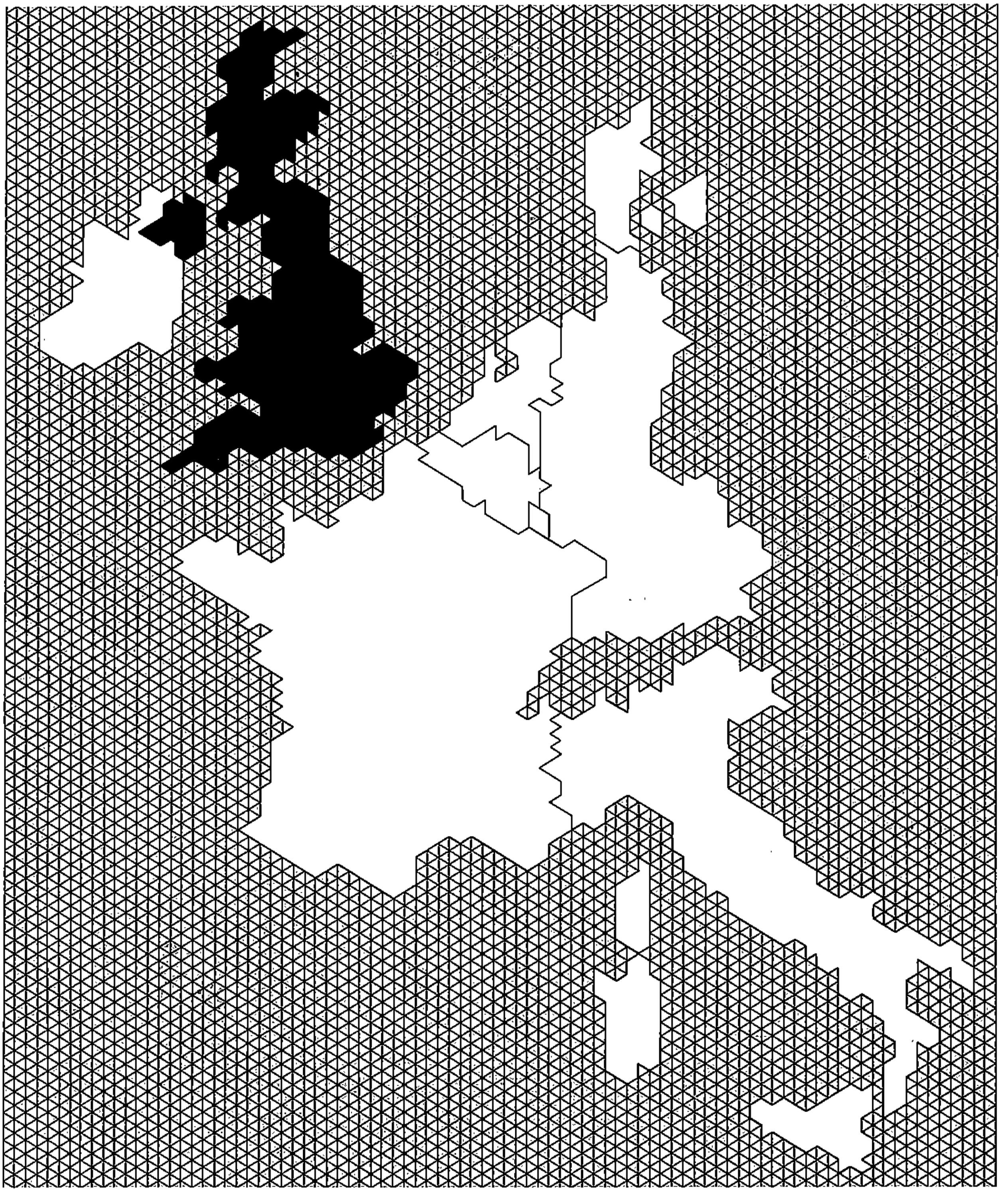
Commission of the European Communities

Groundwater Resources of the United Kingdom



Commission of the European Communities

Groundwater Resources of the United Kingdom

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

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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 (1:500000) 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.

ABSTRACT

The bulk of the report comprises sets of tables listing the groundwater resources within groundwater units of each aquifer in the United Kingdom. Data on actual abstraction in 1977 allows a balance of resources to be derived and potential additional resources to be defined. Methods currently used for the development of groundwater resources are discussed. Geology and hydrogeology of the aquifers are summarised on a set of 8 maps covering the United Kingdom on a scale of 1:500 000. Three other sets of these maps show aquifer properties and groundwater hydrology, groundwater abstractions and potential additional resources.

The report also provides a brief outline of the organisation of the water industry in the United Kingdom, a general description of aquifers, a discussion of past and present use of groundwater resources and an appraisal of the data on which the study is based.

PREFACE

This study of Groundwater Resources in the United Kingdom has been carried out by the Central Water Planning Unit at the request of the Environment and Consumer Protection Service of the European Economic Community. A contract was signed on 31 December 1977, a short interim report submitted in November 1978 and this report completes the study.

Most of the technical information is contained in the set of 32 maps and in the tables of resources in Chapter 5 of the report. We acknowledge with thanks the help received by the provision of information for these maps and tables from the water authorities in England and Wales, the Scottish Development Department, the Department of the Environment for Northern Ireland and the Institute of Geological Sciences in Edinburgh and Belfast.

Collection and collation of the information has been completed by Mr R A Monkhouse with assistance from Mr R Boots. The maps have been compiled by Mr D Bushell and the Head of the Unit's drawing office, Mr V H Williams, has provided help and guidance to the Co-ordinator of the study, Professor J J Fried of Strasbourg University. We also acknowledge the help and enthusiasm for this study of both Professor Fried and Mr M Zampetti, representing the Commission. Finally, thanks are due to Mrs J P Hodges and Miss A M Papierowski for their patience and help in typing the report.

The report has been written by Mr R A Monkhouse and Mr H J Richards, who has supervised the study.

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O GIBB
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1. INTRODUCTION AND SUMMARY OF RESOURCES

The natural resources of the European Community are fundamentally important and the Commission of European Communities has undertaken studies of these, including a series on the availability of water resources in the Community. Groundwater is particularly important to most Member States and the environmental programme of the Commission is aimed at establishing a sound data base for consideration of groundwater resources. An earlier report (Bassler and Benedini 1976) summarised both surface water and groundwater resources and touched on a number of management and other relevant topics. The study reported here is an amplified quantitative assessment of groundwater resources.

Organisation of the study

Consultants have been appointed by the Commission for each of the Member States and their work is co-ordinated by an EEC Expert Consultant, Professor J J Fried of the University of Strasbourg. Discussions towards the end of 1977 led to the signing of a contract on the last day of the year for the Central Water Planning Unit to conduct a study on the "Evaluation of groundwater resources in the United Kingdom". Before the signing of the contract between the Unit and the Commission decisions had been made to ensure that there were common methods of dealing with types of data to be used, cartographic symbols, colours on maps, scales of maps and so on. Many of these problems were already covered by international convention, but differences of scales, some symbols and definitions of resources still remained. Meetings of contractors with Professor Fried, and collectively, have enabled commonly agreed symbols and methods to be developed. As far as possible these comply with the lists published by Unesco (1970), but even these have been somewhat modified after discussion between the contractors, in order to take account of new information.

Objectives of the study

From the outset it was clear that the time scale for the study would allow only a synthesis and review of existing information and that additional field collection of data would not be possible. The study was aimed, therefore, to obtain an estimate of the available resources under existing conditions as well as to estimate the development potential, both with regard to quantities of groundwater and to areas where such additional abstraction might be undertaken.

To achieve this it was necessary to undertake an inventory of groundwater resources, after first determining the geology and hydrogeology of each aquifer, describing its geometry, type, existing abstraction patterns, overdeveloped or problem areas and, finally, the potential resources for future development.

England and Wales are divided into 10 Water Authority areas. With Scotland and Northern Ireland, the United Kingdom is, therefore, divided into 12 areas. Each of these areas are further divided into Units. As far as possible, "natural" groundwater units have been defined in consultation with the local hydrogeologist. This is straightforward when groundwater divides coincide approximately with topographic divides and most, or all, of the natural discharge is to a spring or a river. However, there are many departures from such idealised conditions and here boundaries have been determined by reference to detailed studies which have delineated units with regard to methods of resource estimation or aquifer management.

It was considered important to present a national balance of available groundwater resources in a way which would be consistent with other Member States, so that comparisons could be made if necessary. For similar reasons it was hoped that information could be matched with that provided as a result of other environmental studies being carried out by contractors for the Commission. For this reason talks were held with a team from the South Yorkshire County Council, which has undertaken a study of "Ecological Mapping" on behalf of the Commission, in order to determine whether groundwater information could be presented in such a way as to be helpful in consideration of selected ecological problems. Because the boundaries of the Units defined for the purpose of this study were difficult to match with a coarse (1 km square) grid network, it did not prove possible to adopt the grid used in the mapping study. However, all the data obtained for this survey have been stored in a common format upon computer file. It is therefore possible for further analysis of these data to be undertaken if required in the future.

A major objective was to prepare a set of maps, on a scale of 1:500 000, to summarise the hydrogeology and the groundwater resources of the United

Kingdom. The base for these maps has utilised the World Series 1404 and the boundaries of these are shown on Figure 4.2, eight sheets being required for the United Kingdom.

A set of four maps has been prepared and these are discussed in detail in Chapter 4. They summarise in turn the relevant details of:

1. Aquifer geology and geometry
2. Groundwater hydrology
3. Groundwater abstractions
4. Potential additional resources

Information sources

This study had to be based necessarily on current information and so help was sought from the water authorities in England and Wales, from the Scottish Development Department and the Northern Ireland Department of the Environment. The water authorities have supplied details or summaries of their estimations of groundwater resources, of actual quantities of groundwater abstracted and, in some cases, of unexploited reserves. These calculations form the basis of the resources details provided in Chapter 5 and of those shown on the accompanying hydrogeological maps.

The administration of water resources and supplies differs somewhat between England and Wales, Scotland and Northern Ireland but all of the authorities have been helpful in providing selected information. This study has utilised only information which has been agreed with these authorities.

Information for Scotland has been summarised on draft maps by the Hydrogeology Department of the Institute of Geological Sciences, in their Edinburgh office. Similarly the Geological Office of IGS in Belfast has prepared the information relevant to Northern Ireland. Co-operation with the Irish contractors, the Geological Survey of Ireland, has continued earlier work undertaken by these organisations in the preparation of the relevant sheets of the International Hydrogeological Map.

All of this information has been supplemented from published reports where necessary, and a list of such sources is provided in the selected bibliography.

Summary of groundwater resources

The details of the survey are contained in the tabulations of resources and abstractions for each individual Unit in Chapter 5. In some Units, insufficient data are available to calculate the resources. In these instances, the replenishment is assumed to be equal to the abstractions, although in reality there may be a surplus. A summary of groundwater resources in England and Wales, Scotland and Northern Ireland is given in Table 1.1(A to C).

The major aquifer in England and Wales is the Chalk with a mean annual replenishment in excess of 4 600 x 10^6 m^3 (Table 1.1A). The licensed abstraction is approximately 2 000 x 10^6 m^3/a, leaving a substantial surplus. However, in some areas, particularly where the outcrop is found on the southern and eastern coasts, the proportion of the surplus that is available for abstraction is reduced by the necessity of permitting a sea-ward outflow to prevent saline intrusion or of preventing the ingress of mineralised groundwater. In other areas, constraints may be imposed to maintain a groundwater contribution to rivers where the flow might otherwise fall below a desirable minimum.

In some Units where the Chalk aquifer is present, there is a deficiency, the abstraction exceeding the natural replenishment. This is particularly the case in the London Basin. In most instances, there is a contribution of groundwater by lateral flow from adjoining Units, and it is often necessary to consider Units in conjunction rather than as isolated resource areas. It should be noted that abstraction in excess of replenishment, here and in other aquifers, is an inheritance from the days of uncontrolled abstraction. Since the introduction of the licensing system, the water authorities have taken steps by reducing their own abstractions and by reviewing, and where necessary revoking, licences towards restoring the balance. In addition, artificial recharge techniques have been introduced in the London Basin, and are being investigated elsewhere.

The second most important aquifer is that of the Permo-Triassic sandstones with a mean annual replenishment approaching 1 450 x 10^6 m^3. The overall licensed abstraction is nearly 950 x 10^6 m^3/a. As with the Chalk aquifer, there are a number of constraints which reduce the amount of the balance that is available for further development. Over-pumping of the sandstones has taken place in a number of Units, notably in the north-west of England.

In some Units, where a surplus of replenishment over abstraction may be present, one part of the Unit may in fact be over-pumped, the deficiency being made good from the remainder. In consequence, it is not uncommon for consent to abstract to be refused at a particular location, even in a Unit where there may be an overall surplus.

