Luxemburg, 64 % in the Netherlands, 50 % in France, 31 % in the United Kingdom, 15 % in Ireland. These figures are actualized in this report.

consumption, by protecting aquifer and pumping stations against pollution, by defining the characteristics of surface water for natural or artificial aquifer recharge and by improving the presentation and consistency of national balances of available resources and potential needs (Environmental Programme 1977-1981).

The European Parliament did also show great interest about European groundwater and asked that a map of groundwater resources be made by the Services of the Commission (January 1977).

The present study has been undertaken to obtain a quantitative assessment of the groundwater resources of the Community using a regionalization 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 in 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 quantities of groundwater and to areas where such additional abstraction might be undertaken.

The results of this study should be of help to decisions-makers for a better exploitation and exploration of groundwater resources. They should also point out priority domains of study and development in water management projects, subject to direct help from the Commission of European Communities or the European Bank of Investment. Furthermore, they 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.

0.2. FEASIBILITY OF THE STUDY

The time limits of the Environmental Programme implied the realization of the study within a year, which, in addition to the strict financial constraints, involved the use of existing data only, excluding any additional field work.

The analysis of the project did show some other difficulties :

. scientific difficulties, as the groundwater resource depends on dynamic as well as management parameters, which in many cases can only be estimated from various semi-empirical formulae the application of which is greatly dependent upon the know-how and intuition of the hydrogeologist.

. difficulties related to the scale of the study and particularly of its cartographic representation : due to the different sizes of the Member States, the realization of a given common objective could imply a working scale not practical for some States ; besides, a balance had to be found between a large scale, involving the processing of too many data resulting in maps difficult to read due to an excess of information or requiring too many maps at a high cost, and a small scale, involving a loss of information and of interest.

. difficulties related to the heterogeneous distribution of information, some heavily exploited areas presenting many data while other areas are virtually unknown hydrogeologically.

. difficulties related to the relative importance each Member State attributes to groundwater as a function of its use (preoccupations in Denmark, where it constitutes 98 % of the drinking water, differ from those in Ireland where it constitutes only 15 to 20 % of drinking water) and, also, to the various management criteria and conflicts within a given Member State.

. difficulties related to the types of administrative management of the hydrogeological data in each Member State, frequently scattered between several administrations sharing competence and responsibilities.

Preliminary investigations among the Member States showed that the existing data were sufficient to fulfill the objectives of the project with a useful accuracy within the span of time considered by the Commission. They pointed out the interest of the Member States to the realization of the project : at the economical level of the management of their own groundwater resources, the project gives the Member States the opportunity to analyze the existing national studies, to assess the state of knowledge of their resources, to focus attention of various authorities on groundwater ; at the scientific level of the hydrogeological knowledge, it provides a basis for comparison and harmonization of concepts and methods. This interest was such that, in most cases, the Member States have contributed to the project, either directly by financing part of it or undirectly by providing technical support.

In order to overcome the various difficulties of the project, a methodology was imagined, allowing efficient multinational work in hydrogeology in the context of the European Community.

0.3. <u>METHODOLOGY OF THE STUDY</u>

The study was realized by nine consultants or groups of consultants, one per Member State, one consultant for cartographic problems and a coordinator, leader of the study. All are listed in § 6 below. The methodology is based on active cooperation of all consultants on fundamental problems both scientific and technical allowing the adoption of common concepts well adapted to the specific knowledge of groundwater in each Member State.

To harmonize the scientific approaches, sometimes rather different from one Member State to another, and the presentation of the results in a common frame, a panel was formed comprising the coordinator and staff members sent by each consultant. In a series of meetings convened in Brussels, the panel debated fundamental questions, such as scale problems, the definition of groundwater resource, the validity and significance of the evaluations of potential additional resources ; it also discussed technical questions like the choice of the cartographic support, the choice of ranges for abstraction rates, the definition of large abstractions. Adopted unanimously, the decisions of the panel were then compulsory and had to be applied by the consultants. Particular problems to each consultant were examined during bilateral meetings between the coordinator and the consultant and if they appeared to be of general interest, they were brought to the attention of the other consultants either directly or during a meeting of the panel. Transfrontier problems were given special attention by the concerned consultants, especially for the harmonization of the hydrogeological data along the borders of Member States.

It must be emphasized that this method of work has been given full support by all consultants and as such represents a very interesting and successful sociological experience of work in common by an international team leading to a homogenization of European hydrogeological concepts and approaches and allowing a better understanding of each other problems.

0.4. PRESENTATION OF THE STUDY

The evaluation of groundwater resources is organized in four themes :

. the inventory of the aquifers : the aquifers are located geographically, their geometrical, geological and lithological features are described as well as their types (phreatic or confined) and flow characteristics (intersticial, fissured, karst).

. the hydrogeology of the aquifers : the given hydrogeological information includes transmissivities and piezometry where available and significant, groundwater flow, relationship with surface waters and between aquifers ; it also introduces specific hydrogeological problems like the occurrence of salt water intrusion.

. the abstraction of groundwater : the geographical distribution of abstraction densities computed over a significant grid system is presented, as well as the location of large abstraction sites.

. the potential additional groundwater resources : considering the recharge and the exploitation, taking into account possible management constraints , the geographical distribution of potential additional groundwater resources is presented, showing the zones of possible surplus, the zones of actual equilibrium between the resources and the abstraction, the zones presently overdeveloped and of course the zones without significant groundwater.

The first two themes present a purely hydrogeological regionalization of groundwater, aquifer per aquifer, whereas the last two themes are based on an administrative regionalization, which is introduced by means of a grid system made up of administrative decision units corresponding to the features of the water supply industry in each Member State and also related to the hydrogeological situation in each region.

The results of this study are provided in ten reports, one report per Member State and the present synthetical report, and four sets of maps, each set corresponding to one of the above defined themes.

The national reports are organized per regions (i.e. per large water administrative units, like a river authority or a province), one chapter per region gathering the four parts of the information ; a general chapter is added, giving the main features related to groundwater. Each report contains the description of the aquifers, an evaluation of the groundwater abstractions, a description of its uses, an estimate of the groundwater resources present and potential, an outline of particular problems, a presentation of the data collecting systems and of the computation and approximations procedures used to process the data and to obtain the maps, and of course a complete list of references.

The synthetical report is organized per theme, stressing the features of groundwater evaluation which are significant at the Community level.

It is based upon the data given by the consultants in the national reports and during the various meetings with the coordinator.

The maps represent the bulk of the study, synthesizing the information of all Member States and providing the working basis for an easy comparative study of their groundwater resources. They are meant to be easily understood by non specialists of hydrogeology, especially planners, and their legends were conceived to be simple enough, to clearly emphasize the main aspects in each theme, while gathering all necessary information to fulfill the objectives of the groundwater evaluation.

Maps 1 and 2 are as complete as possible thanks to a graphical representation of up to three superimposed aquifers ; where three dimensional problems could not be solved in that way, the maps have been completed by cross-sections ; some cross-sections may also appear in the reports.

Themes 1, 2, 3 are based upon facts whereas theme 4 is based upon estimates given with assumptions which vary from country to country and sometimes even within a given country. Thus maps 4 must be read together with the national reports ; in chapter 5, we describe and compare the various approaches to the available resource as a key to a better understanding and correct use of these maps 4.

0.5. TECHNICAL FEATURES OF THE STUDY

0.5.1. Scale

Considering that too large a scale involves a loss of regularization of the results , involving an impossibility of comparing them and unaccurately stressing the importance of areas already well developed with respect to other areas, but also considering that too small a scale would handicap the smaller Member States and result in a loss of information, it was decided that the best suitable scale for this study was 1/500 000.

A time scale was also introduced to obtain results valid on a long term basis and yearly averages were made for the most significant years obtained by an analysis of the abstraction trends.

0.5.2. Grid system

A grid system has been introduced which is the basis of the representation of the distribution of abstraction densities and available resources. Introducing groundwater hydrology parameters, like the transmissivities, it could also provide a basis for future management modelling at the Community scale.

It is specific to each Member State and limited by the political boundaries of the Member State. It is made up of varying meshes, usually administrative elementary units, chosen by the consultant to best fit the local situation with the only requirement that the meshes assemble to form water administrative decision units and/or hydrogeological units.

The grids chosen for the nine Member States are defined as follows :

. Belgium : the units are subdivisions of the provinces called economical sectors, defined by the "administration de l'urbanisme, Ministère des Travaux Publics" in 1974. They are economical units for which there exist projects of land use with maps and description. They fit the geology rather well. Their number is 48, with an average area of 630 km^2.

. Denmark : the units are administrative, counties subdivided into communes. The county delivers the licenses for abstraction ; in case of low quantities, it is the task of the commune. There are 14 counties and 242 communes, with areas varying from 9 km^2 to 584 km^2 with an average order of magnitude of 100 - 200 km^2.

. Federal Republic of Germany : the units are administrative, the States (Bundesländer) subdivided into Landkreise (with the major cities or Kreisfreiestädte included in the nearest Landkreis). There are about 260 Landkreise with average areas of 900 km^2.

BILAN DE SYNTHESE DES RESSOURCES EN EAU SOUTERRAINE
BALANCE OF THE GROUNDWATER RESOURCES

PLAN D'ASSEMBLAGE
INDEX TO MAPS

*	éditée par published by	Institut Géographique National 136 bis rue de Grenelle 75007 PARIS FRANCE
•	éditée par published by	Institut Géographique Militaire de Belgique 13 Abbaye de la Cambre BRUXELLES 5 BELGIQUE
	éditée par published by	Directorate of Military Survey Elmwood Avenue Feltham Middelsex UNITED KINGDOM

BILAN DE SYNTHESE DES RESSOURCES EN EAU SOUTERRAINE

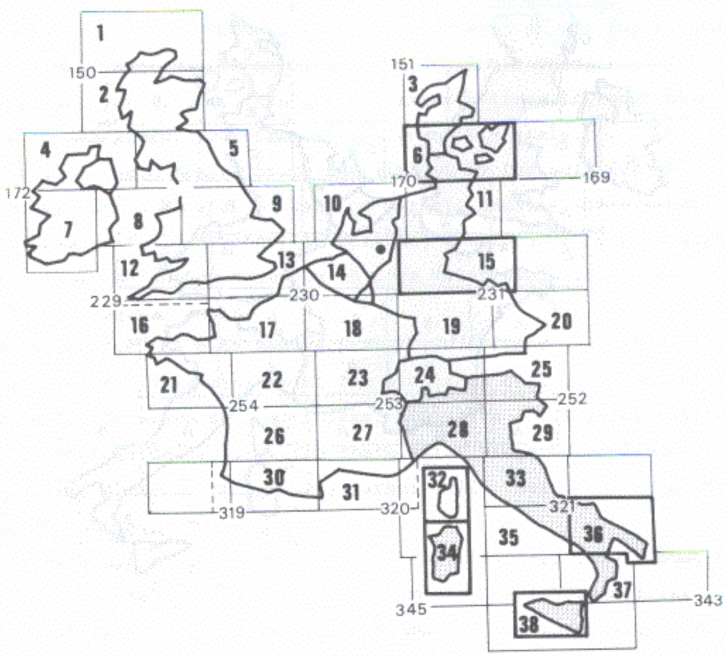
BALANCE OF THE GROUNDWATER RESOURCES

CARTOGRAPHIE DES EAUX SOUTERRAINES DE L'ITALIE

MAPS OF THE GROUNDWATER RESOURCES OF ITALY

PLAN D'ASSEMBLAGE

INDEX TO MAPS



feuilles type World 1404
World type sheets 1404

feuilles spéciales CCE
special sheets CEC

23 numéro d'identification des feuilles
identification number of the sheets

. France : the units are administrative, the "arrondissements" subdivided by watershed limits and sometimes geological limits. Larger units are the Watershed Agencies (Agences Financière de Bassin). There are about 1 500 meshes with average areas of 300 to 600 km^2 ; meshes corresponding to alluvial aquifers are smaller, of the order of 100 km^2.

. Italy : the units are both administrative and hydrogeological. They are regions (20) subdivided into provinces. Within each administrative unit, hydrogeological units have been defined based on various criteria such as purely hydrogeological criteria or surface water divides or the distinction between mountainous areas and plains. The areas of the units vary from 200 to 2 000 km^2.

. Ireland : the units are the Water Resource Regions (7), comprising groups of major river catchments, together with neighbouring smaller catchments and coastal areas. They were defined in 1970 by An Foras Forbatha (National Institute for Physical Planning and Construction Research) and they are "of such a size that all the water requirements of each region can be supplied from the available resources within each region". They are the basis for future water resource management in Ireland.

These regions are subdivided into units with areas of 100 km^2 to 1 000 km^2 the boundaries of which generally coincide with surface water divides. (109 units).

. Luxemburg : the units are administrative, the "canton" with areas varying from 60 km^2 to 300 km^2.

. Netherlands : the units are administrative, composed of the 12 provinces subdivided into districts chosen according to hydrogeological, quality or geological considerations. A district can be almost a whole province in some cases or much smaller. Their areas vary a lot with an average of 500 km^2 to 750 km^2. The provinces are going to play an important role in the new water supply organization.

. United Kingdom : the units are the 10 Water Authorities of England and Wales, Scotland and Northern Ireland, i.e. 12 regions altogether. Each of these regions is further divided into units defined on hydrogeological criteria as well as resource estimation or aquifer management criteria, with areas varying from 80 to 13 000 km^2 with an average order of magnitude of 500 - 1 000 km^2.

0.5.3. Cartographic features

The cartographic support is the map World 1404, at the scale 1/500 000, which allows a homogeneous presentation on sheets perfectly connecting and without distorsions. The numbering of the World 1404 sheets is given on figure 0.1.A reassembling of some of the sheets has also been made to prevent a waste of space and too much discontinuity in the presentation ; figure 0.2 gives the adopted distribution of sheets and their numbering in the project. Their heights are all of 64 cm while their widths vary due to required recombinations and irregularities in the longitude cutting of World 1404, in any case not exceeding 95 cm.

The UTM kilometer grid exists on all sheets and may be of use for ecological cartography, but for the sake of simplicity it has only been started in the margins. For the same reason, only the base plates containing the contour lines and the hydrography have been retained from the original map.

An interesting feature has been introduced to link the movements of groundwater to the various aspects of its evaluation : the map illustrating the hydrogeology (theme 2) is transparent and can thus be superimposed on all other maps.

Although inspired by the UNESCO hydrogeological legend the legend used here has been made to fit the specific European conditions. Its features are presented in the chapters related to each theme. But it must already be stressed that rather extensive discussions among the consultants were devoted to the choice of the parameters to be represented on the maps and to the definition of their cartographic representations with colours and symbols. It was felt that the good level of details of the study corresponding to the chosen scale and to the aims of that study would be best reached through a thorough evaluation of the mapped parameters and their cartographic expressions.

0.6. CONSULTANTS AND STAFF

STUDY LEADER AND COORDINATOR : J.J. FRIED, Professor at the University Louis Pasteur of Strasbourg, 2 rue Boussingault, 67083 STRASBOURG Cedex

BELGIUM : Service Géologique de Belgique
13, rue Jenner - 1040 Bruxelles
Director : A. DELMER
Project leader : F. DERYCKE
Assistants : P. LAGA
H. NEYBERGH

DENMARK : Danmarks Geologiske Undersøgelse
31 Thoravej, 2400 København NV
Project leader : L. J. ANDERSEN
Assistants : N. KELSTRUP, A. BAEKGAARD, C. SONDERSKOV, A. BRUZELIUS, T. TOKSVAD, K. OLSEN

FEDERAL REPUBLIC OF GERMANY : Büro PICKEL

3501 Fuldatal, Postfach 120

Director : H.J. PICKEL

Assistant : D. KLUSSMANN

Advisers : J. LÜTTIG

P.E. GROBA

FRANCE : Société ARLAB

BP 15, 06560 Valbonne

Director : Y. EMSELLEM

Project leader : P. SUZANNE

Assistants : CHAPIGNAC

Advisers : J.P. ARCHAMBAULT (Société BURGEAP)

G. CASTANY (Bureau de Recherches Géologiques et Minières)

J. MARGAT (Bureau de Recherches Géologiques et Minières)

IRELAND : Geological Survey

14 Hume St, Dublin 2

Director : C.E. WILLIAMS

Project leaders : L.R. ALDWELL

C.R. WRIGHT

Assistants : D. DALY

E. DALY

A. WALSH

ITALY : Compagnia Mediterranea di Prospezioni

Via Angelo Bargoni 8 - 2 Roma

Project leader : J. MOUTON

Assistant : M. MANGANO

LUXEMBURG : Service Géologique

4 bd Roosevelt - Luxemburg

Director : J. BINTZ

Project leader : J. BINTZ

Assistant : M. FRANTZ

NETHERLANDS :

Project leader : C. VAN DEN BERG, retired director of the Institut for Land and Water Management Research, Wageningen.

Assistants : Miss S. JELGERSMA, geologist of the Governemental Geological Service, Haarlem

C.R. MEINARDI, hydrologist of the Governemental Institut for Public Water Supply, Rijswik

J.A.M. VAN DER GUN, hydrologist of the Service for Groundwater Survey (Organization for Applied Natural Science), Delft

Drawings : M.A. DAMOISEAUX

UNITED KINGDOM : Central Water Planning Unit

Reading Bridge House, Reading RG1 8PS

Director : O. GIBB

Project leaders : R. MONKHOUSE

H. RICHARDS

Cartography : V.H. WILLIAMS

CARTOGRAPHY : Centre de Géographie Appliquée - Université Louis Pasteur Strasbourg

Director : J. TRICART

Project leader : Mrs C. BELLER

Chapter 1

GENERAL INFORMATION ABOUT GROUNDWATER IN THE COMMUNITY

1.1. GENERAL FEATURES RELATED TO GROUNDWATER RESOURCES

Groundwater resources depend on many physical factors such as the geology, the topography, the climate, the pluviometry, the hydrography, the hydrology, the land use, the vegetation, the evapotranspiration. Although a general description of these factors at the Community level is possible, we think that such a description, certainly interesting from a geographical point of view, would not help to understand the various aspects of groundwater resources which are all very much regionalized. But at the level of each Member State, this information is useful because its regional features can be well presented without being either too general or too detailed and their influence on the resource is then correctly perceived. Each national report thus contains a chapter describing these factors.

1.2. THE WATER INDUSTRY

To know the legal and practical aspects of water, especially groundwater, management in the Community helps to better perceive the difficulties that had to be met during the present study and which relate to the sources of the data, to the means of obtaining them, to their accuracies, to their numbers and densities in time and space. Each Member State has its own water structure from Denmark where every abstraction is licensed and usually recorded to France where everybody has the right to operate wells and where returns are made above thresholds varying from Agence de Bassin to Agence de Bassin. We shortly review the main features of the water industry in the various Member States.

1.2.1. Features of the water industry in the Member States

. Belgium : groundwater is abstracted and supplied by many supply companies, intercommunal societies and single communes. The Ministère de la Santé Publique sometimes helps financially these various societies to establish new abstractions and distribution nets. This Ministère is competent for all questions relating to the distribution of drinking water, the financial helps, the control of water quality, the protection of water abstracted for public supply ; these problems are also examined by the Conseil Supérieur des Distributions d'Eaux composed of representatives of the Ministère de la Santé Publique, of the public supply companies, of the provincial technical services, of the Ministères des Travaux Publics, de l'Agriculture et des Affaires Economiques. The Geological Survey is responsible for hydrogeological studies and the implementation of groundwater abstraction regulations.

Since 1947, every public or private groundwater abstraction above domestic needs as well as long lasting drawdowns must be authorized by the Ministère des Affaires Economiques, in an attempt to protect the resources ; abstractions are divided up into two classes, the abstractions of class 1 being smaller than 96 m^3/d and those of class 2 larger than 96 m^3/d . Class 1 abstractions must only be declared whereas class 2 abstractions must be authorized.

. Denmark : groundwater is abstracted and supplied by single wells or dug wells (for a great number of farms and small households), small private waterworks acting as cooperative societies in villages, rural districts and urban areas, municipal waterworks supplying major cities and even rural districts.

The Water Supply Act (1973) is the legal frame for groundwater utilization : everybody can withdraw groundwater on his land for domestic purposes ; for all other purposes, above 3000 m^3/a the abstractions have to be licensed either by the county or, in case of low quantities, by the commune.

. Federal Republic of Germany : the water industry is organized by Bundesland. In each Land, a Ministry is the highest water authority (Minister für Ernährung, Landwirtschaft und Forsten in Niedersachsen or Minister für Umwelt, Raumordnung und Bauwesen in Saarland, for instance), responsible for water supply companies, the water protection, the constructions in the water industry (Oberste Wasser Behörde). Each Bundesland is divided into Regierungsbezirke and each Regierungsbezirk into Wasserwirtschaftämter (local authorities). Authorizations of water abstraction are given by the Obere Wasser Behörde at the level of the Regierungsbezirk while the Wasserwirtschaftämter controls water abstraction and local water management. To allow common work at federal level, the LAWA (Länderarbeitsgemeinschaft Wasser) has been established among the Bundesländer.

Public water is supplied by about 1500 water companies mostly private and working on a local basis. The industry receives its water partly from these water companies partly from its own waterworks.

. France : groundwater abstraction is free within some limits of use, depth of wells, rate of abstraction, land protection ; outside these limits, it has to be declared and may be submitted to authorization :

all abstractions for public collectivities are submitted to authorization ; this is also the case in some regions for all abstractions over some depth, while in the other areas non domestic groundwater abstracted at more than 8 m^3/h must be declared ; of course the protected zones (for instance the protection zones of wells) are ruled separately.

Water for public supply (drinking water) is provided by communes, intercommunal waterworks and private companies (the latter supply about 50 % of the population). Water for the industry and agriculture is provided by private people and in some part by agricultural or industrial syndicates.

The control of groundwater quantity and quality is placed under the responsibility of six Agences Financières de Bassin which cover one or several river basins. The Agences contribute to the making of research studies and works of common interest to the watersheds they control ; they manage data banks of all abstractions over some threshold which vary with the Agence (from 7200 m^3/a for Adour Garonne to 100000 m^3/a for Rhin Meuse) and for which the users are taxed.

. Italy : each region is autonomous for water problems, under the competence of the Ufficio del Genio Civile. Two phases are defined : search for water and exploitation. In the search phase three zones are defined ; zones without supervision of the Public Authority (the majority) where all search is free, zones with supervision where a license for investigation must be obtained from the Public Authority with a few exceptions and zones where the State only can investigate. In the exploitation phase, all exploited water must be declared to the Public Authority.

Practically, drinking waters are managed by communal supply services (azienda communale per la distribuzione delle acque) and by very few private waterworks and, in Southern Italy, temporarily by the Casa per il Mezzogiorno. Waters for agriculture are supplied by a great many private wells and some agricultural syndicates, financed by the State (Consorzi di Bonifica). Industrial plants have their own wells ; there are a few industrial syndicates (consorzio industriale).

. Ireland : the local authorities (County Councils, County Borough Councils, Urban District Councils) are responsible for public water supply, sewerage and pollution control in their own areas but not for water resource management.

Many industries have their own water supply while part of the water for agriculture and small industry comes from the public supply. There are no water companies and no licensing system. Water for domestic purposes is not measured.

Seven Water Resource regions, comprising groups of major river catchments, together with smaller catchment and coastal areas, have been established in 1970 ; until now they have only been used for some surface water studies but should form the basis for future water resources management.

. Luxemburg : groundwater is supplied by water syndicates, semi-autonomous companies and private wells. There is a law on groundwater protection, which applies only to the Grès du Luxembourg (Luxemburg Sandstones), which states that an authorization must be asked for each abstraction. For all the other aquifers, there is no licensing system and pumping is free.

. Netherlands : until now, all groundwater abstractions for public supply must be licensed, the license being granted by the Minister of Public Health and Environmental Protection upon approval by a national Committee composed of representatives of various ministries, while industrial abstractions are under the responsibility of provincial authorities. A new groundwater law should be implemented soon giving the main role to the Provinces, which will prepare a plan for groundwater management and will be responsible for all abstraction licenses. Returns will be made annually. Groundwater quality is protected by provincial regulations but a new law should take care of this problem rather soon.

Groundwater for public supply is provided to 99.5 % of the households and to industrial plants by a hundred waterworks composed of municipal companies and intercommunal limited liability companies and a few private companies. Groundwater abstractions for the industry and agriculture are mainly private.

. United Kingdom : in England and Wales, ten water authorities manage all aspects of water services such as development and conservation of water resources, water distribution and supply, the prevention of pollution, sewerage and sewage treatment, river management, land drainage, sea defences, recreation and fresh water fisheries. Their boundaries are natural hydrometric limits. 28 statutory water companies supply water as agents of the water authorities while, often, local authority district councils act as agents of the water authority for the design, construction, operation and maintenance of public sewers in their areas. The National Water Coucil advises the Ministers on national water policy and provides a forum for discussions and exchanges on all aspects of the water industry.

In Scotland nine regional and three island councils are responsible for public water supply, sewerage and sewage disposal while the Central Scotland Water Development Board has to develop new major sources of bulk supply for the water boards in the populous central belt of the country. Seven river purification boards are responsible for the regulation of discharge of effluents to rivers. The Secretary of State for Scotland has overall responsibility for the conservation of water resources, the provision by water authorities of adequate water supplies and the cleanliness of rivers.

In Northern Ireland, the Government of Northern Ireland is the sole authority for water and sewerage services, through the Water Service (Department of the Environment of Northern Ireland) with four regional divisions having water supply and sewerage functions, and local water service offices in most of the provincial towns. The Northern Ireland Water Council advises the Department of the Environment of Northern Ireland.

In England and Wales, all significant groundwater abstractions are controlled by a statutory licensing and charging scheme operated by the Water Authorities, while no such system exists in Scotland and Northern Ireland.

1.2.2. The water industry in the Community

From the short presentation of the main features of water industry in the Member States, it appears that two main systems prevail in the Community :

. a system of Water Authorities based on a hydrological division of the country,each Authority having the administrative and economic responsibilities of water management. This is the case of France and part of the United Kingdom, while the Republic of Ireland is acquiring such a system.

. a system providing the regional authorities with full responsibility on the various aspects of water. This is the case of Denmark, the German Federal Republic, Italy, Ireland.

The new waterlaw will provide the Netherlands with such a regional administrative system based on the Province.

The only exceptions are Belgium, where responsibilities for water rest with various ministers and national agencies, and Luxemburg, too small for a regionalization. Yet in Belgium, there is an attempt fo some regionalization through economical sectors corresponding to management projects.

1.3. USES OF GROUNDWATER

To distinguish between drinking, industrial and agricultural purposes is classical but not always possible. In Belgium, waters for the industry and the agriculture are estimated together ; public supply provides water for agricultural purposes in Ireland, for industrial purposes in the Federal Republic of Germany while there seems to be a tendency in the United Kingdom to also increase the part of public supply in industrial water. Many small farms and small industries can use public supply besides having their own wells, not always recorded. Yet the classical categories of uses are convenient for a global compared approach of the groundwater allotment policy of each Member State.

As a first approach to perceive the groundwater use policies of the Member States, we have gathered data on the groundwater used for drinking , industry, agriculture and some other uses, globally per Member State, in table 1.1. In the column marked "drinking water", we put public supply water. The column marked "other uses" mainly concerns the specific uses detailled in § 4.3.2., as fish farming in Denmark or mine drainage in France or Italy for instance, when they

MEMBER STATE	DRINKING WATER	%	INDUSTRY	%	AGRICULTURE	%	OTHER USES	%	TOTAL
Belgium B	425	68	196.5			32			621.5
Denmark DK	461	40	252	22	399	35	38	3	1150
Federal Republic D	3559+	48	3569	49	144++	2	67	1	7339
France F	3125	55	1864	32	462	8	280	5	5731
Italy I	6409	53	> 1586	13	4058	33	109	1	>12162
Ireland IRL	62	65	34	35	incl. in column 1	-			96
Luxemburg L	13	50	13	50					26
Netherlands NL	881	65	398	29	74	6			1353 *
United Kingdom UK	1739	76	497	22		44		2	2280 **

Table 1.1

Groundwater uses per Member State. Volumes in 10^6 m^3/a and percentage of total groundwater for each use.

* excl. brackish water in industry
** returns do not include all aquifers
+ including 817 used by the industry
++ about 2 % of total groundwater

have a national impact. For the Netherlands, the estimates of groundwater quantities exclude the brackish water used for industry but take into account the infiltration of surface water through the dunes.

In table 1.2., we show the quantity of groundwater used per day per inhabitant in each Member State,the quantity of drinking water per day per inhabitant.

The tables display the part played by groundwater for public supply and provide information on how each Member State presently uses such a rather good quality water.

Of course groundwater is of regionalized importance and for that reason, we provide tables of uses, detailed per regions for each Member State where such information is available, in § 4.3.1.

Member State	B	DK	D	F	I	IRL	L	NL	UK
Groundwater in l/d/h	170	630	328	297	603	77	200	261	112
Drinking water	116	252	159	163	320	50	100	170	85

Table 1.2

Total groundwater used per day per inhabitant
(in liters/day/inhabitant)

Part of groundwater used for drinking per day per inhabitant
(in l/d/inh.)

1.4. TRENDS IN GROUNDWATER USE AND ABSTRACTION

The developments of groundwater abstractions are influenced by the general economic developments of the Member States involving a greater demand of water in general, and by the variations of the groundwater allotment policies of the Member States with time.