Lesser aquifers, such as the Middle Jurassic, the Millstone Grit and the Coal Measures, do have a large annual replenishment and would appear to have a large potential resource. However, it is not often possible to develop sufficient yield at a single site to support a supply of any magnitude, and the full development of the potential of such aquifers would entail the construction of a multitude of low-yield wells with the added expense of interconnecting pipelines. The Old Red Sandstone aquifer, with a mean annual replenishment of 378 x 10^6 m^3, against a licensed abstraction of 7 x 10^6 m^3, would likewise appear to be of importance. Nevertheless, the yield of wells from this aquifer is in general so small that there is less chance of developing large resources than in the Millstone Grit or the Coal Measures.

Groundwater in Scotland has in the past been considered to have little importance compared with surface water, and in consequence there has been little development of groundwater resources.

The Old Red Sandstone appears to have the largest potential (Table 1.1B), yet its characteristics are similar to those of the same formation in England and Wales. There is little chance of developing high-yield sources in this aquifer. The Lower Carboniferous has probably the best potential for future development, although insufficient data are available at present upon which to base development proposals.

Superficial deposits with thicknesses in excess of 50 m are known in Scotland. These have not so far been the subject of extensive hydrogeological investigation, yet in the future they may prove to be aquifers of importance.

In Northern Ireland, although some 40 x 10^6 m^3 were abstracted from groundwater in 1977, there are still large reserves available for development. The Permo-Triassic sandstones in particular would seem to have considerable potential (Table 1.1C). At present, the Superficial deposits form a major aquifer, being extensive and relatively easy to develop. The possibility of pollution of these shallow aquifers is less acute over most of Northern Ireland than it is in England, and the Superficial aquifers are therefore more attractive.

Table 1.1C shows a deficiency in some parts of the Chalk aquifer. This is almost certainly unreal, but much of the replenishment to the Chalk is through the overlying Tertiary basalts, and there are few data upon which to base an assessment of recharge. The Chalk aquifer in Northern Ireland differs from that in England in that it is thinner, harder, and yields less groundwater less readily.

The mean annual replenishment of the Carboniferous Limestone exceeds $2\ 300 \times 10^6\ m^3$, and only a minute part of this is pumped. Unfortunately, this aquifer is difficult to develop for large supplies. The fissures through which the groundwater flow takes place are variable in size and relatively sparsely distributed. In consequence, the yield of a well cannot be predicted with any degree of accuracy, being likely to vary at random between nothing and $3 \times 10^6\ m^3/a$.

Table 1.1A. Summary Table of Groundwater Resources
England and Wales

AQUIFER	Mean Annual Replenishment	Licensed Abstraction (Annual)	Actual Abstraction (1977)	BALANCE OF RESOURCES			
				Licensed Quantities		Actual Abstractions (1977)	
				Surplus	Deficiency	Surplus	Deficiency
	10^6 m^3	10^6 m^3	10^6 m^3	10^6 m^3	10^6 m^3	10^6 m^3	10^6 m^3
Superficial Deposits	212.2	22.8	33.6	192.8	3.4	202.9	1.5
Crag	37.8	2.8	1.7	35.0		36.1	
Chalk	4607.6	2080.9	1255.3	2849.6	322.9	3492.9	140.6
Lower Greensand	281.7	162.7	86.2	152.9	33.9	199.2	3.7
Hastings Beds	239.0	56.6	18.6	182.4		220.4	
Spilsby Sandstone	18.9	10.9	8.3	8.0		10.6	
Corallian (Yorkshire WA only)	201.0	26.7	12.9	174.3		188.1	
Middle Jurassic	627.0	71.0	64.6	558.9	2.9	564.5	2.1
Lincolnshire Limestone	85.9	74.0	42.7	48.7	36.8	59.2	16.0
Permo-Triassic Sandstones	1442.1	948.0	586.7	743.6	249.5	914.0	58.6
Magnesian Limestone	248.4	89.3	41.2	163.8	4.7	208.6	1.4
Coal Measures	654.1	40.5	105.6	622.3	8.7	548.5	
Millstone Grit	337.0	53.0	14.1	297.4	13.4	322.9	
Carboniferous Limestone	971.0	101.6	98.1	870.5	1.0	873.0	
Old Red Sandstone (Welsh WA only)	378.5	6.7	4.6	371.8		373.9	

Notes

1. Surpluses and deficiencies occur within different units in the same aquifer. Because a deficit in one unit can not necessarily be offset by a surplus in another, they are tabulated separately.

2. A surplus of resources over actual abstractions indicates the quantity of water available to meet demands. Part of this may be committed to existing abstractions by existing licences. A surplus of resources over licensed abstractions indicates additional potential resources available for development without derogation of the rights of existing licencees.

Table 1.1B. Summary Table of Groundwater Resources
Scotland

AQUIFER	Mean Annual Replenishment	Actual Abstraction (1977)	BALANCE OF RESOURCES	
			Actual Abstractions (1977)	
	10^6 m^3	10^6 m^3	Areas of Surplus 10^6 m^3	Areas of Deficiency 10^6 m^3
Permo-Triassic Sandstones	125.0	0.0	125.0	
Upper Carboniferous	83.9	0.0	83.9	
Lower Carboniferous	402.2	0.0	402.2	
Old Red Sandstone	821.8	0.0	821.8	

Table 1.1C. Summary Table of Groundwater Resources
Northern Ireland

AQUIFER	Mean Annual Replenishment	Actual Abstraction (1977)	BALANCE OF RESOURCES	
			Actual Abstractions (1977)	
	10^6 m^3	10^6 m^3	Areas of Surplus 10^6 m^3	Areas of Deficiency 10^6 m^3
Superficial Deposits	340.6	12.7	327.9	
Chalk	16.1	7.5	8.6	
Permo-Triassic Sandstones	271.5	12.4	259.1	
Carboniferous Limestone	2390.7	8.2	2382.5	

Note 1. Surpluses and deficiencies occur within different units in the same aquifer. Because a deficit in one unit can not necessarily be offset by a surplus in another, they are tabulated separately.

2. THE WATER INDUSTRY IN THE UNITED KINGDOM

The organisation of the water industry is not the same for all parts of the United Kingdom. Scotland and Northern Ireland each have arrangements that differ from those for England and Wales.

England and Wales

In England and Wales there are ten autonomous regional water authorities based on natural hydrometric areas which are responsible for the whole hydrological cycle; water conservation, resource development, river management (including land drainage and fisheries), water supply and distribution, sewage disposal and control of pollution, and the use of water for amenity and recreational purposes. The names and boundaries of these authorities are shown in Figure 2.1.

The members of each authority comprise representatives of the local government (county and district) authorities within the area of the water authority and other members, and the chairman, appointed by the central government. The former comprise the majority and the latter are required to be persons with experience relevant to the functions of the authority, including agriculture, land drainage and fisheries.

The internal working structure of water authorities varies to some extent between one authority and another, but in general they are organised on the basis of territorial or functional divisions under the direction of a headquarters corporate management team of chief officers responsible for particular aspects such as finance, operations, resource planning and scientific services. Local government district councils however frequently act as agents of the water authority in respect of the public sewers in their area; and in some areas statutory water companies which existed before the present water authorities came into being in 1974 continue to provide the public water supply.

At national level, the National Water Council, composed of the chairmen of the ten regional water authorities and an equal number of other members and a chairman appointed by the central government, exercises a co-ordinating role and provides advice to the government on water matters, especially those relating to the government's overall responsibility for the promotion and development of a national water policy for England and Wales. The

Council also advises and assists regional water authorities on matters of common interest in the efficient performance of their functions, including the administration of a staff superannuation scheme and national negotiations on conditions of service in the industry. In addition the Council has a statutory responsibility to operate schemes for training and education in water services and for the testing and approval of water fittings in all parts of the United Kingdom.

Much of the water research for the United Kingdom as a whole is undertaken at the Water Research Centre which is funded largely by the water industry. It also undertakes external contract work including commissions from Government and overseas sources.

Scotland

National water policy in Scotland is ultimately the responsibility of the Secretary of State and is exercised through the Scottish Office. Water management activities are shared on the mainland of Scotland between regional councils and river purification boards. In the 3 islands areas, however, these functions are vested in multi-purpose authorities.

Prior to the reorganisation of local government in Scotland which occurred in May 1975, public water supply was the responsibility of 13 regional water boards and one development board (the Central Scotland Water Development Board), the latter established to develop new major sources of bulk supply for the water boards in the populous central belt of the country. These boards had been formed in 1968 from a large number of local water authorities. Sewerage and sewage disposal, on the other hand, remained the responsibility of 234 large and small local authorities.

River pollution prevention was the responsibility of 9 river purification boards set up under authority of the Rivers (Prevention of Pollution) (Scotland) Act 1951 to cover the more populated areas of the mainland of Scotland, and of 12 local authorities in the remainder of the country. The function of these boards and authorities was to preserve and improve the quality of inland and certain tidal waters in their areas by the issue and enforcement of discharge consent conditions.

In 1975 when local government in Scotland was reorganised and the local authorities were restructured to form regional, islands and district councils, public water supply, sewerage and sewage treatment amongst other functions, became the responsibility of the 9 regional and 3 islands councils, but the role of the Central Scotland Water Development Board was preserved. The boundaries of the councils are based on administrative rather than hydrological criteria.

Although the river purification boards remain outside this regional structure, the former 9 boards were reformed into 7 boards which are responsible for the whole of the mainland of Scotland. In Orkney, Shetland and the Western Isles, the islands councils themselves became the river purification authorities.

The law relating to fisheries and land drainage is also different from that in England and Wales and there is no statutory control over abstraction from inland waters by riparian owners.

The regional and islands councils and river purification boards are shown on Figure 2.1.

Northern Ireland

The Government of Northern Ireland, responsible for water conservation and pollution control under the Water Act (Northern Ireland) 1972, became the sole authority for water and sewerage services under the Water and Sewerage Services Order (Northern Ireland) 1973. The Order came into effect in October 1973. Prior to that date, 79 local authorities and joint water and sewerage boards had statutory responsibility for water and sewerage services. The water services are provided by the Department of the Environment (Northern Ireland) Water Service Divisions. A headquarters unit at Stormont, Belfast, is responsible for policy, co-ordination, finance, planning and capital programme control. The Water Service operates under a structure which has four divisions centred in Belfast (Eastern Division), Ballymena (Northern Division), Craigavon (Southern Division) and Londonderry (Western Division). Each division is sub-divided into water supply and sewerage functions. Local Water Service officers are located in most of the provincial towns.

The Northern Ireland Water Council acts in an advisory capacity to the Department of the Environment (Northern Ireland) in so far as the implementation of the terms of the Water Act (Northern Ireland) 1972 and the Water and Sewage Order (Northern Ireland) 1973 are concerned.

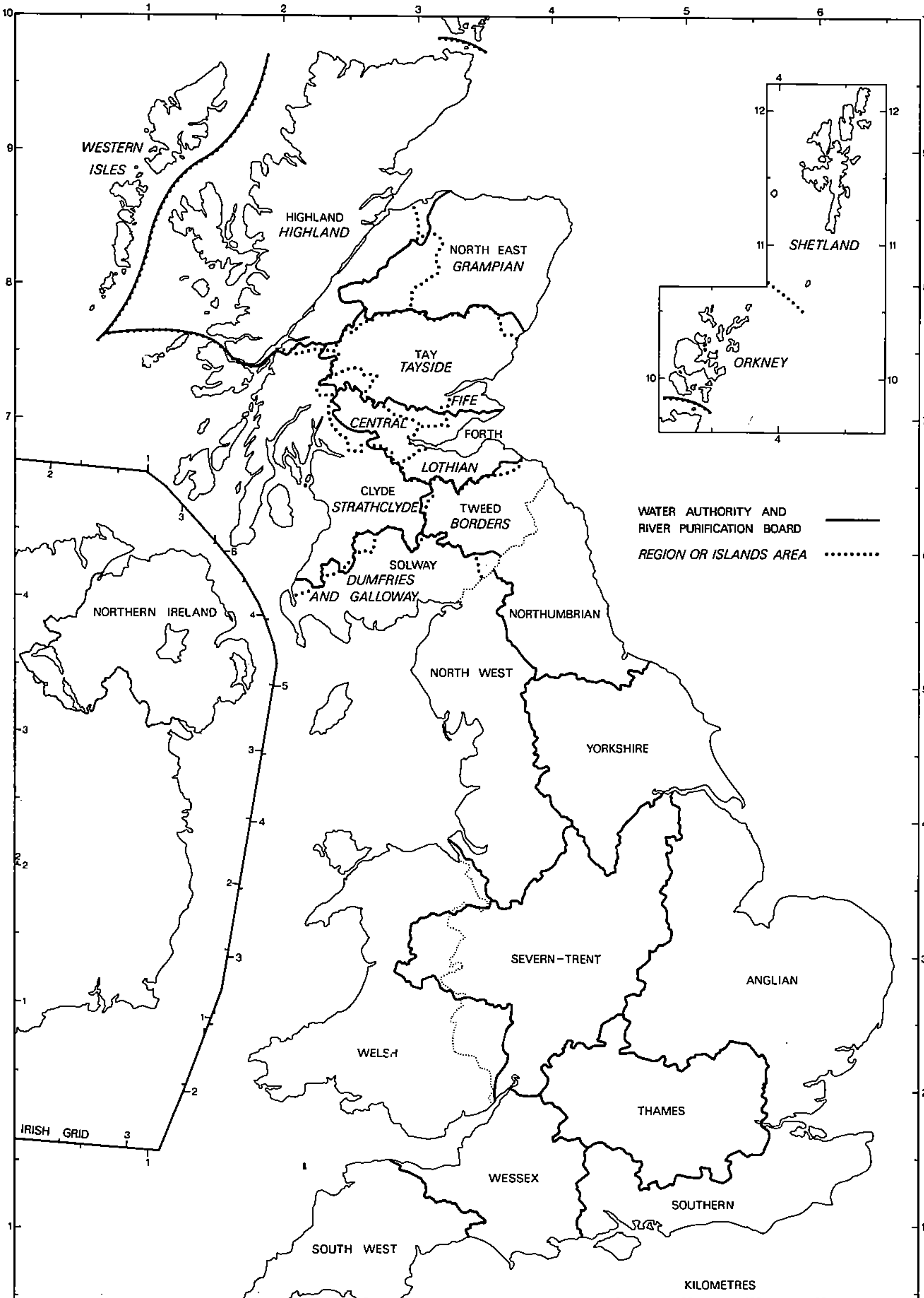

Fig. 2.1 Map showing water authority areas in England and Wales, and river purification boards and region or islands areas in Scotland.