From the analysis of the various trends,it is impossible to define a Community trend for groundwater abstraction and use for the time being and we just present a quick review of the national tendencies.

. Belgium : from 1974 to 1978, the abstraction of groundwater is relatively constant. It is expected to decrease a little (less than 10 %) in the next few years. It should be noticed that the percentage of groundwater to total water is constant too.

. Denmark : although groundwater already represents 95 % of the total water used in this country, there still is a slight increase in the percentage of groundwater used versus total water. It comes from an increased use of groundwater for irrigation. The volume of consumed groundwater per year has risen of 70 % from 1970 to 1977, going up from 684 10^6 m^3 to 1150.10^6 m^3 ; this last figure is already bigger than the forecast for the year 2000 made in 1970.

. Federal Republic of Germany : the quantity of abstracted groundwater is relatively constant, as well as the percentage of groundwater versus total water.

. France : data are missing or too unaccurate for a global analysis of trends. From a survey of three Agences de Bassin (Rhin Meuse, Artois Picardie, Seine Normandie, which cover 2/3 of France) concerning declared industrial and drinking water abstractions, it has been noticed a decrease of industrial abstraction (due to better management, by used water recycling for instance, and increased use of surface water) and an increase of drinking water abstraction (due to the population increase and the decrease in surface water quality). According to a general prognosis of the Agences de Bassin, industrial abstractions should stay at the same level and even slightly decrease while drinking and agricultural water abstractions should largely increase.

. Italy : a general trend analysis is impossible because data, especially time sequences, are missing. From data concerning a few main urban areas (Roma, Milano, Torino and some others in the South) it seems that public supply water abstraction is increasing but that the rate of increase is decreasing substantially. The increase ranges between 1.5 % to 5 % per annum. Very roughly too, it seems that generally speaking agricultural groundwater abstraction is stationary, with local variations. The evolution of industrial groundwater abstraction is unknown.

. Ireland : until recently, the lack of experience in groundwater exploitation has prevented a larger use of this resource. But as surface water is becoming more polluted and engineers are acquiring better knowledge of technical possibilities, especially in well drilling, while there is a tendency to use more water related to the urban and industrial development of rural areas, a gradual increase in the abstracted groundwater quantities may be reasonably expected.

. Luxemburg : from 1973, a slight decrease in the abstracted groundwater has been noticed, related to a decrease in domestic use. But it seems that in the future, groundwater will be more developed.

. Netherlands : although an increase of groundwater abstraction has been observed since 1971 and is expected for 1981, the rate of increase is expected to decrease. This is mainly due to a decrease in industrial use because of increasing costs for the evacuation of the used water. There are increases in public water supply and agricultural uses, although figures for the latter vary from year to year with weather conditions.

. United Kingdom : a trend analysis performed on two periods, from 1948 to 1963 and from 1973 to 1977, shows that groundwater abstraction has risen consistently, due to groundwater development for public water supply. Groundwater abstraction by industry has remained relatively constant since 1954, but, on the other side, the part of public water supply utilized for industrial purposes seems to be increasing. The percentage of groundwater versus total water used for public supply purposes has remained relatively constant over the last 16 years. This analysis leads to assume a future increase of groundwater abstraction but most probably at a much slower rate now that groundwater is considered as a resource with limits of availabilities.

Chapter 2

INVENTORY OF AQUIFER FORMATIONS

2.1. GENERAL FEATURES AND MAPPING

The aquifers of the Community, represented on maps 1, are basically classified by their flows into four categories :

i) intergranular flow : the flow occurs through intergranular interstices ; the aquifers usually present a low rate of flow and a high storage capacity : for example sands and gravels.

ii) fissure flow : the flow occurs through fissures ; the aquifers usually present a high rate of flow and a low storage capacity : for example, limestones.

iii) mixed aquifers, having both fissures and a high storage capacity in the interstices : for example cemented sandstones.

The discussions did show that, although the concept of mixed aquifer is rather clear, its application to characterize a given aquifer depends on the scale at which it is studied and on the habits of the local hydrogeologists. Thus it was decided to list the mixed aquifers of the Community, especially to prevent discontinuities at the borders of the Member States. This list is based upon the geological and lithological features selected for the present study (and detailed below) :

. Belgium : cretaceous chalk ; permian conglomerates ; jurassic sandy limestones, sandstones and sands.

. Denmark : paleocene limestone.

. Federal Republic of Germany :

at the border with Belgium : alternate cretaceous layers of sandstone and sand, with clay marls and limestone lenses.

at the border with Luxemburg : fissured sandstones and sandstones with conglomerates.

at the border with France : fissured sandstones with some conglomerates.

. 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.

. Luxemburg : sandstones with calcareous cements.

. United Kingdom : cemented sandstones ; fissured sandstones in shales.

iv) karst flow : media with a karstic flow were 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.

Each basic category has been given a colour (blue for intergranular flow, green for fissure flow, orange for mixed aquifers), except for the karst represented by a special symbol (small bricks) in the green colour of the fissures.

The alluvial aquifers have been considered as a special category although they present an intergranular flow. Indeed, they are a very important resource but their dimensions are usually small : for example, in Liguria (Northern Italy), they provide most of the resource but only occupy a few cm^2 on the map. Also, their very complex relationships with the rivers and the fact that they are a large natural filter for surface waters set them in a very peculiar position with respect to other aquifers. Thus, they have received a special representation on maps 1.

Some other hydrogeological features have also been considered :

. whether an aquifer is confined or unconfined, which gives some indication on its vulnerability and on the difficulty of its exploitation. Shades in the colours of the flow categories represent the types : a dark shade for unconfined, a light shade for confined. In particular, discussions did show that in a very few cases, karst flow could be confined : it is the case, for instance, of Southern Belgium.

. whether an aquifer is monolayered or multilayered. It has also enabled to represent situations where two distinct aquifers are locally adjacent and exchange water, as for example in Belgium. Also when several superimposed aquifers exist, exchange water and cannot be easily differentiated at the scale of the study, it can be assumed that the whole system is a multilayered aquifer : for instance it considerably simplified the Dutch situation, the Netherlands being underlain by one large multilayered aquifer.

. groundwater seepage areas, natural or artificial, which may be a significant factor of vulnerability.

In many cases, especially due to the scale of the study, small aquifers of very local importance cannot be individualized. The whole area where they occur is represented, in the colours of the various flow categories. Of course, zones without aquifers are left in white.

From a purely cartographic point of view, an experiment has been attempted with successful results : up to three superimposed aquifers are represented on the map thanks to a system of stripes of decreasing widths which enables to follow an aquifer as it dips under one or two other aquifers. Figure 2.1 is an example of a phreatic aquifer with intergranular flow becoming confined as it dips under an unconfined aquifer with fissure flow which in its turn becomes confined as both aquifers dip under a mixed aquifer.

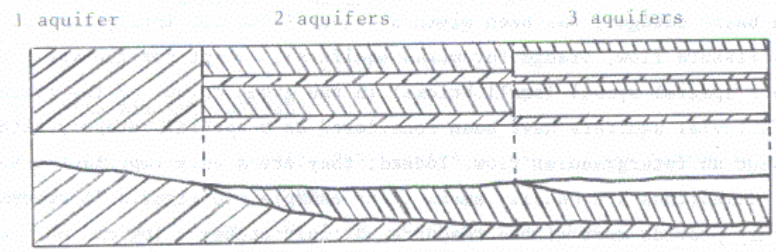


Figure 2.1.

On the maps, the aquifers are bounded in two ways : real limits based upon hydrogeological considerations and artificial limits, when it proves necessary to stop the drawing of the aquifer ; such an artificial boundary usually is a limit of exploitation of the aquifer with depth and salinity : it is not indicated by a line but by a stop of the coloured stripes representing the aquifer.

Where the bidimensional representation of a three dimensional situation is difficult to understand, the maps are completed by cross sections.

Community lithological features have been established after a survey by all consultants of the lithological characteristics of the Member States and they are listed in the following table with their symbols :

alluvia (sands, pebbles, gravels, loam)	A
sands	S
alternate strata sands and clay	Sc
alternate strata alluvia and clay	Ac
sands and gravels (which are not of alluvial origin (marine origin or moraines)	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 limestones	Ld
dolomites	D
calcareous sinters	T
intrusive rocks	I
extrusive rocks	V
acid extrusive rocks	Va
basic extrusive rocks	Vb
metamorphic rocks	M
evaporites (sodic, potassic salts, gypsum)	E
marly-sandstone flysch (alternate marly, sandstones, sandt strata)	Fm
alternate sandstones and shales	Ga
marl	m
pierres vertes	p.v.

The ages of the various formations are represented with the symbols of the International Geological Map of Europe.

The maps 1 are completed by hydrological, geographical and morphological features such as lakes, rivers, main cities, contour lines.

2.2. AQUIFERS OF THE COMMUNITY

On tables 2.1 to 2.8 we represent the main aquifers of each Member State, in a chronological order. We indicate their categories of flow permeability (I = intergranular, F = fissure, M = mixed, K = karst) and, if regionnally significant, their types (C : confined, U : unconfined) ; we give the depths of top and base of the aquifer, its thickness, its transmissivity when, of course, these values have some significant average meaning. For the continental Member States, we indicate whether the aquifer is common to two or more Member States (Transfrontier T.F.).

On these tables the aquifers are also classified according to their estimated importances with respect to yields, dimensions, exploitability, regional influence, into four families :

. aquifers of major importance (four stars) ;

. important aquifers (often providing public supplies) (three stars) ;

. aquifers of local importance (for instance a minor aquifer which is the only aquifer resource of an area) (two stars) ;

. aquifers of minor importance (one star).

All aquifers are discussed in details in each national report.

One table is missing, corresponding to the Netherlands, because the situation in this Member State is peculiar.Only two aquifers have been discerned at the scale of the study :

. a multilayered aquifer composed of unconsolidated sediments of pleistocene and pliocene age, covering 99 % of the country ; flow is intergranular and transmissivities vary from 10^{-3} m^2/s to 10^{-1} m^2/s with an average of 10^{-2} to 5 10^{-2} m^2/s. It is largely confined (in the coastal regions, for instance).

. an aquifer composed of upper cretaceous and paleocene chalks in the southern part of the province of Limbourg, with a mixed interstitial fissure permeability.

A general remark is that, with the exception of a few small regions (in Ireland, for instance), the aquifers of the Community are known geologically and geographically, which of course does not imply that their hydrogeological properties are always known.

Era	System	Subsystem	Aquifer	Permea-bility	Transmissivity m^2/s	Impor-tance	T.F
Cenozoïque	Quaternaire	Holocène	Dunes (sables côtiers)	I		***	
			Plaine maritime	I		*	
		Pleistocène	Vallée flamande	I	$3.5\ 10^{-3}$	***	
			Thalweg bassin de l'Escaut	I	$3\ 10^{-3}$	***	
			Thalweg bassin de la Meuse	I	-	***	
			Haute Terrasse et plaine de Basse Meuse	I	-	****	NL
			Sables de Merksplas	I	$6\ 10^{-3}$	*	
		Pliocène + Pléistocène	Sables de Mol et de Brasschaat	I	$8\ 10^{-3}$	*	
	Tertiaire	Pliocène	Formation de Lillo	I		*	
		Miocène	Sables diestiens, anversiens, boldériens	I		****	NL
		Oligocène	Sables rupeliens	I		**	
		Eocène	Sables ledo-paniseliens	I	5.10^{-4} et 10^{-3}	**	NL
			Sables ledo-bruxelliens	I	-		
			Sables bruxelliens	I	$2\ 10^{-3}$	***	
			Sables ypresiens	I	$3\ 10^{-4}$		
		Paléocène	Sables landeniens	I	$1.1\ 10^{-3}$	**	F
			Landeniens du bassin de la Gette	I	1 à 4 10^{-3}	**	
			Marnes heersiennes	F	10^{-3} et 5 10^{-3}	**	

Table 2.1

Main Aquifers of Belgium

(1)

Era	System	Subsystem	Aquifer	Permea-bility	Transmissivity m^2/s	Impor-tance	T.F
Mésozoïque	Crétacé	Crétacé	Crétacé des Flandres	F	-	**	F
			Crétacé du Brabant	F	$1.5\ 10^{-2}$	***	
			Crétacé de Hesbaye	F	$2\ 10^{-3}$ à $5\ 10^{-2}$	****	
			Crétacé du pays de Herve	F	-	***	D, NL
			Crétacé du bassin de Mons	F	$2.5\ 10^{-3}$ à $6\ 10^{-2}$	****	F
			Tuffeaux maastrichtiens de Geer	M	$4\ 10^{-3}$	****	NL
			Nappe captive du Maastrichtien	M	-	***	NL
	Jurassique	Jurassique	Calcaires bajociens	F	-	**	F, L
			Macignos virtoniens	M	-	***	F, L
			Calcaires sableux, gris et sable du Sinémurien	M	10^{-3}	***	F, L
	Trias	Keuper	Sables et poudingues	I	-	**	
Paléozoïque	Permien	Permien	Conglomérats de Stavelot	M	-	**	
	Carbonifère	Carbonifère	Calcaire carbonifère du Tournaisis	K		****	F
			Calcaire carbonifère du bassin de Namur	K	{ $4\ 10^{-3}$ à $7\ 10^{-2}$	***	
			Calcaire carbonifère du bassin de Dinant	K		***	
	Dévonien	Dévonien	Calcaires dévoniens Bassin de Namur	K		***	
			Calcaires dévoniens Bassin de Dinant	K		***	
			Massifs schisto-gréseux Ardenne	F		**	
	Cambrien Ordovicien Silurien	Cambrien Ordovicien Silurien	Socle des Flandres	F		**	F
			Socle de l'Ardenne	F		**	

Table 2.1

Main Aquifers of Belgium

(2)

Era	System	Subsystem	Aquifers	Permea-bility	Type	Top/Base m	Thickness m	Transmissivity m^2/s	Impor-tance	T.F
Cainozoic	Quaternary	Holocene	Various Sands of Marine and Aeolic origin	I	U and C	0/15			**	
		Pleistocene	Glaciofluvial sand and gravel.							D
			1) Out-wash plains.	I	U	0/50			****	
			2) Continuous sandlayers interbedded with tills.	I	C	0/220	> 20	$10^{-3}/10^{-2}$	****	
			3) Discontinuous layers interbedded with tills.	I	C	0/200			**	
	Tertiary	Miocene	Quartzsand-gravel and Mica-sand	I	U and C	0-200 to top	20 max	10^{-2}	****	
		Paleocene	Greensand Limestone	I + F	C	0-75 to top	150 max	$10^{-2}/10^{-1}$	****	
			Danian Limestone	F	U and C	0-100 to top	5 to 100	$10^{-4}/10^{-3}$	****	
Mesozoic	Cretaceous	Upper Cretaceous	White Chalk	F	U and C	0-150	5 to 80	$10^{-3}/10^{-2}$ locally 10^{-1}	****	
			Bauneodde Greensand	I	C	35-90			**	
			Arnager Limestone	F	C	0-25			**	
			Arnager Greensand	I	C				**	
		Lower Cretaceous	Sandstones	F	C	5-90			**	
			Robbedale-Sand	I	U and C	5-80	40 max		***	
	Jurassic		Sand and sandstone	I + F	C	0/75			**	
Paleo-zoic	Silurian-Middle Cambrian		Shales and limestones	F	C	0/150			*	
Pre-cambrian		Lower Cambrian	Sandstones and quartzites	F	C	0/125			***	
			Granites and gneisses	F	C	0/150			**	