3. AQUIFERS IN THE UNITED KINGDOM

Table 3.1 lists the strata in the United Kingdom which are normally considered as aquifers. The table shows the names used for the different aquifers in this report and also the aquifer type. The latter may be one of three categories; fissure, where the groundwater flow is predominantly through fissures, the specific yield is generally low, and the transmissivity can be high; arenaceous, where the groundwater flow is through the intergranular interstices, the specific yield is relatively high, and the transmissivity is usually low; mixed, where the flow is enhanced by fissuring, the intergranular storage and hence the specific yield is relatively high, and the transmissivity may also be high. It should be noted that, among the more ancient formations, sandstones may contain much intergranular cement and their specific yield can be greatly reduced. In these circumstances, the sandstones may behave as a fissured and not as an arenaceous aquifer.

Superficial Deposits and the Upper and Middle Pleistocene

In the United Kingdom, superficial deposits are broadly divisible into two groups, alluvial and glacial. Sands and gravels of alluvial origin tend to occur in small flood plains and in valley terraces. Pumping of groundwater from flood plain gravels normally induces recharge directly from contiguous rivers and the aquifer tends to perform as a filtration medium rather than as a groundwater storage. In England and Wales, the alluvial deposits are normally very restricted in areal extent and in thickness, and only in the valleys of the larger rivers such as the Thames and Trent do they manifest thicknesses of more than 3 m over areas of several square kilometres. The composition is generally of gravel, with greater or lesser admixtures of sand. Specific yields of 20% or greater are not uncommon and, in the coarser deposits, transmissivities can also be high.

Terrace deposits are generally of little interest to the hydrogeologist. Elevated above the local stream levels and with high inherent tranmissivities, the terrace gravels tend to drain very rapidly leaving no more than a few centimetres of saturated aquifer during much of the year.

Glacial gravels tend to occur over wide tracts of country. In East Anglia and in Shropshire the deposits are sufficiently extensive and thick to provide a useful local groundwater resource for domestic and horticultural purposes. However due to the contamination to which such shallow aquifers are especially vulnerable, they do not form the basis for any long term development. In composition, the glacial gravels resemble their alluvial counterparts, although the sand fraction may be larger and a considerable proportion of argillaceous material can be present.

In England, superficial deposits are little used for development of groundwater storage, their resources being small compared with the aquifers of greater age that are usually available in the neighbourhood. Some investigations have been carried out in the valley of the river Trent into the possibility of improving river water quality by inducing recharge through alluvial gravels. Superficial aquifers have therefore been omitted from the estimation of resources for England, although they do provide significant local supplies.

In the Welsh Water Authority area, the major portion of the strata in outcrop are shales, mudstones, slates and volcanics, all essentially impervious. Superficial deposits in this situation may form the only significant source of groundwater. During prolonged dry periods, surface streams tend to have greatly reduced flows, and groundwater becomes the only alternative source, albeit on a small scale, in the areas remote from existing mains supplies.

In Northern Ireland, aquifers in superficial deposits, mainly alluvial, support a large proportion of the developed groundwater supply.

In Scotland, there are in some areas, particularly in the Central Lowlands, thick and extensive deposits of sand and gravel. However, with a relatively high and persistent rainfall, and hence an abundance of surface water, together with the relatively low demand compared with more heavily populated and industrialised regions in England, groundwater has only a minor role and little serious investigation of the superficial deposits has been carried out. Consequently, these aquifers have been omitted from the estimate of groundwater resources for Scotland.

Much of the country north of a line drawn approximately from the Severn Estuary to the Wash, together with much of East Anglia, is covered by boulder clay. This is generally impervious and restricts infiltration to underlying aquifers. In calculating groundwater resources allowances have been made for reduced infiltration due to boulder clay cover.

Crag and Coralline Crag

These strata are found only in East Anglia. The deposits are dominantly sandy, sometimes shaley sands, and may be ferruginous. When the Tertiary strata are absent, which is the case over much of East Anglia, the Crag rests directly upon the Chalk with which it is often in hydraulic continuity. The sands are unconsolidated and in consequence boreholes must be fitted with sand screens to avoid collapse. Yields of 400 to 900 m^3/d from wells in these strata are not uncommon, and large-diameter wells (of the order of 600 mm diameter) have been known to yield as much as 2 200 m^3/d.

Eocene

The strata of interest within the Eocene are the Bagshot Beds, the Blackheath and Oldhaven Beds, the Woolwich and Reading Beds, and the Thanet Beds. These strata are confined to the London Basin and the Hampshire Basin of south-east and southern England.

The Bagshot Beds comprise current-bedded sands with thin clay bands. In the Hampshire Basin, the formation is divisible into the Bracklesham Beds above, which contain much clayey matter and so are of little importance, and the Lower Bagshot Beds below which here contain frequent clay seams. Yields from wells in the Bagshot Beds are usually small, of the order of 80 to 400 m^3/d.

The Blackheath and Oldham Beds comprise sandy and pebbly deposits, occasionally cemented to form ferruginous or calcareous sandstones. The hydrogeological properties are similar to those of the Bagshot Beds.

The Woolwich and Reading Beds contain two different facies. The Woolwich facies is dominantly sandy, the Reading facies dominantly clayey. Yields from wells are generally fairly low, although the Woolwich facies can yield upwards of 850 m^3/d.

The Thanet Beds reach a maximum thickness of the order of 30 m in East Kent near the mouth of the Thames Estuary, and in this area the formation is dominantly sandy. The thickness diminishes westwards, and the clay content of the strata increases. Westwards from London, the Thanet Beds thin out and are not found in the Hampshire Basin. Few wells are now constructed in the Thanet Beds due to the presence of the underlying Chalk which normally provides a better yield. However, Thanet wells can yield up to 1 300 m^3/d but sand screens are necessary since the sands are unconsolidated. Where the clay content increases, the yield may fall off sharply.

Chalk and Upper Greensand

The Chalk crops out from Weymouth, on the south coast west of the Isle of Wight, in a continuous band to Bridlington in North Yorkshire. The deposit is a soft, fine-grained clastic limestone. The primary, intergranular permeability of the Chalk is very small, and its value as an aquifer depends upon secondary permeability due to fissuring. The density of the fissures decreases with depth, and this leads to an effective saturated thickness of under 50 m beneath high ground inland and to a maximum of about 120 m near the coasts. Large diameter wells (up to 900 mm) in the Middle and Upper Chalk have a 50% probable yield of about 3 200 m^3/d and a 10% probable yield of about 8 000 m^3/d. The Lower Chalk contains more marls and yields are correspondingly lower. In Northern Ireland, the Chalk is present, but tends to be altered by local metamorphism connected with Tertiary volcanic activity and borehole yields are very much less than in England.

Wells in the Chalk generally do not require lining throughout. It is customary to place 5 to 15 m of lining tubes to support the well near to ground surface, and to leave the remainder unsupported.

The Upper Greensand is an incoherent, glauconitic sand, occasionally cemented to form a hard, impervious stratum (Malmstone). It is not always present beneath the Chalk, being progressively replaced laterally towards the west by the Gault Clay and thinning out northwards to be absent in Bedfordshire. Due to its usual hydraulic continuity with the Chalk, it is the normal practice to consider both to belong to the same aquifer for resource calculation. In the South West Water Authority, the Chalk outcrop is very restricted, and the Upper Greensand is the dominant facies.

The Upper Greensand is generally a poor aquifer in outcrop. However, when overlain by the Chalk, yields up to some 25 l/s can be obtained, the resources being reinforced by downward leakage from the Lower Chalk.

Locally, the grain size may be very small, approaching silt size, and yields in such localities are negligible.

Due to its generally unconsolidated nature, the Upper Greensand will not stand readily in unlined wells. Consequently, lining tubes and sand screens are necessary. Poor design of wells and inadequate development may have contributed to the poor yields frequently obtained in the past.

Lower Greensand

The Lower Greensand crops out around the margins of the Weald, in the Isle of Wight, and to the north of London in Bedfordshire and Cambridgeshire. Around the Weald, two aquifers are present, the Folkestone Beds above and the Hythe Beds below, the two being separated by the relatively impervious Sandgate Beds. The Folkestone Beds comprise typically fine and medium-grained quartzose sands, while the Hythe Beds contain layers of sandy limestone and calcareous sandstone. In the Isle of Wight and Dorset and in the outcrops north of London, the Lower Greensand is not divided into separate aquifers, being sandy throughout. For resource calculation, no division is made into separate aquifers.

Where the sandy facies are encountered north of London, up to 2 100 m^3/d may be obtained from a single well. The Hythe Beds may yield up to 300 m^3/d and exceptionally over 8 500 m^3/d, although large wells with diameters in excess of 600 mm are required. The sandy facies in the Isle of Wight and Dorsetshire tend to yield from 850 to 2 000 m^3/d. Overall, the 50% probable yield is 110 m^3/d and the 10% 4 700 m^3/d.

The sands of the Lower Greensand will rarely stand without support, and wells require lining tubes and sand screens. Many wells have failed due to inadequate provision in this respect.

Hastings Beds

The Hastings Beds again comprise two aquifers, both cropping out around the Weald. Below is the aquifer of the Ashdown Beds, mainly sands but becoming clayey approaching the south coast, and above is the Tunbridge Wells Sand, similar to the Ashdown Beds but with lenticular seams of variegated clay. The two aquifers are separated by the Wadhurst Clay, but this is frequently fissured and both yields a small supply of water and permits a hydraulic continuity between the Ashdown Beds and the

Tunbridge Wells Sand. For resource calculation, the Hastings Beds are considered as a single aquifer.

The lower part of the Ashdown Beds are probably Jurassic in age. For hydrogeological purposes, it is, however, convenient to consider them as belonging to the Lower Cretaceous.

The Tunbridge Wells Sand yields to single wells at rates of 400 to 900 m^3/d, while larger diameter wells have obtained up to 2 100 m^3/d. The sandstone of the Ashdown Beds are somewhat better, with typical yields of up to 2 100 m^3/d and exceptional yields of 4 380 m^3/d. Overall the 50% probable yield from the Hastings Beds is 860 m^3/d and the 10% is 3 000 m^3/d.

The sands of the Hastings Beds will rarely stand without support. Lining tubes and sand screens are therefore required.

Upper Jurassic

Aquifers in the Upper Jurassic are found in the Portland and Purbeck Beds and in the Corallian. In the south of England the Portland and Purbeck consists of sands and marls overlain by massive limestones. In south Lincolnshire, north of the Wash, the Portland is represented by the Spilsby Sandstone.

The Corallian aquifer in the south of England is comprised mainly of massive limestones with contiguous marls. In the north, beyond the Humber Estuary, the Corallian again consists of limestones but here more frequently interbedded with calcareous sandstones. However, between the Humber and Oxford, the Corallian is represented by clays (the Ampthill Clay).

In the south of England, yields from the Corallian typically range up to 850 m^3/d, but in Yorkshire yields up to 4 300 m^3/d have been obtained.

The limestones of the Corallian will normally stand without support. In consequence, lining is usually necessary only in the top of a well to prevent collapse near to ground surface.

In Wiltshire and Berkshire, much of the Corallian is confined beneath the Kimmeridge Clay. Within one kilometre of the outcrop, the confined groundwater is generally saline. Development of this aquifer is therefore restricted for the most part to the outcrop.

The Purbeck and Portland limestones of southern England have not been extensively exploited for groundwater and few data are available. It is probable that yields of the order of 400 to 900 m^3/d could readily be obtained.

The Spilsby Sandstone has a 50% probable yield to wells of 860 m^3/d and a 10% of 2 500 m^3/d.

Wells in the limestones of the Portland and Purbeck strata will normally stand unsupported. In the Spilsby Sandstone it is customary to use sand screens since the strata are frequently too incoherent to withstand the turbulence of pumping in a well.