Table 2.2

Main aquifers of Denmark

Era	System	Subsystem	Aquifer	Permeability	Thickness	Importance
Cenozoikum	Quartär	Holozän	Talfüllung	I	- 60 m	* - **
			Dünen	I	a few tens	* - **
		Pleistozän	Talsande	I	little	* - **
			Terrassen	I	a few tens	** - ****
			Rinnen	I	- 400 m	*** - ****
			Sande	I	a few tens	* - **
			Moränen	I	very varied	* - **
			Münsterländer Kiessandung	I	18 - 35 m	***
			Baverische Schotterebenen	I	10 - 90 m	*** - ****
	Tertiär	Pliozän	Kaolinsande	I	10 - 50 m	* - **
			Hauptkiesserie (Niederrhein)	I	100 m	**
		Miozän	Obere Süsswassermolasse	I	- 100 m	** - ***
			Marine Feinsande	I	little	*
			Braunkohlesande	I	- 100 m	** - ****
		Oligozän	Schleichsand	I	- 30 m	*
			Rupelsande	I	- 100 m	*
			Grafenberger Sande	I	60 - 100	*
			Kalke des Mainzer Beckens	F	- 50 m	*
Mesozoikum	Kreide	Oberkreide	Vulkanismus	F + (I)	a few 100 m	** - ****
			Halterner Sandfazies Recklinghäuser Sandmergelfazies	I I + (F)	- 300 m - 80 m	**** ** - ***
			Ostbayerische Kreide	I + F	- 100 m	**
			Kalke und Mergel des Münster-Beckens	F	- 260 m	** - ***

Table 2.3

Main aquifers of the Federal Republic of Germany

(1)

Era	System	Subsystem	Aquifer	Permeability	Thickness	Importance
Mesozoikum	Kreide	Unterkreide	Rothenberger Sandstein	F + (I)	- 100 m	* - **
			Gildehäuser Sandstein	F + (I)	- 100 m	* - **
			Bentheimer Sandstein	F + (I)	30 - 40 m	**
			Gaultsandstein	F + (I)	30 - 40 m	* - **
			Osning-Sandstein	F + (I)	30 - 40 m	**
			Kuhfeld-Schichten	I	100 m	**
			Wealden-Sandstein	F + (I)	- 300 m	* - **
	Jura	Malm	Kalke	F, K	200 - 600	** - ****
		Dogger	Hauptrogenstein	F, K	70 m	*
			Eisensandstein	F + (I)	40 - 100	**
		Lias	Arietiten-Schichten Angulaten-Schichten Psilonoten-Schichten		10 - 35	*
			Luxemburger Sandstein	I + (F)	70	*
	Trias	Keuper	Steinmergelkeuper	F	- 50	* - **
			Stubensandstein Burgsandstein Blasensandstein	F + I	- 100	**
			Schilfsandstein	F + (I)	10 - 40	**
			Estherien-Schichten	F + (I)	15 - 45	* - **
			Benker Sandstein	F + (I)	60	* - ** (?)
			Grenzdolomit	F	20 - 30	*

Table 2.3

Main aquifers of the Federal Republic of Germany

(2)

Era	System	Subsystem	Aquifer	Permeability	Thickness	Importance
Mesozoikum		Muschelkalk	Triconodusdolomit	F, K	- 100	* - ***
			Nodosuskalk			
			Trochitenkalk			
			Wellenkalk	F	50 - 70 m	* - **
		Buntsandstein	Plattensandstein	F + (I)	- 75	* - **
			Chirotheriensandstein	F + (I)	- 65	**
			Mittlerer Buntsandstein	F + (I)	- 500	*** - ****
			Unterer Buntsandstein	F + (I)	- 200	* - **
Palaozoikum	Perm	Zeichstein	Plattendolomit	F, K	40 - 150 m	* - **
			Hauptdolomit			
			Riffkalk			
		Rotliegendes	Kreuznacher Schichten	F + (I)	- 500 m	**
			Waderner Schichten			
			Sötener Schichten			
			Quarzporphyre + Melaphyre	F		*
			Unterrotliegendes	F + (I)	- 1.500 m	*
	Karbon	Unter-Karbon	Deckdiabas		300 m	*
			Kohlenkalk	F	100 m	*
			Platten + Kieselkalk			*

Table 2.3

Main aquifers of the Federal Republic of Germany

(3)

Era	System	Subsystem	Aquifer	Permeability	Thickness	Importance
Paläozoikum	Devon	Ober- und Mitteldevon	Roteisenstein + Diabase	F	– 300 m	*
			Massenkalk	F	– 500 m	** – ***
			Sandstein	F		* – **
			Dolomite	F		**
		Unterdevon	Quarzite		– 500 m	*
			Diabas			*
			Schiefer		– 2.000 m	(*)
	Altpaläozoikum und Kristallin		Quarzite	F	–	*
			Marmore	F	–	*

( ) = partly

Table 2.3

Main aquifers of the Federal Republic of Germany

(4)

ra	System	Subsystem	Aquifer	Permeability	Type	Thickness (m)	Transmissivity (m^2/s)	Importance
Cénozoïque	Quaternaire		Alluvions, Vallées	I	U - localement C	10 à 250	10^{-1} - 10^{-3}	****
			Sables, Landes de Gascogne	I	U	0 à 150	10^{-2} - 10^{-3}	***
	Tertiaire	Pliocène	Alluvions et sables, Astien, Alsace, littoral du Languedoc-Roussillon	I	U à l'affleurement - souvent C sous des niveaux alluviaux limoneux	50 à 200	10^{-3} - 10^{-4}	***
		Miocène Oligocène	Calcaires et sables, Helvétien - Aquitanien, Stampien, Centre du Bassin-Aquitain	F or M	En majorité C dans le centre du bassin	100 à 120	2.10^{-2} à 10^{-3}	***
			Calcaires et sables, Aquitanien, Stampien, Beauce et région de Fontainebleau	F or I	U sauf sous les formations burdigaliennes	75 à 150	10^{-1} à 2.10^{-2}	***
		Oligocène Inférieur Eocène Supérieur	Calcaires de Brie, Champigny et de St Ouen, Stampien, Bartonien, Brie, Biere	F	U	40 à 90	2.10^{-4} à 9.10^{-2}	***
		Eocène inférieur à supérieur	Calcaires, sables calcaires sableux, tout le centre du bassin Aquitain	M or I	C dans la majeure partie du bassin	70 à 125		****
		Eocène inférieur et moyen	Calcaires grossiers et sables du Soissonnais, yprésien et lutétien, Vexin, Valois, Soissonnais, Parisis, Laonnais	M	U à l'affleurement, en grande partie C dans le centre du bassin	70 à 120	5.10^{-3}	****

Table 2.4

Main aquifers of France

(1)

Era	System	Subsystem	Aquifer	Permea-bility	Type	Thickness (m)	Trans-missivity (m^2/s)	Impor-tance
Mésozoïque	Crétacé	Crétacé Supérieur	Craie, Sénonien, Turonien, Cénomanien, Bassin Seine-Normandie, Bassin Artois-Picardie, Bassin Loire-Bretagne (Touraine)	F	U	100 à 500	10^{-2} - 10^{-4}	****
			Sables, Cénomanien, Touraine et Charente	I	U à l'affleurement - C sous toit argilo-marneux	30 à 90	3.10^{-3} à 10^{-4}	**
		Crétacé Inférieur	Sables, Albien, tout le centre du Bassin Parisien	I	C sous les argiles de Gault	30 à 200	4.10^{-3}	**
	Crétacé	Crétacé Inférieur	Calcaires, Aptien à Valanginien	F and K	U dans la majorié des cas			***
	Jurassique	Jurassique moyen et Supérieur	Calcaires, Portlandien à Bajocien Bourgogne, Lorraine, Basse Normandie, Vendée, Poitou, Périgord, Quercy, Jura, Préalpes, Causses, Massifs Pyrénéens, Provence.					
	Trias		Grès, Bundsandstein, Vosges	M	U à l'affleurement C sous marnes de Muchelkalk		0,5 à 20.10^{-3}	***
Paléozoïque	Permien							
	Carbonifère Dévonien		Calcaires, région de Lille et d'Avesnes-Sud de la Montagne Noire-Pyrénées	F	Essentiellement C			***
			Socle (+ arènes)	M or F	U			*

Table 2.4

Main aquifers of France

(2)

Era	System	Subsystem	Aquifer	Permeability	Type	Thickness (m)
Cénozoique	Quaternaire		Alluvions des vallées	I	U en général	quelques m à 300
			Sables	I		
			Alluvions des terrasses et cônes de déjection	I	U en général	quelques m à 200
			Sables, galets alternés à argiles et limons des dépressions quaternaires (niveaux des tufs volcaniques et travertins en Campanie et au Latium)	I	C	100
			Travertins	I	U	100 - 150
			Sables, sables argileux, argiles, conglomérats des dépressions plioquaternaires	I	C	100 - 250
			Sables, conglomérats, grès, calcarenites, calcaires coquillers et intercalations argileuses (formations de plateaux)	I		
Cénozoique à Mésozoique	Tertiaire à Trias	Miocène	Conglomérats, sables, grès	F + K		40 - 60
		Miocène	Gypse			
		Oligocène à crétacé	Grès à intercalations argilo marneuses (Macigno)			
		Oligocène	Conglomérats			
		Miocène à Eocène	Flysch argilo gréseux et marno gréseux			
		Oligocène à crétacé	Flysch marno calcaire et argilo calcaire			
		Miocène	Calcaires marneux	U et C		20 - 150
		Miocène	Calcaires vacuolaires			
		Miocène à trias	Calcaires, calcaires marneux, calcaires dolomitiques, dolomies			
Paléozoique	Cambrien	Cambrien	Calcaires métallifères et dolomies	F + K		50 - 1000

Table 2.5

Main aquifers of Italy

(1)

Era	System	Subsystem	Aquifer	Permeability	Type	Thickness (m)
Cénozoique	Quaternaire	Holocène à pléistocène	Volcanites basiques (tufs, lapilli, basaltes, pouzzolanes, brèches)	M		
	Tertiaire	Mioplicène	Volcanites basiques	F		
	Quaternaire à Tertiaire	Pléistocène et oligomiocène	Volcanites acides (ryolithes, trachytes, andésites, porphyres)	F		
			Schistes, micaschistes, phyllades, quartzites	F		≤ 50
			Granites, granodiorites, gneiss, migmatites	M sauf dans les Alpes		≤ 50
			Roches vertes	F		≤ 50

Table 2.5

Main aquifers of Italy

(2)

Era	System	Subsystem	Aquifer	Permea-bility	Type	Thickness (m)	Transmissivity (m^2/s)	Importance
Cenozoic	Quaternary		Alluvium (widespread)	I				*
			Fluvio-glacial sands/gravels (widespread)	I				***
Mesozoic to paleozoic	Permo-triassic		Sandstones (Kingscourt area E.)	I + F	U + C	up to 500		**
Paleozoic	Carboniferous	Westphalien	Sandstones (S.E.)	F	C	5 to 20		**
		Namurian	Sandstones (S, S.E., M - W)	F				*
		Upper Visean	Clean Calcarenites (widespread)	F + K				****
		Visean Calp	Sandstones (N.W, W, Shannon)	F(? + I)				**
		Tournaisian	Massive Waulsortian reef limestones - (Widespread)	F				*** (S) **/* (elsewhere)
			Sandstones (N.W., E.)	F				**
	Devonian		Sandstones (S.E., S., Shannon)	F	C mostly		4 to 8.10^{-4}	
	Ordovician		Tuffs, lavas (S.E., E.)	F			4.3×10^{-3} (S.E.)	

Table 2.6

Main aquifers of Ireland

Era	System	Subsystem	Aquifer	Permeability	Type	Top/base (m)	Thickness (m)	Transmissivity (m^2/s)	Importance	T.F.
Cenozoique	Quaternaire	Holocène	Alluvions (limons, sables, graviers)	I		0/	4 - 12		*	
Mesozoique	Crétacé à Jurassique	Bajocien Aalénien,Toarcien Toarcien	Calcaire à polypiers Minerai de fer oolithiques Grès supraliasique	M		0-210/	135 - 210		**	
		Domérien Supérieur	Grès médioliasique ou Grès de Macigno (grès marneux)	M		0-200/	0 - 100		**	
		Hettagien sup. + Sinémurien inf.	Grès de Luxembourg (grès calcaire)	M	U+C	0-400/	20 - 100	10^{-3}	****	
	Trias	Keuper moyen	Grès à roseaux (grès micacé)	M		0-100/	0 - 50	6.10^{-4}	*	
		Muschelkalk supérieur	Calcaire coquillier (dolomitique)	F		0-100 > 100 : mineral.	55	$3.9\ 10^{-3}$	***	
		Muschelkalk inférieur	Grès coquillier (dolomitique)	M		0- 50/	15 - 20		*	
		Buntsandstein sup. et moyen	Grès bigarré (grès et conglomérats)	I		0-800/	0 - 250	$9.3\ 10^{-4}$	***	
		Keuper moyen inf. Keuper inférieur Muschelkalk	Trias en faciès de bordure (grès, conglomérats, dolomies, grès dolomitiques)	M		0-800/	50 - 250		***	

. All aquifers, excepted grès à roseaux, are transfrontier (B, D or F)

Table 2.7

Main aquifers of Luxemburg

Era	System	Subsystem	Aquifer	Permeability	Importance
Cainozoic	Quaternary	Holocene	Superficial deposits	I	*
		Pleistocene	Upper and Middle Pleistocene	I	*
			Crag	I	**
	Tertiary	Pliocene	Coralline Crag	I	**
		Oligocene			
		Eocene	Bagshot Beds	I	*
			Blackheath & Oldhaven Beds	I	*
			Woolwich & Reading Beds	I	*
			Thanet Beds	I	**
Mesozoic	Cretaceous	Upper Cretaceous	Chalk & Upper Greensand	F	****
		Lower Cretaceous	Lower Greensand	I	***
			Hastings Beds	I	**
	Jurassic	Upper Jurassic	Portland & Purbeck Beds (Spilsby Sandstone)	F (I)	* (***)
			Corallian	F	**
		Middle Jurassic	Great & Inferior Oolitic Limestone	F	***
		Lower Jurassic (Lias)	Bridport & Yeovil Sands	I	**
			Marlstone Rock	F	*

Table 2.8

Main aquifers of the United Kingdom

(1)

Era	System	Subsystem	Aquifer	Permeability	Importance
Meso-zoic	Triassic	Keuper	Permo-Triassic Sandstones	M	****
		Bunter			
Upper Palaeozoic	Permian				
			Magnesian Limestone	F	***
	Carboniferous	Upper Carboniferous	Upper Coal Measures	M (multi-layered)	**
			Middle & Lower Coal Measures	M (multi-layered)	*
			Millstone Grit	M (multi-layered)	**
		Lower Carboniferous	Carboniferous Limestone	F	**
	Devonian	Old Red Sandstone	Old Red Sandstone	M or F	*

- All aquifers present large unconfined areas. Generally the upper carboniferous aquifers are multilayered and act as confined.
- Due to a widespread distribution of these aquifers and of their characteristics, no significant transmissivity, top/base and thickness values are given. They appear in the local descriptions (National Report).

Table 2.8

Main aquifers of the United Kingdom

(2)

Chapter 3

GROUNDWATER HYDROLOGY

Groundwater hydrology is mainly concerned with all features relating to the movements and storage of groundwater, and used to determine the characteristics of exploitation and possible movements of pollution. Many features will influence the management of groundwater but they should not be taken into account altogether : the choice of useful parameters and of their distributions in time and space will depend on the scale at which the aquifers are studied.

It should be stressed that the purpose of this theme is to provide a survey of the dynamics of the more important aquifers (mean flow directions, mean flow velocities, mean flow rates), helpful for a quantitative large-sized management modelling of the Community based on the discretization of the Community territory into the units of the grid system, and also preparing the vulnerability study of the Community groundwater resources.

3.1. FEATURES OF COMMUNITY GROUNDWATER HYDROLOGY

Three categories of features have been selected as useful for both a qualitative and quantitative utilization of the present study in terms of management modelling at the Community scale :

. features of the movement of water within the aquifer ;

. features of the movement of water between the aquifer and other systems ;

. features related to particular problems.

3.1.1. Features of the movement of water within the aquifer

They are the transmissivity, the piezometry and the boundary conditions. In most cases, an average value of transmissivity is known per aquifer, sometimes even several values have been determined up to one value per elementary unit of the grid system when the aquifer spreads out on several such units.

Although water levels in wells are easy to obtain, the piezometric lines are more difficult to derive because it involves a good density of observation points recorded frequently : some aquifers have been extensively studied and are equipped with many wells but a great number of aquifers are not well known. Major aquifers are usually well studied. Besides, the scale and the purpose of the study implied a choice among the available piezometric information to estimate the mean yearly movements of groundwater and, when significant, the yearly fluctuations of the piezometric levels : thus, the number of piezometric contours represented here is considerably reduced, when they exist, with respect to larger scale maps.

Introduced only on the maps, the boundary conditions are of two kinds, flow condition and zero flow condition (or impervious boundary) ; the flow condition exists when an aquifer receives or gives water laterally. A groundwater divide may also be taken into account if need be, as a zero flow limit within the aquifer. The boundary conditions are not often introduced, only when it is felt that they are known correctly and are adding information to the geological description of maps 1.

The general movement of water is qualitatively shown in many aquifers, even without piezometric contours, by an estimate of the flow directions of the aquifer obtained from more detailed piezometric maps or from known direct evaluation. On the maps 2, the use of arrows visualizes these movements rather well and gives an immediate view of the dynamics of the aquifer, especially useful for future pollution studies.

In the national reports, the storage coefficient is sometimes provided, very locally.

3.1.2. Features of the movement of water between the aquifer and other systems

The most important feature is the estimate of the transfer of water between an alluvial aquifer and the river. Alluvial aquifers play a very peculiar part in the supply of water : abstractions in the vicinity of the river usually pump river water, the banks behaving like a natural filter. Thus it is not possible to distinguish between river water and aquifer water, which means that the resource provided by an alluvial aquifer cannot be estimated as the resource of another aquifer : because of bank infiltration, a small alluvial aquifer may be a much more important resource than a classical hydrogeological balance might tell. A consequence will also be that these aquifers have to be specially protected against surface water pollution.

The relationships between an alluvial aquifer and the river are complex, depending upon the clogging of the banks and various hydrological factors like the water levels in the river or the distribution and pumping rates of the wells. It was thus decided that the most practical way of expressing the relationships between a river and an aquifer was to derive various classes according to the ease with which water is transferred between the two systems. Three classes have been defined : good, medium or weak aquifer-river exchanges.

The possible exchanges between two aquifers are also taken into account. This feature may prove useful for vulnerability studies of superimposed aquifers.

Springs are an important water supply mainly in Luxemburg, Italy, West Germany and France. Of course they can be found in most Member States, excepted probably in the Netherlands, but usually have then very low flow rates. Only springs presenting a flow rate of more than 30 l/s (∿ 1 million m^3/a) are shown, divided up into normal springs, mineral springs and thermal springs.

3.1.3. Features related to particular problems

Groundwater seepage areas, being particular hydrological features, are of course also represented on maps 2 as well as on maps 1. In conjunction with the movements of the aquifer, they play an important part for the vulnerability of phreatic aquifers.

Another feature which brings a pollution constraint on the exploitation of groundwater is saline water, due either to sea water intrusion or to saline domes. Sea water intrusion, important in some Member States (Italy, Belgium, France, Denmark), is most important in the Netherlands, where brackish water is a large part of the resource and is used rather extensively as industrial water (about 20 % of the total industrial water).

3.2. CARTOGRAPHIC ASPECTS

Maps 2 are presented on a transparent support so that they can be used together with maps 1, 3 or 4. The combination of maps 1 and 2 provides a complete hydrogeological survey of the Community, whereas the combinations of maps 2 and 3 or 4 enable to link the abstraction densities and wells and the possible resources to the hydrogeological properties of the individual aquifers.

The piezometry, directions of groundwater flow and transmissivities of up to three superimposed aquifers are represented.

Although planned in the legend, the boundaries of aquifers have not been introduced everywhere, because in many cases they did not help to individualize the aquifers better than with the existing piezometric contours : it is the case of France and Italy for instance, while the United Kingdom has kept these lines as a reader's help for the combination of maps 2 and 3 or 4. Of course, it should be remembered that aquifer boundaries appear also on maps 1.

The colours of maps 2 are those of maps 1, which helps for a better use of the combination of maps 1 and 2.

The limits of saline intrusion correspond to 500 mg Cl^-/l at depths less than 50 m.

3.3. PIEZOMETRIC AND TRANSMISSIVITY DATA

Piezometric data are obtained by field measurements of the levels of water in wells at different times ; the piezometric contour lines are then derived by extrapolation in space at these times. The measurements in the wells are very good but the accuracy of the extrapolation may be limited in many regions of the Community by the small number of observation points usually available and by the limited frequency of the observations : sufficient for a control of the levels of an aquifer with time and at various locations, the existing data are not in general enough for a management study of the aquifer involving the location of new wells and the derivation of a pumping policy, which would require more field work in conjunction with mathematical modelling. Anyway, it appears from this study that to know the piezometry is not a big problem in the Community although some regions are certainly badly underequipped in observation points (Ireland, for instance). It also fulfills the purpose of the present study by providing a good survey of the general flow dynamics of various significant aquifers.

In order to specify these general considerations, the characteristics of the observation network of the aquifers are now examined for each Member State.

. Belgium : two aquifers (carboniferous limestone of Tournai and Chalk of Mons) are equipped with about 15 limnigraphs each, recording continuously (one graph per week with an accuracy of ten minutes). In the other aquifers, the measurements are manual by piezometric sounding. Four regions (Campine, Mons, Tournaisis, Terrasse de la Meuse) have a good number of wells.

Many abstraction wells are also used for dynamical measurements.

. Denmark : the piezometry is derived from soundings carried out by the drillers after completion of wells, on about 70 000 to 100 000 wells (a density of 2 to 4 wells per km^2). The measurements are thus rather heterogeneous, sometimes made at intervals of 50 years ; but in the last ten years, a great number of the wells have been sounded again and only small changes have been noticed which implies that the presented data are of sufficient accuracy.

There exists a National Groundwater Network comprising 110 wells with manual recording monthly or twice a month, two or three wells being continuously recorded. In particular, the mean yearly fluctuations of piezometry, which appear for some important aquifers, have been estimated from the data obtained at some representative wells of this Network during 10 to 25 years.

Water Supply Companies too measure the levels regularly. Many agricultural plants have received their licenses to abstract water on the condition that they measure the water levels twice a year.

. Federal Republic of Germany : each Land is equipped with a good number of wells ; for instance about 2500 wells are sounded weekly in Baden-Württemberg for a total area of 35 751 km^2, while in Berlin altogether 1 151 observation points are regularly used for an area of 480 km^2. Many of these points are equipped with continuous recorders.

. France : there are about 9 000 piezometers in France but 80 % in alluvial aquifers. A small number of the large aquifers is observed regularly, which implies that, although the general piezometry is known, its variations are not recorded.

. Italy : the inventory of piezometric data is rather complete. The measurements are performed manually by electrical soundings and very locally continuous recordings are made for relatively short periods of time. Although the Hydrographic Service has observation wells in some regions, the fluctuations of the piezometric surface are scarcely known.

A number of springs are also regularly observed : flow rates are measured weekly, monthly or yearly.

. Ireland : the piezometry is very little known in this Member State. Less than 200 observation wells are regularly maintained, with about fourty recorded continuously.

. Luxemburg : the piezometry is not well known and a maximum of twelve piezometers can be found. It should be stressed that most of the used groundwater comes from springs and not from wells.

. Netherlands : the piezometric level measurements are performed manually (with very few exceptions) on a national network of about 15 000 observation wells including 7 500 shallow wells (less than 5 m deep). 55 % of these wells are observed twice a month and 35 % once per three months. Many local piezometer networks exist too.

. United Kingdom : England and Wales possess a groundwater observation well network of more than 1 400 wells. 20 to 25 % of these wells are equipped with continuous recorders ; the others are measured manually weekly or monthly.

In most of the large wells pumped for public supply, dynamic levels are measured upon a continuous basis.

In Scotland and Northern Ireland, there are only a very few observation wells, of the order of two to four and piezometry is almost unknown.

Point transmissivity values are obtained by pumping tests everywhere but no areal transmissivity values are generally available. Mathematical models are sometimes used, generally for specific studies of local problems only.

Chapter 4

GROUNDWATER ABSTRACTION

4.1. GROUNDWATER ABSTRACTION RECORDS

All Member States maintain some records of their groundwater abstraction, but with the exception of Denmark, which has a licensing system covering all abstractions, the Member States cannot present a complete accurate record of the abstracted volumes :

. Belgium : there are two classes of abstractions, class 1 and class 2.

Class 1 abstractions are less than 96 m^3/d, must be declared and are automatically authorized ; they are private wells, they are not recorded (excepted in the Ardennes region) but the total volume they produce is negligible with respect to the total groundwater abstraction.

Class 2 abstractions are more than 96 m^3/d and must be authorized ; the users declare the abstracted rates annually to the Corps des Mines. As the law has been implemented in 1947 only, information on 10 to 15 % of Class 2 abstractions of the Flemish part is missing ; in this work, these abstractions have been estimated from the figures in the licenses and the estimate has been calibrated on known abstractions.

. Federal Republic of Germany : in all States, public water supply is accurately known, including of course the part provided to the industry. Besides the industries must declare their own abstractions to the offices of statistics in each State, data then gathered at the Federal Office of Statistics. For agriculture, information is either missing or old ; in this work the volume of groundwater used for agriculture has been estimated at 1 to 2 % of the total abstracted volume.

. France : pumping is free excepted in a few regions where a license is required. Returns have to be made to the Agences Financières de Bassin but only above some threshold which varies from 7 500 m^3/a in Loire Bretagne to 100 000 m^3/a in Rhin Meuse. This means that small abstractions are not recorded.

Two Agencies only (Seine Normandie and Loire Bretagne) maintain records of agricultural abstractions. In all other cases, these abstractions have been estimated.

One Agence (Adour Garonne) puts surface water, water from phreatic aquifers and spring water in the same category ; only deep aquifers are recorded separately. Consequently a reasonable assumption is that the total abstracted groundwater in France is known with an uncertainty of 10 % (and probably + 10%), the agricultural abstractions being generally underestimated.

. Italy : at the level of the country, there is a general census of all drinking groundwater supplies of all communes, the Piano degli Aquedotti, dating back to 1965 and drawn on a map at 1/100 000, a single copy of which only exists. These rather old data have been completed for this work thanks to information released by various distribution services, but in some regions, the provided data are certainly less than reality.

Water for agriculture has been estimated for this work from the existing data concerning irrigated areas and unit dotations per type of culture and irrigation.

Water for industry data are the most uncertain and are missing in many areas. When existing, these data have been provided by official services or directly by the industries.

The uncertainty on the total abstraction is about 10 % of the total amount of abstracted water i.e. about 1 000 million m^3/a.

. Ireland : Local Authorities collect information on abstractions greater than 5 m^3/d and this information practically concerns local authority and industrial wells only. Numerous farms abstracting more than 5 m^3/d have been omitted and an allowance of 10 % over and above the large abstractions was made to take these farm abstractions into account as well as the numerous small abstractions of less than 5 m^3/d from single houses and small farms. In some areas, mostly where groundwater is least important, these data are not available and, for this work, abstractions have been estimated on the basic of personal knowledge and limited data at the Geological Survey ; anyway, the volume of water concerned is very small with respect to the total abstraction.

. Luxemburg : flow rates of springs and wells are very irregularly measured, at most once a year and sometimes a few years are missing. Spring values have been averaged and because of the lack of data, these averages are sometimes uncertain. Furthermore, for a few springs it is impossible to differentiate between actual use and flow rate. Industrial abstractions are recorded at 80 %. The uncertainty on abstraction is large, because pumping is free everywhere excepted in the Luxemburg sandstones and autonomous wells are not recorded.

. Netherlands : groundwater abstraction for public and industrial water supplies is accurately recorded by state and provincial governmental institutes and records are assumed to be complete for abstractions greater than 10^4 m^3/a.

Abstraction for agriculture is not recorded and, for this work, it has been estimated from regional enquiries and a 1976 complete enquiry, providing a ten year average.

Some significant quantities of groundwater cannot be estimated : they concern the water pumped by the building industry to lower the watertable.

Of course, small private abstractions cannot be taken into account in the evaluation.