Middle Jurassic

The Middle Jurassic comprises two formations, the Great Oolite above and the Inferior Oolite below. In the southern Cotswold Hills, the two formations both comprise massive oolitic limestones with subordinate calcareous marls, and are separated by the impermeable Fullers Earth Clay. Further north, this separating layer is absent, and a single aquifer is present. In Lincolnshire, north of the Wash, the Inferior Oolite limestone forms an important aquifer known as the Lincolnshire Limestone, separated from the Great Oolite by the interbedded silts, sands and clays of the Upper Estuarine Series.

For the purposes of resource calculations, the Lincolnshire Limestone is treated as a separate aquifer, and, in the areas where this formation occurs, the Great Oolite is referred to by name. Eleswhere, the Great and Inferior oolites are assessed as a single unit, the Middle Jurassic.

Wells in the Lincolnshire Limestone can yield at high rates. The 50% probable yield is 2 600 m^3/d and the 10% is 10 600 m^3/d.

Artesian flows are common, and a well at Rippingdale had a free flow on completion of 32 000 m^3/d, the largest artesian flow known in Britain. Since yields are dependent upon the intersection of suitable water-bearing fissures, wells in this aquifer are always to some degree speculative.

Wells in the limestones of the Middle Jurassic generally stand without support. However, some wells have intersected very broken rock and lining is occasionally necessary.

When the limestones of the Upper and Middle Jurassic are taken together, the 50% probable yield is 480 m^3/d and the 10% is 4 200 m^3/d. These values exclude the yields from the Lincolnshire Limestone.

Lower Jurassic

The uppermost aquifer in the Lower Jurassic is a sandy formation known variously as the Cotteswold, Bridport, Yeovil or Midford sand. This sand is in hydraulic continuity with the overlying Inferior Oolite. The deposit occurs only in the south-west of England. The sands tend to have a rather variable clay content.

Yields from these sands tend to be rather small, from 80 to 400 m^3/d being typical. Spring sources rather than wells tend to be used, and the flow of such springs is often reinforced by leakage from the overlying aquifers of the Middle Jurassic.

Wells in the Lower Jurassic sands require support and the use of sand screens is necessary.

The other aquifer present in the Lower Jurassic is the Marlstone Rock, located at the top of the Middle Lias. This is essentially a development of thin limestones in an otherwise dominantly argillaceous succession. In the Banbury area and northwards towards Northampton and in Yorkshire, the Marlstone contains valuable ironstones which are worked commercially. In these areas, groundwater often contains high concentrations of iron which may render it non-potable.

Yields from the Marlstone Rock are typically small, less than 200 m^3/d. Consequently, although of importance locally for domestic and agricultural supplies, this aquifer is not considered to be significant as a national resource.

Wells in the Marlstone Rock generally required lining tubes and sand screens. The limestone beds stand without support, but the intervening sandy layers are prone to collapse.

Permo-Triassic Sandstone

The Triassic sandstones comprises the Keuper Sandstone above and the Bunter Series below. The latter can be further sub-divided into the Upper Mottled Sandstone, the Pebble Beds, and the Lower Mottled Sandstone. In parts of northern England, the Permian strata underlying the Trias are also sandstones. Since in this situation the Permian and Triassic together form a single aquifer, resources are calculated for the one unit, collectively called the Permo-Triassic sandstones.

The strata comprise predominantly fine to medium-grained sandstones, but include pebble beds (and occasionally conglomerates), coarse sandstones, siltstones and mudstones. In some areas, mudstones may form an appreciable portion of the Keuper Sandstone.

Although arenaceous in character, with a specific yield varying from 5 to 25%, flow is commonly through fissures. Of 15 sites investigated by Lovelock (1972), the ratio of transmissivity calculated from pumping tests to inter-granular transmissivity, expressed as $^{Tt}/T_i$, ranged from 1.0 to 8 500, with only two sites registering less than 4.0. The Permo-Triassic sandstones may therefore be regarded as being of the mixed type with the specific yield of an arenaceous aquifer and the transmissivity more representative of a fissure aquifer.

Wells of 600 to 900 mm diameter in the Midlands generally yield 3 000 to 10 000 m^3/d. Yields in the Cheshire Basin and the Vale of Clwyd are generally less, ranging from 300 to 700 m^3/d. In the north of England, in the Vale of Eden and in the Carlisle Plain, the mean yield is of the order of 1 000 m^3/d, but the aquifer in this area is very much under-exploited and no serious attempts have been made to construct high-yield sources. Taken throughout the country, the 50% probable yield is 220 m^3/d and the 10% is 9 000 m^3/d.

Wells in the Permo-Triassic sandstones normally stand without support. It is customary to place 10 to 20 m of lining tubes in order to support unstable ground near the surface. However, thick superficial deposits (typically boulder clay) often overlie the aquifer and these require lining. In a few areas, even the sandstones are unstable, apparently due to a local lack of cementation.

Magnesian Limestone

The Magnesian Limestone has a fairly narrow outcrop running from Sunderland in the north to Nottingham in the Midlands of England. The rock is a compact, fissured dolomite which in some areas, such as east of Durham, may be brecciated and cavernous. The strata may be divided into the Upper, Middle and Lower Magnesian Limestones, separated by marls and siltstones. The Middle Limestone tends to be rather more porous than the Upper or the Lower, but for resource calculation the Magnesian Limestone is treated as a single aquifer.

Yields from this aquifer are dependent upon wells intersecting fissures, and this introduces an element of chance into exploitation of the groundwater. The 50% probable yield is 3 600 m^3/d and the 10% is 8 000 m^3/d.

Wells normally will stand unsupported in the Magnesian Limestone. However, the marls separating the three divisions may need support and some wells have been lined throughout.

Coal Measures

The Coal Measures comprise a succession of mudstones, clay shales, grits, sandstones and subordinate coals. Coal seams are worked mainly in the Lower and Middle Coal Measures. The Upper Coal Measures tend to contain a greater proportion of sandy strata.

Yields from wells in the Coal Measures are very variable. Generally 200 to 300 m^3/d is as much as can be expected, although yields in the Upper Coal Measures may be larger. Much groundwater is pumped as mine drainage, and rates in excess of 5 000 m^3/d are not uncommon.

Groundwater levels in the vicinity of coal mining areas are frequently depressed due to dewatering during mining operations. Water quality also tends to be seriously affected in such areas.

Although wells in the grit and sandstone beds usually need no support, it is usual to use lining tubes and occasionally sand screens are also fitted.

Millstone Grit

The Millstone Grit consists of a succession of grits and sandstones interbedded with mudstones and clay-shales. The grits and sandstones can be thick and massive. The inter-granular storage can be high, depending upon the degree of cementation in any particular location; but flow is dominantly through fissures.

Wells in the Millstone Grit commonly yield 1 200 to 1 700 m^3/d, and exceptionally up to 4 300 m^3/d. The fissuring tends to decrease with depth and flows tend to be negligible beneath a cover in excess of 200 m. Flows also tend to diminish with time since faulting often cuts off confined strata from the outcrop and thus from recharge.

It is not usual to line wells throughout in the Millstone Grit since the grits and sandstones generally stand without support.

Carboniferous Limestone

The Carboniferous Limestone Series includes a variety of sedimentary rocks, but the rock type generally associated with the series is the massive limestone, well developed in the Peak District of Derbyshire, the Mendip Hills, north and south Wales, and north-west Yorkshire. In the Craven district of Yorkshire, a predominantly shale sequence is found, but further north, in Northumberland and the Midland Valley of Scotland, the succession is more arenaceous but includes shales and thin limestones.

In general, the limestones are compact and have a low porosity. Jointing is well developed. Flow is entirely along joints and fissures and the specific yield from the body of the rock is negligible. The fissures are generally enlarged by solution, and in the areas of north-west Yorkshire, the Peak District and the Mendip Hills, the limestones are karstic.

Yields in the Carboniferous Limestone are very variable due to the necessity of intercepting suitable fissures, and the probability of failure is high. Among successful wells, the 50% probability is for a yield of 350 m^3/d and the 10% probability is for 3 000 m^3/d

Wells in the Carboniferous Limestone rarely require lining because the limestone stands without support.

Old Red Sandstone

The Old Red Sandstone crops out over large areas of central Wales and the Welsh Borderland, and also over large areas of Scotland. The lithology comprises sandstones and flaggy sandstones, often micaceous, and, particularly in Scotland, large conglomerates near the base. In the northern outcrops, the formation contains large thicknesses of volcanic rocks.

As an aquifer, the Old Red Sandstone is poor. The transmissivity rarely exceeds 1.0×10^{-3} m^2/s, and yields from individual wells are unlikely to exceed 100 m^3/d. However, it is commonly the case that no alternative source of groundwater is available, and many small-holdings and domestic requirements are supplied from this aquifer.

Wells in the Old Red Sandstone rarely require lining beyond the first few metres below ground surface.

Table 3.1. List of aquifers in the United Kingdom

Era	System	Subsystem	Aquifer names	Aquifer type	Importance
Cainozoic	Quaternary	Holocene	Superficial deposits	arenaceous	*
		Pleistocene	Upper and Middle Pleistocene	arenaceous	*
			Crag	arenaceous	**
	Tertiary	Pliocene	Coralline Crag	arenaceous	**
		Oligocene			
		Eocene	Bagshot Beds	arenaceous	*
			Blackheath & Oldhaven Beds	arenaceous	*
			Woolwich & Reading Beds	arenaceous	*
			Thanet Beds	arenaceous	**
Mesozoic	Cretaceous	Upper Cretaceous	Chalk & Upper Greensand	fissure	****
		Lower Cretaceous	Lower Greensand	arenaceous	***
			Hastings Beds	arenaceous	**
	Jurassic	Upper Jurassic	Portland & Purbeck Beds (Spilsby Sandstone)	fissure (arenaceous)	* (***)
			Corallian	fissure	**
		Middle Jurassic	Great & Inferior Oolitic Limestone	fissure	***
		Lower Jurassic (Lias)	Bridport & Yeovil Sands	arenaceous	**
			Marlstone Rock	fissure	*
	Triassic	Keuper	Permo-Triassic Sandstones	mixed	****
		Bunter			
Upper Palaeozoic	Permian				
			Magnesian Limestone	fissure	***
	Carboniferous	Upper Carboniferous	Upper Coal Measures	mixed (multilayered)	**
			Middle & Lower Coal Measures	mixed (multilayered)	*
			Millstone Grit	mixed (multilayered)	**
		Lower Carboniferous	Carboniferous Limestone	fissure	**
	Devonian	Old Red Sandstone	Old Red Sandstone	mixed or fissure	*

* Aquifer of minor importance only

** Aquifer providing useful local supplies

*** Aquifer of importance locally, often providing public supplies

**** Aquifer of major importance

4. THE MAPS ACCOMPANYING THE REPORT

Scale, sheet size and numbering

The cartographic representation of the study has been provided by the preparation of a set of four multi-coloured maps on a scale of 1:500 000 (one centimetre to five kilometres).

In order to cover the nine member states on this scale and, at the same time avoid having large, unwieldy maps, a sheet size of 95 cm x 65 cm has been adopted. In this way, coverage of the member states is achieved with 38 sheets, and 8 of these relate to the United Kingdom.

The sheet numbering is illustrated in Figure 4.1.

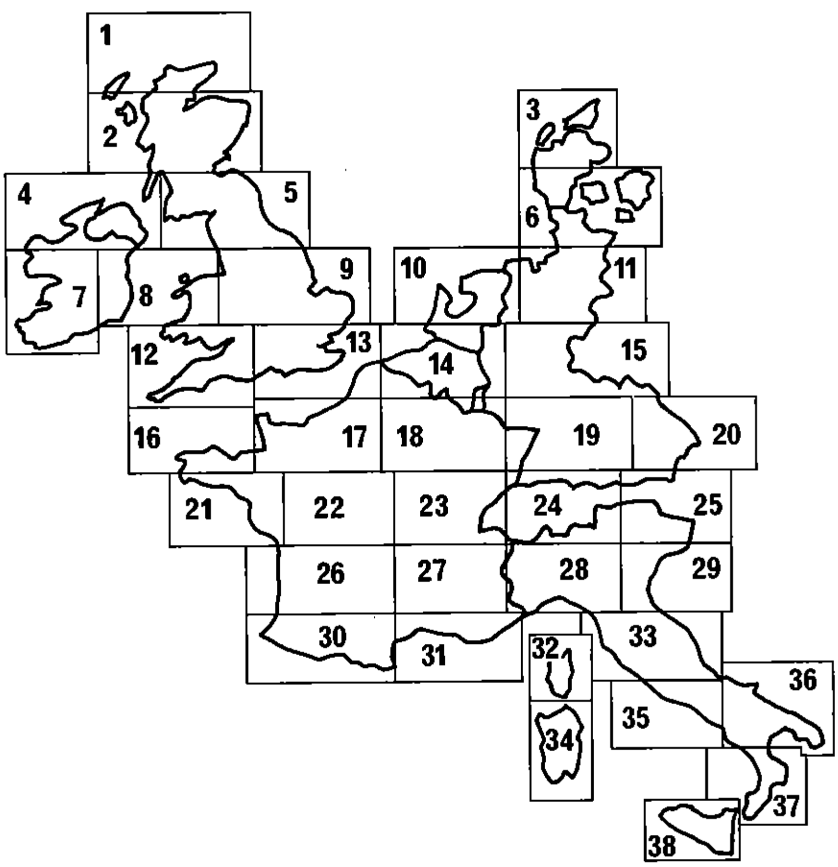

Figure 4.1 Sheet numbers

Each sheet carries a location name as well as a number and the location names of the United Kingdom sheets are shown in Figure 4.2.

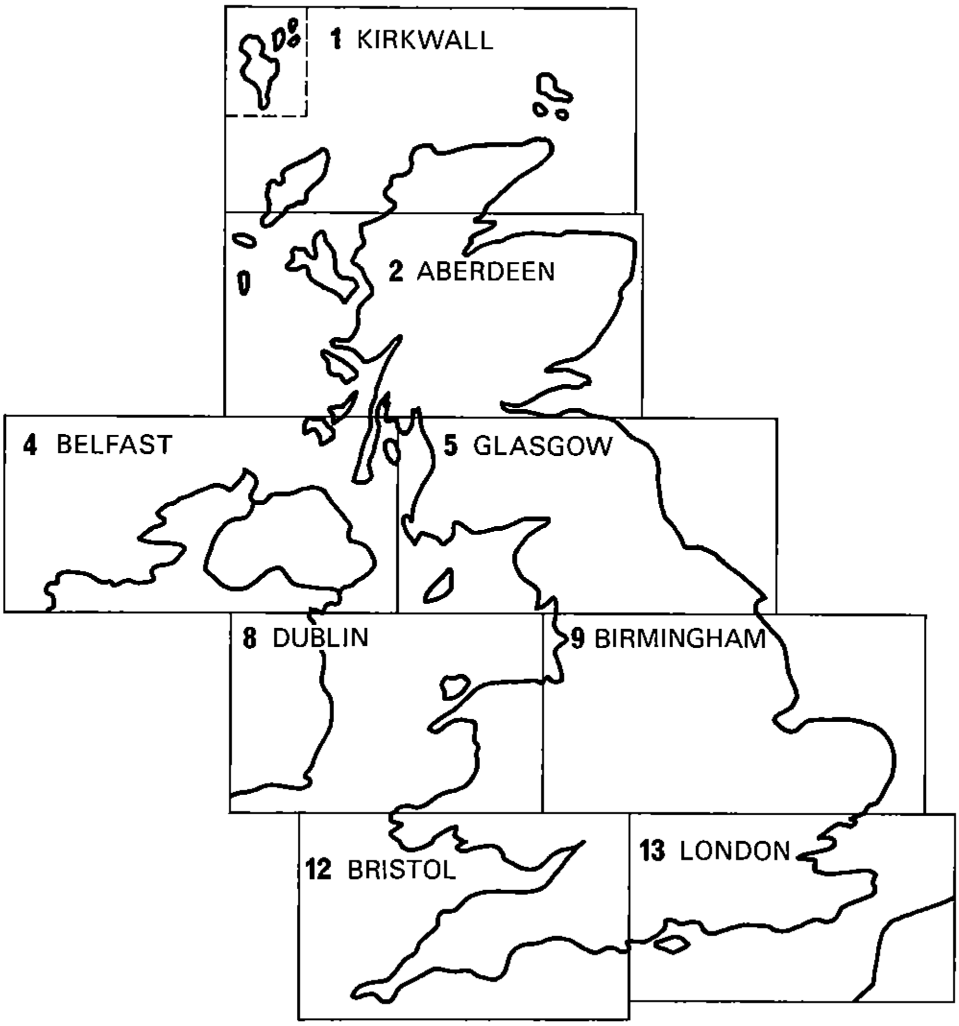

Figure 4.2 Location names and numbers of UK sheets

Descriptions

(1) Map 1: Aquifers: Showing the locations of the aquifers and defining their geometry and geology. Features are as follows:

(a) Aquifers: geometry and type

- extent of areas underlain by one or more aquifers
- areas of surface outcrop
- single and multilayered aquifers
- depth and thickness of aquifers
- poor, or complex, local aquifers of restricted extent
- confined aquifers
- unconfined aquifers

(b) Aquifers: geology and lithology

- intergranular flow
- fissure flow
- mixed aquifers
- karst areas
- alluvium
- faults
- lithology and age
- positions of aquifers in the vertical plane (illustrated by means of typical cross-sections)

(c) Other features

- relief (by contour lines)
- surface water
- groundwaters seepage areas (not shown on UK maps)
- selected urban areas
- water authority boundaries (England and Wales only)
- national grid (by reference points along the edges of the sheets)

(2) Map 2: Groundwater hydrology: Showing aquifer boundaries and movement of groundwater. Features are as follows:

(a) Groundwater movement

- piezometric surface
- fluctuations of piezometric surface
- directions of groundwater flow

- transmissivity
- movement of water between aquifers
- transfers between rivers and aquifers
- karst areas

(b) Aquifers

- aquifer boundaries
- alluvium

(c) Other features

- surface water
- selected urban areas
- areas of significant artificial recharge
- saline intrusion
- groundwater seepage areas (not shown on UK maps)
- limits of mineralized waters (not shown on UK maps)
- springs
- national grid (by reference points along the edges of the sheets)

Note: This map has been prepared on transparent material so that it can be laid over Maps 1, 3 and 4.

(3) Map 3: Groundwater abstractions: Showing sizes of abstractions; locations of wells and springs; mine drainage

(a) Abstraction rates

- groundwater units
- abstraction densities
- sizes of abstractions

(b) Springs or groups of springs

- average discharges

(c) Mine drainage

(d) Other features

- relief (by contour lines)
- surface water

- selected urban areas
- national grid (by reference points along the edges of the sheets)

(4) Map 4: Potential additional resources: Showing recharge and availability of resources. Features are as follows:

(a) Recharge

- areas with significant artificial recharge

(b) Availability of resources

- groundwater units
- probable movement of groundwater between units
- areas with surplus available
- resources fully developed
- resources over-developed
- aquifers without significant resources

(c) Other features

- relief (by contour lines)
- surface water
- selected urban areas
- national grid (by reference points along the edges of the sheets)

5. GROUNDWATER RESOURCES

This chapter contains 12 sections, dealing individually with the 10 water authority areas in England and Wales, and with Scotland and Northern Ireland. The area covered by each section is divided into Units, these being numbered both in the section and upon the maps accompanying this report (see Chapter 4). The resources of the individual Units, omitting those containing no groundwater resources, are given in a series of accompanying tables. These show for each aquifer within each Unit mean annual rainfall, evaporation and infiltration, details of existing abstractions and computed water balances.

The infiltration in each Unit is a mean annual value estimated by the authority concerned. Allowances have been made for drift cover which may reduce infiltration. Rainfall, evaporation and infiltration are all expressed in millimetres (mm). The outcrop area of each aquifer within each Unit is expressed in square kilometres (km^2). The mean annual replenishment of each Unit is then calculated by multiplying the outcrop area by the mean annual infiltration. Because the groundwater storage within aquifers is very large, the effect of a greater or lesser replenishment in any year can usually be disregarded and the meaningful figure is the average annual recharge.

In England and Wales, all significant groundwater abstractions are controlled by a statutory licensing and charging scheme operated by the Water Authorities. Licences may specify the maximum permitted abstraction annually, seasonally or daily. Exemptions from the licensing system are abstractions for purely domestic use, for agricultural requirements other than spray irrigation, for mine drainage and for Crown properties. In addition, certain specified areas containing no significant groundwater resources have been exempted from licensing requirements. In the tabulations, the annual licensed abstraction and the actual abstraction in 1977, for which totals were provided by the authorities, are shown in millions of cubic metres per annum (10^6 m^3/a). In Scotland and Northern Ireland there is no equivalent licensing system and the tabulations show only the actual abstractions in 1977, although for Scotland the abstraction figures are uncertain, albeit very small, and have been omitted.

The balance of resources in 1977 is shown as the difference between the calculated annual replenishment and the actual abstraction in that year. Where an annual replenishment value has not been estimated, because some or all of the necessary parameters were not available, then the replenishment is assumed to be equal to the abstraction. In reality, there is generally some surplus in such cases.

A positive balance of resources over present use indicates that resources are available to meet growth in demand but this does not mean that the quantity so estimated is necessarily available for development and use by other abstractors. In Scotland and Northern Ireland, where no licensing system exists, existing abstractors will probably have developed boreholes and installed plant with a capacity exceeding the actual abstraction in 1977. These abstractors will assume a common law right to abstract the full quantity for which plant has been provided. In England and Wales the licensed abstractions are in effect a commitment of resources. The Water Authorities are required by the Water Act 1963 not to license new abstractions which might derogate from the rights of existing licence holders. Thus in principle they should not license abstractions in excess of the total available resources. Additional resources are available for development only if there is a uncommitted surplus of resources over existing licensed quantities, and other constraints, such as the effect on stream flows or the control of groundwater quality, do not preclude further development. In the period leading up to full utilisation the licensed abstractions will always exceed the actual abstractions.

In the tabulations for some Units it will be noted that the licensed abstractions already exceed the natural recharge even though there may be a balance of resources over actual abstractions in 1977. This over-commitment of resources resulted, in most cases, from the automatic granting of licences of right to existing abstractors at the time that the licensing system was introduced. Rectification of this situation, or re-allocation of resources, can only be achieved by the cancellation of some existing licences and this would entail payment of compensation by the Water Authority to the existing licensee for his loss or rights. The Water Authorities are already taking steps to restore the balance in these areas of over-abstraction by reducing their own abstractions and by reviewing, and revoking, licences where necessary.

5.1 Scotland

General Features

Scotland occupies 77 246 km^2 of the north of the United Kingdom (Fig 2.1). Orographically, it may be divided into three parts. The most northerly is generally referred to as the Northern Highlands (Fig 5.1.1), an area of rugged, heather-covered hills among which are the highest peaks in the British Isles, Ben Nevis (1343 m) and Ben Muich Dhui (1309 m). This area is floored largely by strata of Pre-Cambrian age with outcrops of Old Red Sandstone around the Moray Firth, and a few small outcrops of Mesozoic strata. Intrusive and volcanic rocks of various ages up to the Tertiary are common, notably in the Inner Hebrides.

The second division is known as the Central Lowlands (or the Midland Valley), comprising the area between the Highland Boundary Fault and the Southern Uplands Fault. This region is floored mainly by strata of Palaeozoic age, the higher parts reaching altitudes of 600 m and more above sea-level in the Lennox and Ochill hills.

The third division is known as the Southern Uplands, comprising an undulating landscape, less rugged than the Northern Highlands. The higher peaks are Merrick (840 m), Hartfell (808 m) and Broad Law (840 m). This area is floored for the most part by Lower Palaeozoic rocks. Intrusive rocks are common, ranging from numerous dykes and sills to large granitic bodies. Considerable thicknesses of extrusive strata are developed in the area close to the English border.

In addition to the mainland, there are numerous islands, almost all being off the western and northern coasts.

There are many rivers draining the country, but none are of any great length. The longest are the rivers Clyde draining to the west, and the Tweed, Tay and Spey, draining to the east coast. Due to the large areas of impervious strata and the heavy rainfall, the variation in flow in the Scottish rivers tends to be very great.

The population in 1974 was of the order of 5.2 million. The principal towns include Edinburgh (the capital city; population 475 000), Glasgow (856 000), Aberdeen (212 000), Dundee (194 000), Inverness (35 000) and Thurso (10 000).

Industry is largely confined to the Central Lowlands. Extensive coal mining once took place in this region, but deep mine operations at the present day are much reduced. Opencast mining now supplies a large proportion of Scottish coal. Agriculture is widespread in the Central Lowlands and the Southern Uplands, but in the Northern Highlands the land is mainly given over to deer forest and open moorland although many sheep also graze there.

Aquifers

The Old Red Sandstone of the Northern Highlands (including the islands of Orkney and Shetland) outcrops on the east coast, and is over 4 000 m thick. It comprises for the most part sandstones and flaggy sandstones. In the Central Lowlands, the maximum thickness is about the same, but the succession contains volcanic rocks, and the sandstones are less flaggy. Conglomerates are common, particularly near to the base. In the Southern Uplands, the total thickness is uncertain, but it is estimated that some 400 m of volcanics are present within a sequence of sandstones, marls and breccias with conglomerates at the lower horizons.

Transmissivity has been determined at 5 sites in the Old Red Sandstone. The mean value was 6.6×10^{-4} m^2/s. There is no significant variation between Units. The specific yield has a mean value of about 1×10^{-2}.

The Lower Carboniferous contains a number of different rock types, varying from limestone to calciferous sandstone to shale and mudstone with coal. The maximum thickness is about 1 500 m in the Central Lowlands and about 2 000 m in the country adjacent to the English border. However, the thickness varies considerably from one locality to another. The transmissivity has been determined at one site in Unit 8, where a value of 5.0×10^{-4} m^2/s was obtained, and values are probably low throughout the aquifer. No useful data on the specific yield is available.

The Upper Carboniferous comprises a succession of sandstones, marl, shales and sandstones with coals. In the Central Lowlands, the maximum thickness is of the order of 900 m, and in the Southern Uplands it reaches a total of 1 300 m in the Canonbie area although poorly developed elsewhere.