United Kingdom : in England and Wales, there is a licensing system and licensed abstractors must provide information to the River Authorities. Records are kept of licensed abstractions greater than 60 000 m^3/a ; the part of abstractions less than 60 000 m^3/a is considered as negligible with respect to the total volume abstracted ; they concern households and small farms.

In Scotland and Northern Ireland, there is no licensing system at present. Only public supply is recorded and there is almost no indication for industry and no indication at all for agriculture.

A general conclusion is that the abstraction is underestimated, sometimes rather largely, on all the Community territory, due to the present management of groundwater.

4.2. GROUNDWATER ABSTRACTION TYPES

The most common types of abstractions of Community groundwater are wells, springs, mine drainage, drainage galleries (adits).

Although wells represent the most frequent type of abstraction, in several Member States springs provide a large amount of the groundwater : in Luxemburg they give 81.7 % of all groundwater against 18.3 % by wells ; in Italy they represent 27.5 % of all groundwater against 71.9 % for wells and 0.6 % from other sources (like mine drainage for instance) ; in the German Federal Republic, the part of springwater in Public Supply groundwater is about 10 % ; in France, springwater is about 15 to 20 % of all abstracted groundwater. A few springs exist in Denmark, Ireland, Belgium and the United Kingdom with a small rate of flow.

Mine drainage contributes to the groundwater abstraction in several Member States but the water obtained in that manner is usually unsuitable for public supply. Recorded mine drainage accounts for about 2.5 % of the total abstracted groundwater in the United Kingdom (Northwest, Yorkshire and Welsh water authorities), for about 5 % in France (Agences de Bassin Artois-Picardie, Loire Bretagne, Rhône Méditerranée Corse and Rhin Meuse, the last one accounting for 94 % of the total mine drainage), for about 0.4 % in Italy (Sardinia). Some mine drainage exists in Belgium (Limbourg) and in the Federal Republic of Germany.

Drainage galleries exist in Italy (on the Etna, in Calabria, near Napoli), where they are accounted for as springs, and in Northeastern Belgium where they are very large (about 21 10^6 m^3/a) and in the chalk of the London Basin where they occur in large number.

It should be mentioned that groundwater is not always used where it is abstracted or nearby. Often, large cities are supplied from far away as, for example, the cities of Brussels and Ghent in Belgium supplied by the chalk aquifer of Mons, but also there are examples of water transfers from a region to another as, in Italy, from Campania to Puglie by the Aquedotto Pugliese (Pugliese Water Company). These examples are certainly interesting attempts for a better distribution of the groundwater resources.

4.3. GROUNDWATER USES

Groundwater is currently used for public supply, for industrial and agricultural purposes, as surface water. It has also a few specific uses related to the fact that it is stored and moves underground. It is important to know how much groundwater is used, whether it is used adequately or not and, when surface water may play a part, to evaluate the respective importances of ground and surface water ; all these data are significant for water management and protection.

4.3.1. Classical uses

In chapter 1, we already have presented a table showing the total volumes of groundwater devoted by each Member State to the various uses. It is a general indication of the groundwater use policy of each Member State and may be of help for a better utilization of groundwater by attracting the attention of the Member States on the possible increases of groundwater consumption in domains where the use of a good quality water is justified and the possible decreases (and replacement by other waters) of groundwater use in other domains.

To better compare the possibilities and policies of the Member States, it is necessary to have a better picture of the groundwater uses at the regional scale of the administrative decision units, well related to the regionalized aspects of groundwater and better fitting the economical features of a country. To this purpose, we present hereafter tables showing the regionalized distribution of uses in each Member State with the exception of the United Kingdom where such an information at the level of water authorities could not be obtained.

As table 1.1, these tables show the parts of drinking water, water for the industry, water for the agriculture (mostly irrigation) and water for some other uses detailed in § 4.3.2. In the drinking water column, we put the data relating to the public supply in many national reports and to domestic uses in the Danish report. As already said in chapter 1, it is not always possible to distinguish between the various uses : for instance, in the German Federal Republic, a part of the water for industry comes from public supply ; or in Ireland, the public supply will provide some water for agriculture ; or in Belgium, industrial and agricultural waters are not differentiated.

Besides, as already mentioned in § 4.1, these figures do not cover all abstractions. All that can be said is that these data are as close to reality as allowed by data recording practices in each Member State.

We also present three tables showing the regionalized use of groundwater and surface water in the Federal Republic of Germany*, the Republic of Ireland and England and Wales (United Kingdom). Whereas for the FRG and UK, only public supply data were available, all water data could be obtained for Ireland. For the Netherlands, groundwater accounts for 2/3 of public water supply used while for Luxemburg it accounts for 45 % of all water used (56 % of public supply water and 38 % of industrial water) ; in Belgium, groundwater represents 67 % of all public water supply. For England and Wales, the total abstraction of surface water was 11320 10^6 m^3 in 1977 while the total abstracted groundwater was 2374 10^6 m^3, representing 17 % of the total water abstracted.

The Irish situation illustrates very clearly the significance of regionalization : although 23 % of the total amount of water used in Ireland is groundwater, there are many regions where the actual percentage of used groundwater is greater than 60 %, showing that groundwater is locally very important in rather extensive areas. The difference is due to the influence of a single area, the Dublin city and county, heavily populated and almost entirely supplied by surface water.

The French situation illustrates both the significance of regionalization and the emphasis put on groundwater use for drinking : whereas an order of magnitude, based on 1973 data, is 22 % of groundwater versus total abstracted water (5 10^9 m^3 against 23 10^9 m^3), the percentages of groundwater versus surface water estimated in four Agences respectively are :

- for drinking purposes, 96 % in Artois-Picardie, 80 % in Rhin Meuse, 56 % in Seine Normandie ;
- for industrial purposes, 40 % in Artois-Picardie, 30 % in Rhin Meuse, 35 % in Seine Normandie ;
- for agricultural purposes, 72 % in Rhin Meuse, 12 % Rhône Méditerranée Corse.

The differences with the global estimate results mainly from the extensive use of surface water for the industry and, in some areas, for the agriculture.

The use of brackish water for industrial purposes by the Netherlands is an interesting hint for a preferential use of low quality waters whenever quality is not a necessity, especially when considering how extensively groundwater is used for the industry in many regions of the Community.

---

* with a purely indicative value as it is based on data older than 1977

4.3.2. Specific use

Besides the classical uses as drinking water, water for the industry and for the agriculture, groundwater has also some specific uses in several Member States.

The most peculiar use of groundwater is the Italian Soffioni i.e. groundwater coming out as vapour jets at 220° that supply energy to several electrical plants. Located in Tuscany, these Soffioni utilize about 25 to 32 10^6 m^3/a representing about 6 to 8 % of the groundwater abstracted in the region and 0.2 % of the total abstracted groundwater in Italy.

Very specific to Denmark, fish farming uses a large amount of groundwater (about 40 10^6 m^3 in 1977). It is practiced along the streams which have groundwater conditions and flowing wells. This activity consumes about 3 % of the total groundwater abstracted in Denmark.

The drainage of marshland, existing in all coastal plains in Italy (the lower part of the Po basin for instance) and not considered in that country as a use of groundwater but as another way of carrying groundwater to the sea, is taken as a use in Belgium (Mons basin). This water is not generally put in the public supply or reused in agriculture or industry.

A rather common use of groundwater concerns civil engineering : in order to lower the water table in the building industry, large amounts of groundwater may be pumped out and put into sewers of rivers. This is, for example, the case in the Netherlands, where the volumes abstracted in that way cannot be estimated, or in Denmark near huge buildings of Copenhagen or near motor ways.

Mine drainage, already mentioned above, can be considered as a kind of use. This water is sometimes reused when it is suitable for classical utilizations.

4.4. REPRESENTATION OF THE GROUNDWATER ABSTRACTION

The groundwater abstraction is represented by means of the grid system which subdivides a Member State into units individualized by administrative and hydrogeological characteristics and chosen in such a way that they also represent subdivisions of larger administrative decision units. The various systems have been presented in chapter 0.

Two features have been selected for this representation : the density of abstraction and the large abstraction wells, plants or springs.

The density of abstraction i.e. the amount of abstracted groundwater per km^2 is very useful for a compared study in the Community, as it expresses the spatial distribution of pumpings and can be easely visualized on maps. Of course, for practical purposes, an averaging procedure has to be introduced in order to get the required information without investing into too many details : the

density is related to each mesh of the grid system, meaning that it is defined as the total volume abstracted in a given mesh from all aquifers divided by the area of the mesh ; besides, these pumping densities are classified into ten categories which represent the usual ranges of densities in the Member States and have been obtained by synthesizing the results of preliminary enquiries of all consultants. These categories, expressed in mm/a (1 mm/a = 10^3 $m^3/km^2/a$) respectively are :
0-50 ; 0-25 ; 25-50 ; 50-200 ; 50-100 ; 100-200 ; 200-300 ; 300-400 ; 400-500 ; > 500.

Each category is visualized by a colour or a shade in a colour. The distribution of these colours give an instantaneous visual feeling of the distribution of abstractions in the Community. The exact values of the densities are provided of course in the national reports but are also written on the maps, in each mesh.

Large abstraction wells, plants or springs are often used for public supply and may occur in densely populated areas. Their vulnerability may be high and their protection may cause problems. It is then necessary to know where they are located. Also, the presence of a pointwise large abstraction in a mesh may change the density in that mesh which will no longer represent an areal distribution of pumpings. To show this abstraction explicitly helps to prevent such distorsions.

In this study, a large abstraction is defined as producing 10^6 m^3/a or more. A large sized abstraction station is either a single well yielding more than 10^6 m^3/a or a pumping station made up of a cluster of wells, the total yield of which exceeds 10^6 m^3/a. As, in some areas, several such large sized abstraction stations may occur very near one to the other, their representations may cause problems at the scale of the maps : it has been decided to group as one large station the large stations within a circle of 1.5 to 2 km radius.

Large abstraction wells or springs have been classified into four categories compatible with the data of all Member States :
1 to 2 10^6 m^3/a ; 2 to 4 10^6 m^3/a ; 4 to 10 10^6 m^3/a ; > 10.10^6 m^3/a.
For the last category, the abstraction figure is written on the map.

For the wells, a difference is made between wells producing water from one aquifer or from several aquifers. For the springs, the difference is made between normal, thermal and mineral springs.

REGION	DRINKING WATER	%	INDUSTRY AND AGRICULTURE	%	TOTAL
Flandre occidentale	11.4	68%	5.5	32%	16.9
Flandre orientale	6.9	28%	17.8	72%	24.7
Anvers	44.8	65%	24.5	55%	69.3
Limbourg	30.1	50%	30.5	50%	60.6
Brabant Flam.	23.9	68%	11.3	32%	35.2
Bruxelles	2.5	48%	2.7	52%	5.2
Brabant Wallon	32.5	88%	4.5	12%	37.0
Hainaut	119.0	59%	81.0	41%	200.0
Namur	62.1	92%	5.7	8%	67.8
Liège	66.6	81%	15.6	19%	82.2
Luxembourg	21.9	97%	0.7	3%	22.6
Total for Belgium	425.2	68%	196.3	32%	621.5

Table 4.1

Distribution of uses for Belgium
in 10^6 m^3/a

COUNTY	DRINKING WATER	INDUSTRY	AGRICULTURE	OTHER USES FISH FARMING	LICENSED TOTAL ABSTRACTION
Greater Copenhagen	70	27	3		214.4
Vestsjoelland	79	18	3		63.2
Storstrom	90	8	2		43.7
Bornholm	71	15	14		9.3
Fyn	64	32	4		101
Sønderjylland	54	11	34		132.7
Ribe	43	7	50		115.7
Vejle	34	16	21	29	160.4
Ringkøbing	20	14	64	2	149.2
Arhus	88	11	1	included in drinking water	116
Viborg	39	25	36		55
Nordjylland	48	14	13	25	156.4
Total for Denmark	40	22	35	3	1317

Table 4.2

Distribution of uses for Denmark in %
and licensed total abstraction in 10^6 m^3/a

AGENCE DE BASSIN	DRINKING WATER	%	INDUSTRY	%	AGRICULTURE	%	OTHER USES (MINE DRAINAGE)	%	TOTAL
Adour Garonne	226	68	49	14	60	18			335
Artois Picardie	277	46	265	44	57	9	6	1	605
Loire Bretagne	420	78	78	15	31	6	8	1	537
Rhin Meuse	278	27	443	44	28	3	264	26	1013
Rhône Méditerranée Corse	985	56	617	35	170	9	2	~0	1774
Seine Normandie	939	64	413	28	116	8			1468
TOTAL FRANCE	3125	55	1865	32	462	8	280	5	5732

Table 4.3

Distribution of uses in France

quantities in 10^6 m^3/a

REGION	DRINKING WATER	%	INDUSTRY	%	AGRICULTURE	%	OTHER USES	%	TOTAL
Vallée d'Aoste	22	33	46	66	1	1			69
Piémont	507	35	360	22	624	43			1491
Ligurie	188	61	76	25	43	14	–		307
Lombardie	1268	49	299	11	1027	40			2594
Trentin Haut Adige	116	57	51	25	37	18			204
Vénétie	866	66	103	8	309	23	35	3	1313
Friuli Vénétie Julienne	127	62	39	19	38	19			204
Emilie Romagne	292	44	220	34	147	22	–		659
Toscane	227	52	60	14	129	29	24	5	440
Marches	184	∿64	?		106	∿36	–		> 290
Ombrie	81	∿80	?		20	∿20	–		> 101
Latium	826	∿80	> 34	∿ 4	165	∿16			> 1025
Abruzzes	129	∿61	?		81	∿39			> 210
Molise	36	∿95	–		2	∿ 5	–		>38
Campanie	555	∿60	?		374	∿40			> 929
Pouilles	59	19	> 12	3	254	78	–		325
Basalicata	171	93	–		12	7			183
Calabre	219	53	82	20	111	27	–		412
Sicile	485	42	194	17	472	41	–		1151
Sardaigne	51	23	10	5	106	49	50	23	217
TOTAL FOR ITALY	6409	53	> 1586	12	4058	34	109	1	> 12162