The Permo-Triassic sandstones comprise aeolian and water-lain deposits. The maximum thickness of about 1 000 m is attained in fault-bounded troughs at Stranraer, Dumfries and Lochmaben together with thinner accumulations on the Solway coast, in Ayrshire and on the Isle of Arran. Transmissivities are in the range 0.1 to 1.0 x 10^{-2} m^2/s, but are locally variable depending on facies development, fissure frequency and the development of minor igneous intrusions.

Resources

Although groundwater in Scotland is considered to be of limited importance due to the abundance of surface sources supported by relatively persistent, heavy rainfall, valuable yields may be obtained where a suitable aquifer coincides with an area of low rainfall or where surface supplies may be difficult to develop. Superficial deposits are widespread, comprising mainly boulder clay and peat in upland areas and mixed fluvio-glacial and raised-beach deposits in low-lying and coastal areas. These are locally exploited for groundwater but are often neglected due to the availability of a mains supply. The resources for the aquifers for which data are available are given in Tables 5.1.1 and 5.1.24. However, there are several Units in which potential aquifers are present, but for which no information exists, and those Units are considered for the purpose of this report to have no aquifers and are omitted from the tables.

There is also no licensing system such as that in force in England and Wales. Consequently, there is very little information available on the yields of wells and it has not been possible to estimate present abstraction for the purposes of Tables 5.1.1 to 5.1.24. There is scope for considerable investigation in this area.

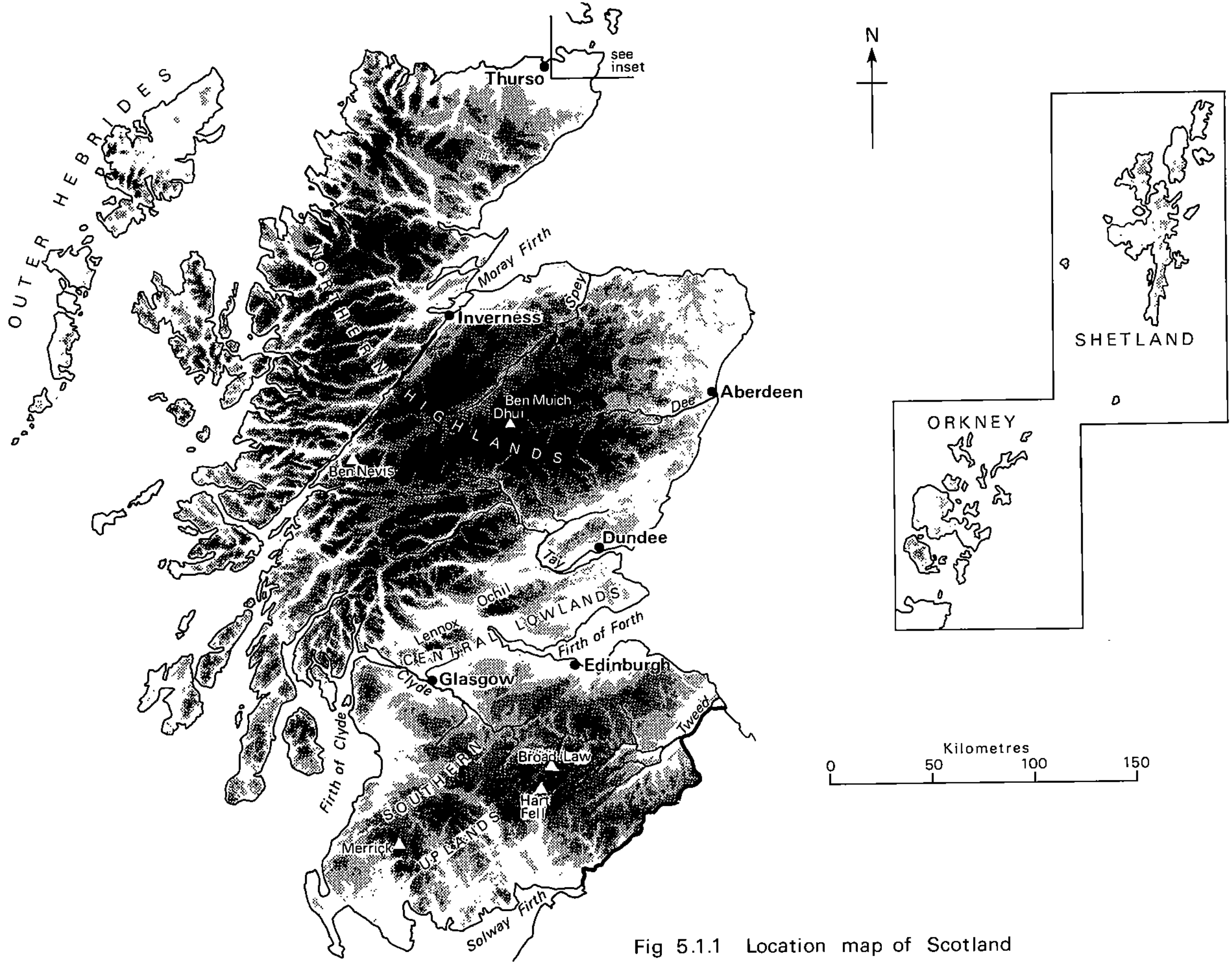

Fig 5.1.1 Location map of Scotland

Table 5.1.1. Groundwater resources for Unit 1 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Old Red Sandstone	1440	790	355	75	0.0	0.0	108.0

Table 5.1.2. Abstraction of groundwater and balance of resources for Unit 1 of Scotland (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Old Red Sandstone	0.0	0.0	60.4

Table 5.1.3. Groundwater resources for Unit 2 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Old Red Sandstone	2179	800	355	90	0.0	0.0	196.1

Table 5.1.4. Abstraction of groundwater and balance of resources for Unit 2 of Scotland (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Old Red Sandstone	0.0	0.0	14.7

Table 5.1.5. Groundwater resources for Unit 8 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Old Red Sandstone	3866	901	380	93	0.0	0.0	356.9
Upper Carboniferous	64	750	450	100	0.0	0.0	6.4
Lower Carboniferous	2661	901	422	120	0.0	0.0	319.3
Total					0.0	0.0	682.6

Table 5.1.6. Abstraction of groundwater and balance of resources for Unit 8 of Scotland (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Old Red Sandstone	0.0	0.0	40.7
Upper Carboniferous	0.0	0.0	0.7
Lower Carboniferous	0.0	0.0	36.4
Total	0.0	0.0	77.8

Table 5.1.7. Groundwater resources for Unit 11 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Old Red Sandstone	918	750	380	75	0.0	0.0	68.9
Lower Carboniferous	261	700	400	120	0.0	0.0	31.3
Total					0.0	0.0	100.2

Table 5.1.8. Abstraction of groundwater and balance of resources for Unit 11 of Scotland (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Old Red Sandstone	0.0	0.0	15.1
Lower Carboniferous	0.0	0.0	6.9
Total	0.0	0.0	22.0

Table 5.1.9. Groundwater resources for Unit 12 of Scotland

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	$10^6\ m^3$	$10^6\ m^3$	$10^6\ m^3$
Lower Carboniferous	516	1200	380	100	0.0	0.0	51.6
Permo-Triassic sandstones	157	1000	420	150	0.0	0.0	23.5
Total					0.0	0.0	75.1

Table 5.1.10. Abstraction of groundwater and balance of resources for Unit 12 of Scotland (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Lower Carboniferous	0.0	0.0	51.7
Permo-Triassic sandstones	0.0	0.0	23.5
Total	0.0	0.0	75.2

Table 5.1.11. Groundwater resources for Unit 13 of Scotland

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	$10^6\ m^3$	$10^6\ m^3$	$10^6\ m^3$
Permo-Triassic sandstones	121	1175	400	150	0.0	0.0	16.6

Table 5.1.12. Abstraction of groundwater and balance of resources for Unit 13 of Scotland (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	0.0	0.0	17.3

Table 5.1.13. Groundwater resources for Unit 14 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Upper Carboniferous	51	1400	380	120	0.0	0.0	6.1
Permo-Triassic sandstones	265	1126	431	150	0.0	0.0	36.8
Total					0.0	0.0	42.9

Table 5.1.14. Abstraction of groundwater and balance of resources for Unit 14 of Scotland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Upper Carboniferous	0.0	0.0	4.1
Permo-Triassic sandstones	0.0	0.0	24.9
Total	0.0	0.0	29.0

Table 5.1.15. Groundwater resources for Unit 16 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	93	1050	450	150	0.0	0.0	13.9

Table 5.1.16. Abstraction of groundwater and balance of resources for Unit 16 of Scotland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	0.0	0.0	6.8

Table 5.1.17. Groundwater resources for Unit 18 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Old Red Sandstone	163	1200	420	100	0.0	0.0	16.3
Upper Carboniferous	595	1200	470	120	0.0	0.0	71.4
Permo-Triassic sandstones	46	1050	450	150	0.0	0.0	6.9
Total					0.0	0.0	94.6

Table 5.1.18. Abstraction of groundwater and balance of resources for Unit 18 of Scotland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Old Red Sandstone	0.0	0.0	6.9
Upper Carboniferous	0.0	0.0	30.0
Permo-Triassic sandstones	0.0	0.0	2.9
Total	0.0	0.0	39.8

Table 5.1.19. Groundwater resources for Unit 30 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	182	1600	450	150	0.0	0.0	27.3

Table 5.1.20. Abstraction of groundwater and balance of resources for Unit 30 of Scotland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	0.0	0.0	12.6

Table 5.1.21. Groundwater resources for Unit 33 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Old Red Sandstone	880	1020	355	75	0.0	0.0	65.6

Table 5.1.22. Abstraction of groundwater and balance of resources for Unit 33 of Scotland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Old Red Sandstone	0.0	0.0	74.5

Table 5.1.23. Groundwater resources for Unit 34 of Scotland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Old Red Sandstone	135	1100	355	75	0.0	0.0	10.0

Table 5.1.24. Abstraction of groundwater and balance of resources for Unit 34 of Scotland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Old Red Sandstone	0.0	0.0	7.8

Table 5.1.25. Areas of Units in Scotland (km^2)

Unit	Area	Unit	Area
1	1789	18	2377
2	13330	19	814
3	1545	20	720
4	1414	21	808
5	1336	22	1390
6	2117	23	1177
7	2027	24	1327
8	8771	25	1153
9	5081	26	1679
10	976	27	1061
11	4549	28	2196
12	998	29	1958
13	960	30	2163
14	1480	31	2508
15	1526	32	2733
16	2046	33	880
17	1078	34	1279

5.2. Northern Ireland

General Features

Northern Ireland comprises a land area of 14 194 km^2. Bounded by the sea to the north and the east, it is bordered to the west and south by the Republic of Ireland (Eire).

The country is dominated by the low lying valley of the river Bann and the large lake of Lough Neagh (Figure 5.2.1.). This area is less than 75 m above sea-level. To the west, there is higher ground dominated by the Sperrin Mountains rising to 680 m in the peak of Sawel Mountain. To the east lies a range of coastal high lands, rising to 550 m in the peak of Trostan. In the extreme south-east are the highest hills in Northern Ireland, the Mourne Mountains, the highest peak being Slieve Donard at 852 m above sea-level. The country is drained by numerous rivers, the longest of which are the rivers Bann and Foyle. The population in 1974 was of the order of 1.5 million. The principal towns are Belfast (population 363 000) and Londonderry (51 000).

Industrial areas are mainly concentrated around Belfast and Londonderry, the remainder of the country being almost wholly agricultural.

The geological formations present in Northern Ireland range from the Pre-Cambrian to the Recent. The geology is, however, dominated by the Tertiary basalts covering the country from Belfast to the north coast at Lough Foyle. Most of the Cretaceous (Chalk and Greensand) rocks lie under this basaltic layer with outcrops restricted to narrow bands at the margins. Permo-Triassic sandstones outcrop near Belfast in the valley of the river Lagan and in an interrupted belt from Armagh, south-west of Loch Neagh, to the coast near Limavady. Elsewhere, the strata can be divided into two areas, the Pre-Cambrian rocks of the Londonderry region as far south as the Sperrin Mountains, and the Devonian and Carboniferous which lie between the Sperrin Mountains and the border with the Irish Republic to the south.

Aquifers

The Carboniferous Limestone Series reaches a maximum thickness of 2 000 m to the east of Lough Erne. The middle part of the succession contains some sandstone and argillaceous limestone, but in the upper and lower parts the limestone is generally massive. Groundwater flow is through fissures and these may be large although distributed relatively sparsely through the aquifer. No data are available concerning aquifer properties.

The aquifer formed of the Permo-Triassic sandstones attains a maximum thickness of 600 to 700 m, but is generally less than 450 m thick. The basal rocks are often breccias (known as "brockrams"), but the remainder of the succession comprises sandstones with frequent clay partings. The transmissivity has been determined at 8 sites, and a mean value of 1.5×10^{-3} m^2/s was obtained (Figure 5.2.2.), the values ranging from 3.5×10^{-4} m^2/s to 6.0×10^{-3} m^2/s. The mean coefficient of storage is 4.3×10^{-4}.

The Chalk differs from that of England by being much harder and less pervious. The outcrop areas are small, the aquifer being largely overlain by basaltic rocks of Tertiary age. Most of the recharge is by leakage from fissures in these basalts, and this has yet to be assessed. The transmissivity was determined at a single site in Unit 5 where a value of 4.2×10^{-3} m^2/s was obtained, but it is uncertain whether this is representative of the Chalk as a whole. The coefficient of storage was not determined.

In Northern Ireland, superficial deposits form useful aquifers. They comprise sands and gravels, usually of glacial origin although some are of fluvial origin. Thicknesses are generally small, the mean being less than 10 m.

The transmissivity has been determined at 10 sites, and a mean value of 1.9×10^{-2} m^2/s was obtained, with values ranging from 7.5×10^{-4} m^2/s to 5.5×10^{-2} m^2/s. The mean value for the specific yield was 5.2×10^{-2}.

There are other potential aquifers in Northern Ireland, for example, the Old Red Sandstone, the Carboniferous sandstones, the Hibernian Greensand and the Tertiary basalts. However, there are no data at present available upon which to base a useful assessment of resources and they have, therefore, been omitted.

<u>Resources</u>

Yields of wells in the Carboniferous Limestone average about 0.4×10^{6}

m^3/a, and the maximum recorded in 1977 was 1.3 x 10^6 m^3. Occasionally, wells fail to provide a significant yield due to failure to intersect suitable fissures.

Wells in the Permo-Triassic sandstones aquifer usually yield between 0.4 and 0.7 x 10^6 m^3/a. The largest abstraction in 1977 was 1.9 x 10^6 m^3.

In the Chalk, the greatest abstraction during 1977 was 1.8 x 10^6 m^3, but the mean was nearer 0.4 x 10^6 m^3. The larger yields are much less than in the Chalk of England and this is mainly due to the greater degree of induration.

Yields in the Superficial Deposits aquifer are very variable. The largest recorded in 1977 is of the order of 1.6 x 10^6 m^3. However, the safe yield is dependent more upon the resources available in a given location rather than in the ability of the well to be pumped at high rates. In the more extensive outcrops, yields of 0.6 to 0.8 x 10^6 m^3/a can be obtained, while the smaller outcrops may only support an abstraction of 0.1 x 10^6 m^3/a or less.

Wells in the Superficial Deposits aquifer require sand screens and full lining, since the deposits are unconsolidated and require support. In the other aquifers, the strata will stand without support, and lining tubes are usually necessary only through overlying drift deposits and in the uppermost few metres of the aquifer. Details of the resources in the individual Units are shown in Tables 5.2.3. to 5.2.14. There are no groundwater resources in Unit 7, which has, therefore, been omitted. The outcrop area of the Chalk is very limited and most of the natural recharge comes from leakage through the overlying basalts. This has not yet been accurately assessed, but for the purposes of calculating resources it is assumed that the resources equal the abstraction so that the balance shown in the Tables will be zero. In reality, there is probably a surplus in these instances.

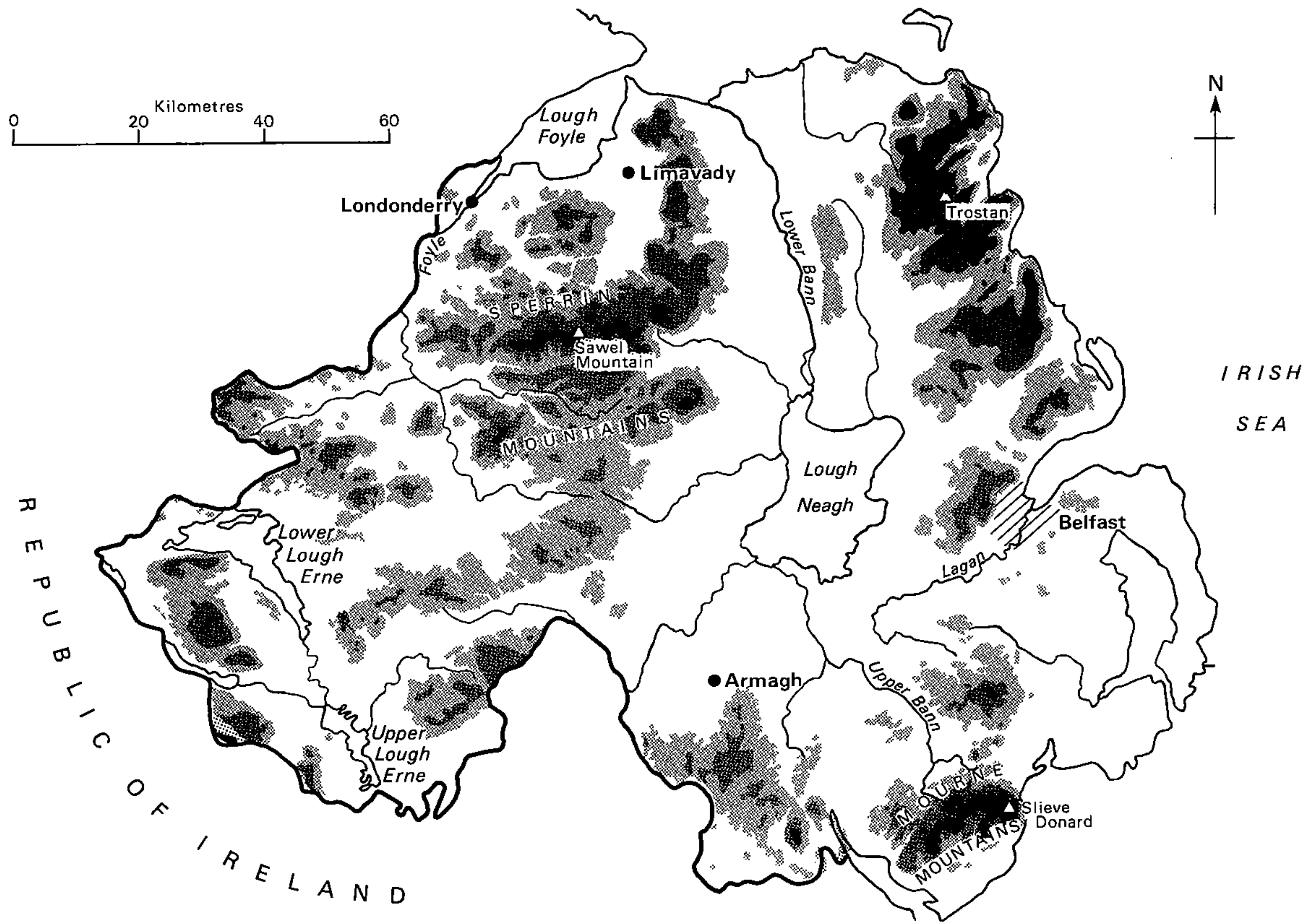

Fig. 5.2.1 Location map of Northern Ireland

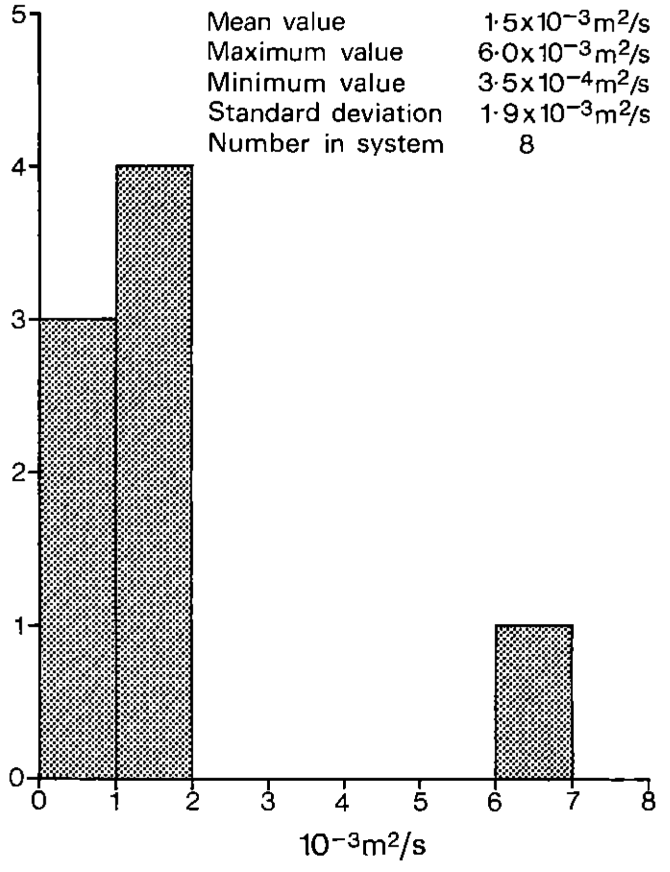

Fig: 5.2.2. Transmissivities of the Permo-Triassic sandstones aquifer in Northern Ireland (m^2/s)

Table 5.2.1. Transmissivities in the Permo-Triassic sandstones aquifer in Northern Ireland (m^2/s)

Unit	Number of determinations	Mean	Minimum	Maximum	Mean as % of overall mean
3	1	1.2×10^{-3}	-	-	80
6	7	1.6×10^{-3}	3.5×10^{-4}	6.0×10^{-3}	107
All Units	8	1.5×10^{-3}	3.5×10^{-4}	6.0×10^{-3}	100

<u>Table 5.2.2.</u> Transmissivities in the Superficial aquifer in Northern Ireland (m^2/s)

Unit	Number of determinations	Mean	Minimum	Maximum	Mean as % of overall mean
1	1	2.5×10^{-2}	-	-	130
2	1	4.1×10^{-3}	-	-	22
3	1	7.5×10^{-4}	-	-	4
4	6	2.6×10^{-2}	2.1×10^{-3}	5.5×10^{-2}	140
6	1	5.6×10^{-3}	-	-	29
All Units	10	1.9×10^{-2}	7.5×10^{-4}	5.5×10^{-2}	100

Table 5.2.3. Groundwater resources for Unit 1 of Northern Ireland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Superficial	29	1300	388	365	0.0	1.0	9.7
Carboniferous Limestone	1514	1300	388	912	0.0	1.8	1379.0
Total					0.0	2.8	1388.7

Table 5.2.4. Abstraction of groundwater and balance of resources for Unit 1 of Northern Ireland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Superficial	0.0	0.5	4.9
Carboniferous Limestone	0.0	0.9	703.3
Total	0.0	1.4	708.2

Table 5.2.5. Groundwater resources for Unit 2 of Northern Ireland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Superficial	460	1145	389	302	0.0	0.0	138.8
Chalk	0	1145	389	0	0.0	0.2	0.0
Carboniferous Limestone	283	1145	389	912	0.0	0.0	258.1
Total					0.0	0.2	396.9

Table 5.2.6. Abstraction of groundwater and balance of resources for Unit 2 of Northern Ireland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Superficial	0.0	0.0	67.9
Chalk	0.0	0.1	0.0
Carboniferous Limestone	0.0	0.0	126.3
Total	0.0	0.1	194.2

Table 5.2.7. Groundwater resources for Unit 3 of Northern Ireland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Superficial	137	1100	435	266	0.0	1.6	34.9
Chalk	0	1100	435	0	0.0	1.1	0.0
Permo-Triassic sandstones	45	1100	435	598	0.0	1.1	25.8
Carboniferous Limestone	161	1100	435	665	0.0	0.0	107.1
Total					0.0	3.8	167.8

Table 5.2.8. Abstraction of groundwater and balance of resources for Unit 3 of Northern Ireland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Superficial	0.0	1.7	37.5
Chalk	0.0	1.2	0.0
Permo-Triassic sandstones	0.0	1.2	27.7
Carboniferous Limestone	0.0	0.0	115.1
Total	0.0	4.1	180.3

Table 5.2.9. Groundwater resources for Unit 4 of Northern Ireland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Superficial	484	1170	409	304	0.0	8.8	138.2
Chalk	0	1170	409	0	0.0	0.6	0.0
Permo-Triassic sandstones	223	1170	409	685	0.0	0.2	152.6
Carboniferous Limestone	847	1170	409	761	0.0	6.4	638.3
Total					0.0	16.0	929.1

Table 5.2.10. Abstraction of groundwater and balance of resources for Unit 4 of Northern Ireland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Superficial	0.0	1.6	25.2
Chalk	0.0	0.1	0.0
Permo-Triassic sandstone	0.0	0.0	27.9
Carboniferous Limestone	0.0	1.2	116.5
Total	0.0	2.9	169.6

Table 5.2.11. Groundwater resources for Unit 5 of Northern Ireland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	21	1240	413	579	0.0	3.6	8.6
Permo-Triassic sandstones	5	1240	423	744	0.0	0.0	3.7
Total					0.0	3.6	12.3

Table 5.2.12. Abstraction of groundwater and balance of resources for Unit 5 of Northern Ireland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	0.0	4.1	9.7
Permo-Triassic sandstones	0.0	0.0	4.2
Total	0.0	4.1	13.9

Table 5.2.13. Groundwater resources for Unit 6 of Northern Ireland

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Superficial	36	970	446	210	0.0	1.3	6.3
Chalk	5	970	446	367	0.0	2.0	0.0
Permo-Triassic sandstones	187	970	446	472	0.0	11.1	77.0
Total					0.0	14.4	83.3

Table 5.2.14. Abstraction of groundwater and balance of resources for Unit 6 of Northern Ireland (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Superficial	0.0	0.7	3.4
Chalk	0.0	1.1	0.0
Permo-Triassic sandstones	0.0	6.1	42.0
Total	0.0	7.9	45.4

Table 5.2.15. Areas of Units in Northern Ireland (km^2)

Unit	Area
1	1961
2	2044
3	931
4	5479
5	883
6	1835
7	1061

5.3. Northumbrian Water Authority

General Features

The Northumbrian Water Authority covers an area of 9220 km^2 in the north-east of England (Fig 2.1). On the east, the area is bounded by the sea, and to the west and the north by the high ground of the Pennines and the Cheviots (Figure 5.3.1). The lower-lying country between the Pennines and the sea is undulating and occasionally heavily dissected, with a mean altitude of approximately 70 m above sea-level. The main rivers, the Tyne, Wear and Tees, drain eastwards to the sea, and there are numerous smaller rivers flowing in the same direction.