Table 4.4

Distribution of uses in Italy in 10^6 m^3/a

County	Public Supply	%	Industrial and private supplies	%	Total
Carlow	1.74	57	1.33	43	3.07
Cavan	0.29	15	1.64	85	1.93
Clare	0.71	69	0.32	31	1.03
Cork (incl. city)	(6.55)	-	(13.14)	-	-
Donegal	(0.16)	-	-	-	-
Dublin (incl. city)	-	-	(1.83)	-	-
Galway	(3.65)	-	(0.18)	-	-
Keny	3	59	2.12	41	5.12
Kildare	(0.55)	-	(1.10)	-	-
Kilkenny	5.41	70	2.31	30	7.72
Laois	3.83	95	0.2	5	4.03
Leitrim	0.90	83	0.18	17	1.08
Limerick (incl. city)	3.61	61	2.31	39	5.92
Longford	0.71	60	0.48	40	1.19
Louth	0.27	18	1.22	82	1.49
Mayo	(1.83)	-	(0.18)	-	-
Meath	0.29	28	0.73	72	1.02
Monaghan	0.18	17	0.85	83	1.03
Offaly	2.34	100	-	0	2.34
Roscommon	9.56	100	-	0	9.56
Sligo	1.13	95	0.06	5	1.19
Tipperary North	2.05	70	0.86	30	2.91
Tipperary South	(3.65)	-	(1.83)	-	-
Waterford (incl. city)	4.33	90	0.46	10	4.79
Westmeath	0.68	97	0.02	3	0.70
Wexford	3.57	85	0.61	15	4.18
Wicklow	(0.37)	-	-	-	-
Total	61.36	64	33.96	36	95.32

Table 4.5

Distribution of uses in the Republic of Ireland in 10^6 m^3/a

(Figures in brackets are rough estimates)

PROVINCES	DRINKING WATER	%	INDUSTRY			AGRICULTURE	%	TOTAL
			FRESH WATER	BRACKISH WATER	% TOTAL			
Groningen	25	45	24.7	5.5	55	0.1	∿ 0	55.3
Friesland	40.2	65	18.3	3.3	35	0.2	∿ 0	62
Drenthe	43.2	67	20.5	–	32	0.6	1	64.3
Overijssel	72.4	64	34.8	–	31	5.9	5	113.1
Ijsselmeerpolders	4.9	96	–	0.1	2	0.1	2	5.1
Gelderland	111.3	48	100.8	–	44	18.8	8	230.9
Utrecht	63	73	22	–	25	1.7	2	86.7
Noord Holland	135.1	72	10.4	40.7	27	0.5	1	186.7
Zuid Holland	129.3	71	15.3	37.9	29	0.1	∿ 0	182.6
Zeeland	5.4	66	0.6	2.2	34	–		8.2
Noord Brabant	185.6	57	103.9	6.5	34	31.3	9	327.3
Limburg	65.5	52	46.6	–	37	14.7	11	126.8
TOTAL FOR THE NETHERLANDS	881	61	398	96	34	74	5	1449 *

Table 4.6

Distribution of uses in the Netherlands in 10^6 m^3/a

* brackish water incl.

BUNDESLAND	PUBLIC SUPPLY	INDUSTRY	AGRICULTURE	OTHER USES	TOTAL
Schleswig-Holstein	182.3	69			251.3
Hambourg	76.2	54.4			130.6
Bremen	10.1				10.1
Niedersachsen	430.7	159.7		minedrainage 67	657.4
Nordrhein Westfalen	640	2177.10			2817.1
Hessen	411.1	96.3			507.4
Rheinland Pfalz	206.8	103.7			310.5
Baden Württemberg	559	264			823
Bayern	784.6	532			1316.6
Saarland	71.10	57.4			128.5
Berlin	187.2	55			242.2
TOTAL	3559	3569	∿ 2% of total = 144	67	7339

Table 4.7 a

Distribution of uses for the Federal Republic of Germany in 10^6 m^3/a

BUNDESLAND	SURFACE WATER	GROUNDWATER	TOTAL	% gw/Total water
Schleswig-Holstein	0.2	135.2	135.4	∿ 100
Hamburg	1.2	155.7	156.9	∿ 99
Bremen	3.5	16.7	20.2	83
Niedersachsen	57.7	421	478.7	88
Nordrhein-Westfalen	197	1210.3	1407.3	86
Hessen	0.01	348.7	348.7	100
Rheinland Pfalz	9.9	193.8	203.7	95
Baden Württemberg	144.1	367.3	511.4	72
Bayern	3.8	521.4	525.2	99
Saarland	0	75	75	100
Berlin West	0	169.9	169.9	100

Table 4.7 b

Groundwater and Surface Water in the Public Supply in the Federal Republic of Germany (1977) in 10^6 m^3/a

(89 - Wasserstatistik, Berichtsjahr 1977 - zfGW Verlag Frankfurt/Main)

County	Public supply		Industrial & private supplies		Total Supply	% gw/ total water
	Surface water	Ground water	Surface water	Ground water		
Carlow	2.21	1.74	0.37	1.33	5.65	54.4
Cavan	2.48	0.29	4.27	1.64	8.68	22.3
Clare	3.71	0.71	4.54	0.32	9.28	11.1
Cork (incl. city)	(39.6)	(6.55)	(0.73)	(13.14)	(60.02)	32.8
Donegal		(0.16)		–	7.47	2.2
Dublin (incl. city)		–		(1.83)	(109.50)	–
Galway		(3.65)		(0.18)	16.07	23.8
Kerry	10.99	3.00	0.15	2.12	16.26	31.5
Kildare		(0.55)		(1.10)	5.13	32.0
Kilkenny	3.88	5.41	0.37	2.31	11.97	64.5
Laois	(0.40)	3.83	0.37	0.20	4.8	84.1
Leitrim	0.71	0.90	~0.01	0.18	1.80	59.9
Limerick (incl. city)	10.85	3.61	3.00	2.31	19.77	28.4
Longford	2.10	0.71	0.33	0.48	3.62	32.7
Louth	5.50	0.27	0.61	1.22	7.60	19.6
Mayo		1.83		(0.18)	(16.43)	(11.1)
Meath	11.41	0.29	0.29	0.73	12.72	8.0
Monaghan	2.77	0.18	1.82	0.85	5.62	18.3
Offaly	2.93	2.34	–	–	5.27	44.4
Roscommon	0.05	9.56	–	–	9.61	99.5
Sligo	3.55	1.13	0.11	0.06	4.85	24.5
Tipperary North	6.69	2.05	0.20	0.86	9.8	29.7
Tipperary South		(3.65)		(1.83)	(10.95)	(50.0)
Waterford (incl. city)	9.68	4.33	2.99	0.46	17.46	27.4
Westmeath	5.36	0.68	0.04	0.02	6.10	11.5
Wexford	9.27	3.57	2.54	0.61	15.99	26.1
Wicklow		(0.37)		–	(5.48)	(6.7)
Total		61.36		33.96	407.9	23.3

Table 4.8

Groundwater and Surface Water in the Republic of Ireland (in 10^6 m^3/a)

(figures in brackets are rough estimates)

WATER AUTHORITY	SURFACE WATER	GROUNDWATER	TOTAL	% gw/TOTAL WATER
Northwest	596	112	708	16
Northumbrian	346	23	368	6
Severn Trent	388	312	700	45
Yorkshire	345	77	422	18
Anglian	230	252	482	52
Thames	723	521	1244	42
Southern	94	285	379	75
Wessex	136	108	244	44
Southwest	116	23	138	16
Welsh	673	26	699	4
Total for England and Wales	3647	1737	5384	32

Table 4.9

Groundwater and Surface Water in the Public Supply in England and Wales (1977) in 10^6 m^3/a

Figures are taken from an analysis of selected aquifers

Chapter 5

GROUNDWATER RESOURCES

5.1. DEFINITIONS

5.1. The resource

This part of the study is very delicate because it involves an attempt to quantify a hydrogeological being which does not only vary with time and space, but also with the economical habits of each country. The resource depends on scientific parameters but also on economical and political parameters ; it is linked to the recharge of the aquifers and to their management.

A common definition of the resource has been first adopted :

For an aquifer system, the resource is the mean annual recharge minus the quantities of water mobilized to satisfy the various constraints, economical, technical, ecological or others, on yearly averages.

This definition means that only exploitable resources are considered, which can be mobilized by pumping the aquifers using their natural regulatory capacities and without consequences degrading the environment. These exploitable resources are evaluated under technical and economical constraints. The permanent reserve, or total volume of water of the aquifer, is not taken into account and yearly averages have been considered in order to let natural replenishment regularize possible temporary uses of the reserve.

In general valid for aquifers largely unconfined, these considerations are difficult to apply to confined aquifers which usually have a low and complex recharge. In that case, it is mainly the reserve which is pumped and the estimate of the resource will have to be related to the drawdown of the piezometric surface : the resource will then usually be the quantity of water that can be mobilized from the permanent reserve, taking into account technical and economical constraints, essentially related to the depth of the aquifer system, the possible yields of the wells and the drawdown of the piezometric surface.

Also, this definition is not applied in the case of springs where the resource is the mean annual discharge of the spring and is accurately known.

Last but not least, the case of alluvial aquifers with strong connections with the rivers is special as much water is obtained from the rivers and the resource is then related to river flow.

5.1.2. The potential additional resource

Actually, the idea of this study is to take into account the present groundwater abstraction policy and to estimate how much more water, if any, can still be exploited, by interpreting the basic equation

(a) resource - abstraction = additional resource

where the additional resource may be positive (surplus), negative (deficit) or zero (balance, or, also, zones without significant water availabilities) and where the abstraction represents the actual quantity of water presently exploited.

If we consider that the present trend is towards an increase in water use in general, related to the demographic increase and expansion of industrialization and agriculture, and that, consequently, groundwater abstraction will either increase or, at least, remain constant, the additional resource correctly represents the available resource.

Actually, the equation is very formal because of the large uncertainties on its terms :

. Most often, the resource is not computed accurately : the recharge depends on many factors and some of them can be thoroughly known only through very detailed studies, involving mathematical modelling for instance, and which have been very seldom performed ; furthermore, the various constraints cannot be always quantified in terms of water volumes. The resource will generally only be roughly estimated with an uncertainty difficult and sometimes impossible to quantify.

. The estimation rules for abstraction differ from Member State to Member State and even within a Member State ; abstraction figures are often underestimated, as data may be missing.

. Last but not least, abstracted water volumes are usually much more important than actually consumed water volumes, the latter varying between 1 % and 90 % of the former, depending on the type of use.

Practically, this means that the additional resource is not a computable quantity. This is the reason why we introduce the concept of potential additional resource (p.a.r.).

The potential additional resource is an estimate of the additional resource proper to each Member State. It is based on the approximation of the resource obtained from the hydrogeological assumptions and computations in use in each Member State, and from the usual application they make of the constraints. The potential additional resource is actually an order of magnitude of the additional resource of each Member State, consistent with the present policies and state of knowledge prevailing in each Member State and, of course, estimated from the basic equation (a) where the resource has the meaning given in § 5.1.1. It is subject to refinements and even significant changes as the scientific knowledge and expertise increase and also as management priorities evolve. This

In the case of springs, the potential additional resource is accurately known as the difference between the mean annual discharge and the present abstraction.

The potential additional resource is a good picture of groundwater availability at Community scale, which enables to classify the territory of the Community into five categories :

. zones with a surplus of groundwater when the potential additional resource is positive,

. zones with a balance of resource and abstraction when the potential additional resource is zero,

. zones of overdevelopment when the potential additional resource is negative,

. zones with unsignificant, local resources,

. zones without groundwater.

These categories are represented by colours on map 4.

5.1.3. Use of the potential additional resource

Practically the p.a.r. is estimated from equation (a) for each unit of the grid system, yielding the amount of water available per elementary unit and, by a combination of these elementary units, per unit of administrative decision. Furthermore, the possible disposal in a unit of more water by pumping the neighbouring units is indicated by arrows on maps 4 : these arrows give the direction of the transfer of water.

A few difficulties may arise from these definitions :

. the potential additional resource integrates all aquifers present in a unit ; in the case of superimposed aquifers, this globalization may hide exploitation problems related, for instance, to the fact that the upper aquifer, most easily exploited, is already overdeveloped while the zone presents a surplus because of the other aquifer.

. the potential additional resource characterizes a unit as a whole ; if the unit is large, the resource may well be located in some area of the unit only.

These difficulties, related to the scale of the study, can be avoided by bearing in mind that maps 4 and the corresponding tables have to be used in conjunction with maps 1 and 2, which will indicate when a zone of surplus may present exploitation problems related to the location of groundwater in the units.

It should be stressed that the p.a.r. should be used as an <u>indicator</u> for management and planning at the scale of the study : it emphasizes zones with already acute problems (overpumping) and zones with problems in a near future (balance) ;

it indicates the zones where a surplus of groundwater can be expected and where possible new developments may take place, subject then of course to a much more detailed study to specify the available amounts of groundwater and their locations.

This indicator is valid within a given Member State and it is not possible, at least for the time being, to compare the available surpluses in terms of quantities of water, because of the water management differences reflected in the present study. Even in a given Member State, the estimated surpluses are liable to variations with the water management policies, sometimes depending upon the regional water authority.

5.2. EVALUATION OF THE GROUNDWATER RESOURCE

A basis for a comparison of groundwater availabilities is obtained by examining the various elements taken into account by the Member States for their groundwater budget.

5.2.1. Hydrological and hydrogeological factors

The mean annual recharge is the mean quantity of water which infiltrates to the aquifer in a year. It is equal to the mean groundwater flow and hence to the mean interannual natural flow brought by the aquifer to the rivers. This infiltration depends on many factors like the precipitations, the lithology, the vegetation, the topography. It verifies the global balance equation, on a mean annual basis :

$$I + QS = P - ETR$$

where I is the infiltration, QS the runoff, P the precipitation and ETR the real evapotranspiration.

While P and ETR are measured or computed with reasonable and comparable accuracy in the Member States, yielding the mean interannual total flow I + QS, there is usually no intrinsic method providing I or QS. Two approaches are generally considered for the measurement of I : I, considered as the mean groundwater flow, is obtained from an evaluation of the mean low water flow (base flow) of the draining rivers and of other direct losses to the sea ; or I is taken as a given fraction of the net precipitation P - ETR , called infiltration factor or hydrogeological index, and directly estimated from lithological considerations and also from factors like geology, topography, depth to the water table, climate (winter and summer conditions). In a very few cases the infiltration is computed with good accuracy with the help of mathematical models but, in most areas, its estimation is based upon the intuition and experience of the hydrogeologists. QS is also sometimes directly measured by gauging river basins.

In France, for instance, infiltration in karstified or highly fissured limestones, where water infiltrates very easily, is taken as the part of the net precipitation reaching a "real" infiltration area obtained by removing the impervious levels (clay, for instance) from the total area and the index is simply the ratio of real infiltration area to total area. Otherwise the indices are very approximative, obtained by extrapolating many point balance studies and a few models.

In Belgium, the order of magnitude of the infiltration factor is 20-30 % while in Ireland four types of ground covers have been defined with infiltration factors of 80 % (permeable), 50 % (moderately permeable), 20 % (poorly permeable), 0 % (virtually impermeable). In Denmark, a global reduction factor is introduced, taking into account the infiltration and several constraints related to flow and quality of the groundwater.

In Italy, catchment water balance studies are performed where many data exist, which are based on the evaluation of the basin output (base river flow, direct flow to the sea, abstractions) ; analog or mathematical models can also be used ; infiltration values are then extrapolated to other formations. The orders of magnitude of the infiltration factors are : 25 - 35 % for sands, 30 - 45 % for vulcanites, 25 - 55 % for limestone.

While in the German Federal Republic, base stream flow is measured, in the United Kingdom a combination of three methods is used : as most catchments in England and Wales are gauged, run-off QS is directly measured yielding I by difference with the mean interannual total flow ; the results are double checked by an evaluation of the base stream flow ; third, the relationships between actual rainfall and actual surface flow have been studied for various catchments (about twelve) and an index derived mainly depending on the geology and which can be extrapolated to other formations ; relatively few computer models have also been derived.

In the Netherlands, the infiltration is directly estimated from the aquifer characteristics and the net precipitation, taken as the upper bound of possible replenisment of the aquifer. The situation in the Netherlands differs from the situations of other Member States because the permissible abstraction is actually determined by the constraints of the saline intrusion and the water table lowering and not by the infiltration which is usuallly much larger ; thus the accuracy on the infiltration does not play an important part.

With the exception of the areas where many data are known and catchment water balances and models can be made, the infiltration is thus known very approximately by extrapolations based on the know-how of the hydrogeologists. The net precipitation, of course, is the upper limit of infiltrations and can sometimes be used as such in estimations of resources. Mention should be made of specific recharge means like artificial recharge, river regulation schemes (in the United Kingdom) and bank infiltration ; in the Netherlands artificial infiltration through the dunes represents about 12 % of the total abstracted groundwater.

While all Member States have long and dense records of precipitations (up to the year 1727 in England and Wales, for instance), evapotranspiration is more difficult to measure. Three main approaches are used in the Community, the Penman method, the formulas of Thornthwaite and of Turc and the direct measurement :

. the Penman equation gives a daily evaluation of the evaporation from a hypothetical water surface (related to the amount of radiative energy gained by the surface), which is converted to potential evapotranspiration from various types of vegetation and then to actual evapotranspiration by applying a root constant which varies according to the vegetation type. The Penman method is used in Ireland, the Netherlands, the United Kingdom.

. the formula of Thornthwaite relates the monthly potential evapotranspiration to the monthly mean temperature, while the formula of Turc relates the annual actual evapotranspiration to the mean annual temperature of air and to the annual rainfall. These formulas are used in Belgium, France, Italy.

. the direct measurement of actual evapotranspiration is performed in lysimeters, in Denmark.

5.2.2. <u>The constraints</u>

The mean annual recharge is the renewable natural groundwater resource for the concerned aquifer. The actual (or exploitable) resource is usually much smaller because the infiltrated water cannot be pumped out totally for technical and economical reasons (except when for some time period, the reserve is pumped. In general then, natural replenishment will regularize the piezometric levels ; of course, this use of the aquifer depends on the adopted pumping policy and on the type of aquifer (confined or largely unconfined)). These constraints are of various types but can be classified in three main categories :

i) constraints related to the possible drawdown of the piezometric level :
   . necessity of maintaining a minimum river flow (B, F, I, L, UK)
   . necessity of protecting existing abstractions (B, F, I)
   . necessity of protecting the vegetation (very important in NL, important in some regions of F, B)
   . necessity of protecting the environment in general (B, D, DK, F, I, NL)
   . civil engineering problems, essentially related to soil stability and subsidence (F, I with the famous cases of Venice and the tower of Pisa, NL)
   . prevention of overdevelopment (B, F, UK)

ii) constraints related to the quality of groundwater :
   . essentially the prevention of seawater intrusion (most important in NL, I, DK, B, F, IRL, UK)
   . prevention of low quality water use (F, DK, I, UK)
   . prevention of river aquifer contamination (DK, D, F)

iii) constraints related to exploitation difficulties, technical or economical :

These difficulties come from the nature of the aquifers (hardness of the rocks, too fine sands, low yields), from their depths (sometimes increasing with the pumping), in general from the costs of wells and equipments (F, I, UK, D) ; for example, in France it is usually considered that such technical constraints will limit the abstractions to a third of the groundwater flow of most aquifers.

Between brackets, we have mentioned the Member States which most usually make use of these constraints. Usually, these constraints are not subject to specific regulations and are determined at local levels according to the existing environmental policy and general protection rules of existing abstractions.

It should be stressed that a quantitative estimate of the amounts of groundwater mobilized by the application of these constraints is generally difficult. Again the intuition and experience of the hydrogeologists will play the most important part, sometimes helped by mathematical models.

5.2.3. Evaluation of the groundwater resources in the Member States

The various components of the evaluation of groundwater resources are difficult to obtain : the infiltration is seldom accurately known ; besides, only part of this groundwater flow will usually be the available resource and many constraints will be introduced, reducing the available amount of groundwater ; furthermore it will generally be difficult to compute this reduction, the value of which may sometimes be determined with some accuracy in very specific cases. Thus two attitudes are reflected by the national reports and maps : to give resource values which integrate the possible reductions due to constraints, especially when they express a rather permanent concern in the regional water policy, or to give resource values based on the infiltration only ; in the last case, constraints are listed separately, from a purely qualitative point of view, considering that a purpose of the present study is to draw the attention of managers and planners on their existence and that only specific local studies and models will enable their correct introduction according to the water management and environmental policies.

The analysis hereafter shows that the first attitude has been adopted for Denmark, the Federal Republic of Germany, the Netherlands and some regions of Italy while the second attitude has been adopted for the other Member States.

. In Belgium, when estimated, the resources are obtained from the infiltration values. Constraints are local, usually considered more as advices than obligations, and each authorization of exploitation may take them into account : they often exist in equilibrium or overdevelopment zones, where a priority is given to a replenishment of the aquifers (to prevent subsidence, for instance). They are not included then in the figures of the present study. A special mention should be made of the Franco-Belgian Commission on carboniferous limestones which has the task of finding solutions to prevent the lowering of the piezometric levels of transfrontier aquifers.

. In Denmark, estimated everywhere, the resources are obtained from the net precipitation reduced by a factor which simultaneously accounts for the infiltration (related to various transmissivity, storage and run off constraints) and for the existing constraints in the present policies (mostly water quality conditions). Thus the figures provided in this study represent a reasonable estimation of the presently utilizable groundwater resources.

. In the Federal Republic of Germany, the resources are obtained from the infiltration values reduced by technical and economical constraints. The figures of the study represent the utilizable groundwater resources according to the present policies of the Länder. This will explain the observed differences in estimated resources for similar aquifer formations between, for instance, Belgium and Germany.

. In France, the resources are obtained from the infiltration values. The constraints are considered from a very general point of view and listed separately ; they are not introduced quantitatively in the estimates of the resources. The available resources are discussed qualitatively, from the infiltration values taken as upper limits of resources.

. In Italy, the resources are obtained from the infiltration values, reduced by existing constraints (related to groundwater quality, to exploitation difficulties, to subsidence problems, to the necessity of protecting existing rights).

. In Ireland, the resources are obtained from the infiltration values ; when it occurs, sea water intrusion is taken into account as a limiting constraint.

. In Luxemburg, the resources are obtained from the infiltration values, empirically divided by two to account for the inaccuracies of the infiltration estimates and the necessity of maintaining some stream flows.

. In the Netherlands, the resources are obtained from the infiltration values reduced by two types of constraints, respectively relating to sea water intrusion and to water table lowering, which are quantified with the help of mathematical models and regional cause-effect analysis. The figures provided in the study thus represent the utilizable groundwater resources according to the present environmental policy of the country.

. In the United Kingdom, the resources are obtained from the infiltration values. Some constraints (sea water intrusion or exploitation difficulties) are listed but not taken into account. Besides, the additional resources are estimated by subtracting the actual abstractions from the resources, which does not account for already existing licenses not fully used and the rights of which must be preserved.

For all Member States, the case of confined aquifers is complex : unless they present some outcrop area or are completely modelled, their recharge is estimated with difficulty. It is usually assumed to be zero and the resources are estimated from the volume of the aquifer, the lowering of the piezometric surface and economical constraints related to the exploitation difficulties.

5.3. SOME CONCLUSIONS

The present work shows that the quantification of the potential resources is very difficult because of the lack of field data and of regional studies. The National Reports provide an order of magnitude of the upper bounds of available groundwater volumes mostly based on infiltration estimates, sometimes weighted by constraints. For alluvial aquifers, figures are not given, considering that even geometrically small, these aquifers may yield a huge amount of water related to the flow rate and quality of the river itself. In some reports, comments help to get a more accurate local picture of the availabilities.

A quantitative comparison of resources between the Member States is thus unrealistic at the present stage of knowledge of groundwater resources. Yet the maps 4 are a useful indication of the geographical distribution of potential resources for the first stage of a development planning by displaying the five categories of the Community territory (surplus, balance, overdevelopment, local resources, no resources) in a synthetical picture related to both the aquifers and their exploitation.

The first analysis of these maps shows that although surplus zones occupy the major part of the territory, they are far from being homogeneously distributed and that extended areas are already fully developed (i.e. there is a balance between the estimated resource and abstraction) and even overdeveloped, a very rough planimetry for instance showing that overdeveloped areas occupy about 16 % of the Dutch territory and 4 % of the United Kingdom.

Chapter 6

CONCLUSION

The purposes of this study have been

. to provide community bases for an estimate of the groundwater resources of the European Community i.e. to find a common hydrogeological approach, to harmonize the concepts, to compare the scientific tools, to obtain a common expression of the scientific features.

. to provide an estimate of the groundwater resources within the frame of present national water policies, with indications of possible other developments, based upon available data up to 1979.

These aims have been achieved thanks to a community mapping supported and completed by national reports.

The study has gathered the following elements of the groundwater resource balance :

i) an inventory of the aquifers described by their geological, lithological, geometrical and geographical features, with a cartographical representation of three superimposed aquifers when necessary and indications of confinement and permeability types.

ii) a hydrogeological description of the aquifers, stressing the transmissivities and the flow directions.

iii) an estimate of the abstractions per unit area, also showing the main pumping stations pointwise, distributed over a partition of the Community space into combined administrative and hydrological units.

An estimate of the capacities of the Community to provide groundwater has then been made by dividing the Community space into areas with more or less extra available groundwater with respect to present abstraction, from an interpretation of the groundwater resource balance. In particular, elements of the groundwater balance have been tabulated, such as the net precipitation or the long term annual average recharge.

It has been noticed that the general features of most aquifers are correctly known but that many hydrogeological data are missing, especially for smaller or less exploited aquifers. The exploitation data also display a lack of accuracy, mainly due to missing records, involving a general underestimate of the abstractions.

In spite of these difficulties, the study provides the necessary elements for both a Community and a national approach to groundwater management by bringing facts together, that have been usually dispersed among various studies, and analyzing data which have sometimes been processed here for the first time.

It provides water planners and decision makers of the Community with a reference basis at two levels : at the national level, it enables each Member State to improve its knowledge of its own wealth ; at the Community level, it helps the Member States to understand the problems of the others and gives them an integrated picture of the Community potential resources.

This study confirms the fact that the Community as a whole has enough groundwater to satisfy most needs. Yet a most important result is that although globally large and renewable, the groundwater resource regionally behaves like a limited resource, even when considering the long term annual average recharge and neglecting all constraints and quality aspects : it means that regionally the groundwater balance is such that problems arise sufficiently acute to be perceived at national and even Community levels. For instance, every Member State has large areas without resources or with local resources only ; furthermore, some Member States display zones of water balance or overdevelopment (mainly in urban and industrial areas) which altogether are far from negligible.

Besides, it appears that groundwater, which is the only water resource of Denmark and Italy, is already largely tapped in most Member States with the exception of the Republic of Ireland, as illustrated by the following very rough estimates of present abstraction versus potential resources under present water policies : 60 to 70 % in Belgium, 40 % in Denmark, 25 to 50 % in France, 50 % in Italy, 3 % in Ireland, 37 % in Luxembourg, 62 % in the Netherlands, at least 25 % in the United Kingdom.

Careful management is then needed at regional, national and Community levels, integrating both hydrological and administrative and political regionalizations to optimize the decision making processes.

The processing of data and the reviewing of metrology and methods required by this study have displayed the unadequacy of the present scientific tools to obtain all necessary parameters of the groundwater balance ; particularly, our knowledge of recharge mechanisms and groundwater flow is partial. Hence, if the Community wants to correctly manage its groundwater, it should develop systematic field work combined with mathematical modelling to improve the fundamental knowledge of groundwater mechanisms and to refine the quantitative estimate of groundwater resources. At last, the processing of exploitation data has shown that, in many cases, abstractions are not known : if groundwater has to be managed like a limited resource, better adapted and better enforced licensing and return systems should be developed in most Member States.

In conclusion, it should not be forgotten that groundwater management is part of total water resources management. This study provides the necessary quantitative bases for the management of the groundwater component of the hydrologic cycle. It will be completed by a study of the quality and vulnerability aspects of Community groundwater to refine the estimate of groundwater availabilities and provide the qualitative bases for the management of the groundwater component of the hydrologic cycle.

Conclusive remark about this Community work :

Not only does the present survey have the advantage of gathering the significant data and facts concerning groundwater of the nine Member States in one comprehensive study, insuring a homogeneous presentation and providing a basis for possible comparisons, but it has been performed in such a way as to be a lesson for future Community work. Nine teams, from the private as well as the public sector, with different ways of thinking and different field experiences, have been set to work together under the leadership of the coordinator. They have been asked of course to perform a given task, defined by the coordinator, but also, from the very beginning, their active participation to conceptual aspects of the study has been required by the coordinator during several general meetings ; their responses were then analyzed by the coordinator into a common approach, yielding guidelines to the study. This method has enabled direct confrontations of ideas, methods and uses between the consultants, better understanding of each other's problems and sometimes of own problems ; above all, it has brought confidence and interest in a very difficult and new task. The adopted methodology has encouraged all participants to put much more work in the study than required by their written contracts and to consider it also as a scientific and human experience for themselves, bringing them new openings. We think that much can be learned from this experience in the handling of Community problems by scientific teams.

European Community's Atlas of Groundwater Resources

Contents:

Text

1. General survey volume*
   and survey volume for Belgium
2. General survey volume*
   and survey volume for the Federal Republic of Germany
3. General survey volume*
   and survey volume for Denmark
4. General survey volume*
   and survey volume for France
5. General survey volume*
   and survey volume for Ireland
6. General survey volume*
   and survey volume for Italy
7. General survey volume*
   and survey volume for Luxembourg
8. General survey volume*
   and survey volume for the Netherlands
9. General survey volume*
   and survey volume for the United Kingdom

* Only one general survey volume is supplied with the whole work

Maps

1. Belgium
2. Federal Republic of Germany
3. Denmark
4. France
5. Ireland
6. Italy
7. Luxembourg
8. Netherlands
9. United Kingdom