The total population in 1974 was of the order of 2.7 million. The major towns are Newcastle (population 217 000), South Shields (99 000), Sunderland (215 000), Middlesborough (150 000) and Darlington (86 000).

The region around Newcastle, Sunderland and Teeside is heavily industrialised and coal is also mined in this area. Much of the remaining area is agricultural.

Excluding superficial deposits, the area is floored by Palaeozoic strata with some rocks of Triassic age.

Aquifers

There are two major aquifers, the Permo-Triassic sandstones and the Magnesian Limestone.

The Permo-Triassic sandstones are of the order of 100 m thick in this area. The underlying strata comprise marls and saliferous beds as well as sandstones and are therefore not included within the aquifer. No data are available concerning the aquifer properties.

The Magnesian Limestone is about 240 m thick. The transmissivity has been determined at 3 sites within Unit 10, and has a mean value of 5.5×10^{-3} m^2/s. The mean specific yield at these sites is 2×10^{-3}.

Wells in the Permo-Triassic sandstones have yielded up to 3.0×10^6 m^3/a although the normal expectancy is likely to be about 2.0×10^6 m^3/a.

In the Magnesian Limestone, the yield from wells is dependent upon intersecting suitable fissures, and it is not unknown for wells to be dry.

Yields of 7.0 x 10^6 m^3/a are recorded, but a maximum of about 3.0 x 10^6 m^3/a would be the normal expectancy.

The resources of the Units in this area are shown in Tables 5.3.1 to 5.3.6. Units 1 to 6, 9 and 11 have no estimated resources and are omitted from the tables.

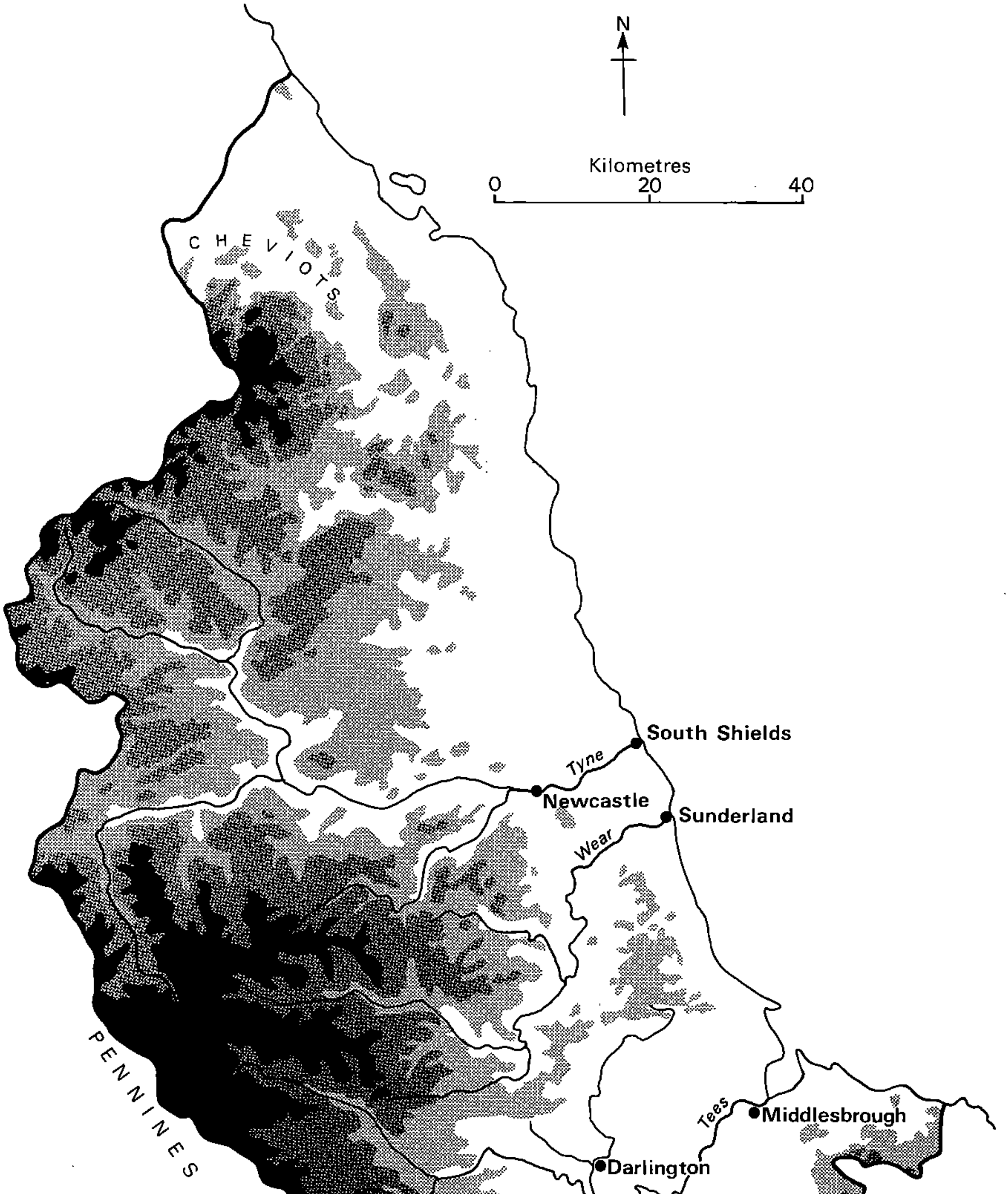

Fig: 5.3.1 Location map of the Northumbrian Water Authority

Table 5.3.1. Groundwater resources for Unit 7 of the Northumbrian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Magnesian Limestone	260	700	360	135	29.6	12.5	22.6

Table 5.3.2. Abstraction of groundwater and balance of resources for Unit 7 of the Northumbrian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Magnesian Limestone	67.1	28.3	51.2

Table 5.3.3. Groundwater resources for Unit 8 of the Northumbrian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Magnesian Limestone	133	660	368	103	18.3	15.0	-1.4

Table 5.3.4. Abstraction of groundwater and balance of resources for Unit 8 of the Northumbrian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Magnesian Limestone	82.4	67.6	-6.3

Table 5.3.5. Groundwater resources for Unit 10 of the Northumbrian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Magnesian Limestone	240	680	810	130	19.0	3.6	28.6
Permo-Triassic sandstone	320	600	383	33	4.9	3.1	7.5
Total					23.9	6.7	36.1

Table 5.3.6. Abstractions of groundwater and balance of resources for Unit 10 of the Northumbrian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Magnesian Limestone	20.5	3.9	30.9
Permo-Triassic sandstones	5.3	3.3	8.1
Total	25.8	7.2	39.0

Table 5.3.7. Areas of Units in the Northumbrian Water Authority (km^2)

Unit	Area
1	855
2	2013
3	1121
4	856
5	987
6	773
7	441
8	222
9	859
10	927
11	166

5.4. The North West Water Authority

General Features

The North West Water Authority covers an area of 14 598 km^2 in the north-west of England (Fig 2.1) and is bounded to the east by the high ground of the Pennines which, from the Cheviot Hills in the north on the Scottish Border, run southwards to the Peak District. Peaks rising above 600 m are not uncommon with the highest, Cross Fell, at 893 m. To the west, the area is bounded by the sea. Much of the coastal area is not more than 60 m above sea-level, but this coastal plain is broken by the Lake District massif with peaks rising to more than 900 m. The low-lying coastal areas are thus divided into the Carlisle Plain to the north, with its southerly extension into the Vale of Eden; the Lancashire Plain lying between Morecambe Bay and the river Mersey; and, farthest to the south, the Cheshire Plain.

The Carlisle Plain is drained by the river Eden and its tributaries, the Lancashire Plain by the Ribble and the Douglas and the Cheshire Plain by the rivers Mersey and Weaver.

The total population in 1974 was of the order of 7.1 million. The major towns include Manchester (population 489 000), Liverpool (528000), Preston (127 000), Blackpool (150 000), Lancaster (124000), Barrow-in-Furness (72 000) and Carlisle (99 000).

The country around Manchester, Liverpool and Preston is heavily industrialised and there is coal mining in south Lancashire and West Cumbria. Much of the remaining area is agricultural, with crop farming in the coastal plains and livestock rearing on the bleaker high lands.

Excluding superficial deposits, the area is floored entirely by rocks of Palaeozoic and early Mesozoic age. Dominant are the Carboniferous of the north and central Pennines and the Lower Palaeozoic massif of the Lake District.

Aquifers

The major aquifer is that of the Permo-Triassic sandstone which crops out in the Carlisle, the Lancashire and the Cheshire plains. Taken through the area as a whole, these sandstones show a mean transmissivity of about 7×10^{-3} m^2/s (Table 5.4.1), although the range of known values is from less than 6×10^{-5} m^2/s to more than 6×10^{-2} m^2/s. Although a mixed type of aquifer, the storage coefficient is generally low.

The Permo-Triassic sandstones aquifer comprises cross-bedded sandstones with subordinate mudstones and siltstones. These strata were deposited in a series of basins, and thick sequences may be present, for example 925 m in the Carlisle basin, 2 860 m in the West Lancashire or East Irish Sea basin, and 1 900 m in the Cheshire basin. Folding and faulting have also led to a considerable variation in the present day thickness throughout the region. However, the effective saturated thickness of the aquifer commonly exceeds 200 m and, whilst yields tend to decline with depth, it is possible to obtain groundwater at great depths.

The Coal Measures also attain great thicknesses, over 1 000 m at the maximum. However, the effective thickness tends to be less for two reasons. First, these strata are predominantly shales and mudstones, with water being obtained from the interspersed sandstone and grit horizons. The deeper of the water-bearing horizons tend to be very much enclosed with consequently limited replenishment.

Secondly, the movement of groundwater is predominantly through fissures, and the density of fissuring lessens with depth. The effective saturated thickness may be anywhere between 50 and 150 m on average. In areas where coal mining is being carried out, extensive dewatering may take place, reducing the saturated thickness still further, while such activities also lead to mineralisation of groundwater so that it may become non-potable.

The Millstone Grit also reaches a maximum thickness in excess of 1 000 m. However, the same criteria tend to apply as with the Coal Measures in that water is found within the sandstone and grit horizons and yields tend to decrease with depth. The effective saturated thickness is unlikely to be more than 100 m. The sandstones tend to be rather thicker than in the Coal Measures.

The thickness of the Carboniferous Limestone in the south of the area is of the order of 500 m. Further north, the thickness of the limestones decreases, being replaced by more shaly beds. Movement of groundwater is dominated entirely by fissuring, the density of these fissures decreases rapidly with depth, and an effective saturated thickness of 80 m at best may be expected. In the areas of the Peak District and around Ingleton (to the east of Morecambe Bay), karst features are developed with many large cavern systems being present.

Resources

Yields of wells in the Permo-Triassic sandstones, taken from large diameter (over 600 mm) wells are usually between 1×10^6 and 3×10^6 m^3 per annum. Exceptionally, yields in excess of 4×10^6 m^3 per annum have been obtained. The available storage is large, and these yields can usually be sustained.

In the Coal Measures, yields are generally smaller, 2×10^6 m^3 per annum being near the maximum. The discharge from coalmines can be somewhat larger, but the water is generally non-potable. Similarly, yields from the Millstone Grit rarely exceed 2×10^6 m^3 per annum. However, in both of these aquifers, natural replenishment is generally restricted and yields can fall off in time as the storage becomes exhausted.

Yields from wells in the Carboniferous Limestone in this authority area are generally very small, under 1×10^6 m^3 per annum. The relative infrequency of fissuring in the Carboniferous Limestone militates against well construction due to the uncertainty of the yield obtained.

Details of the resources for each Unit are given in Tables 5.4.2 to 5.4.39. Units 3, 15 and 18 contain no significant aquifers and are omitted.

When the net resources per annum are unknown, the replenishment is assumed to be equal to the abstraction, and the balance of resources is shown as zero. In reality, there is likely to be some surplus in such instances.

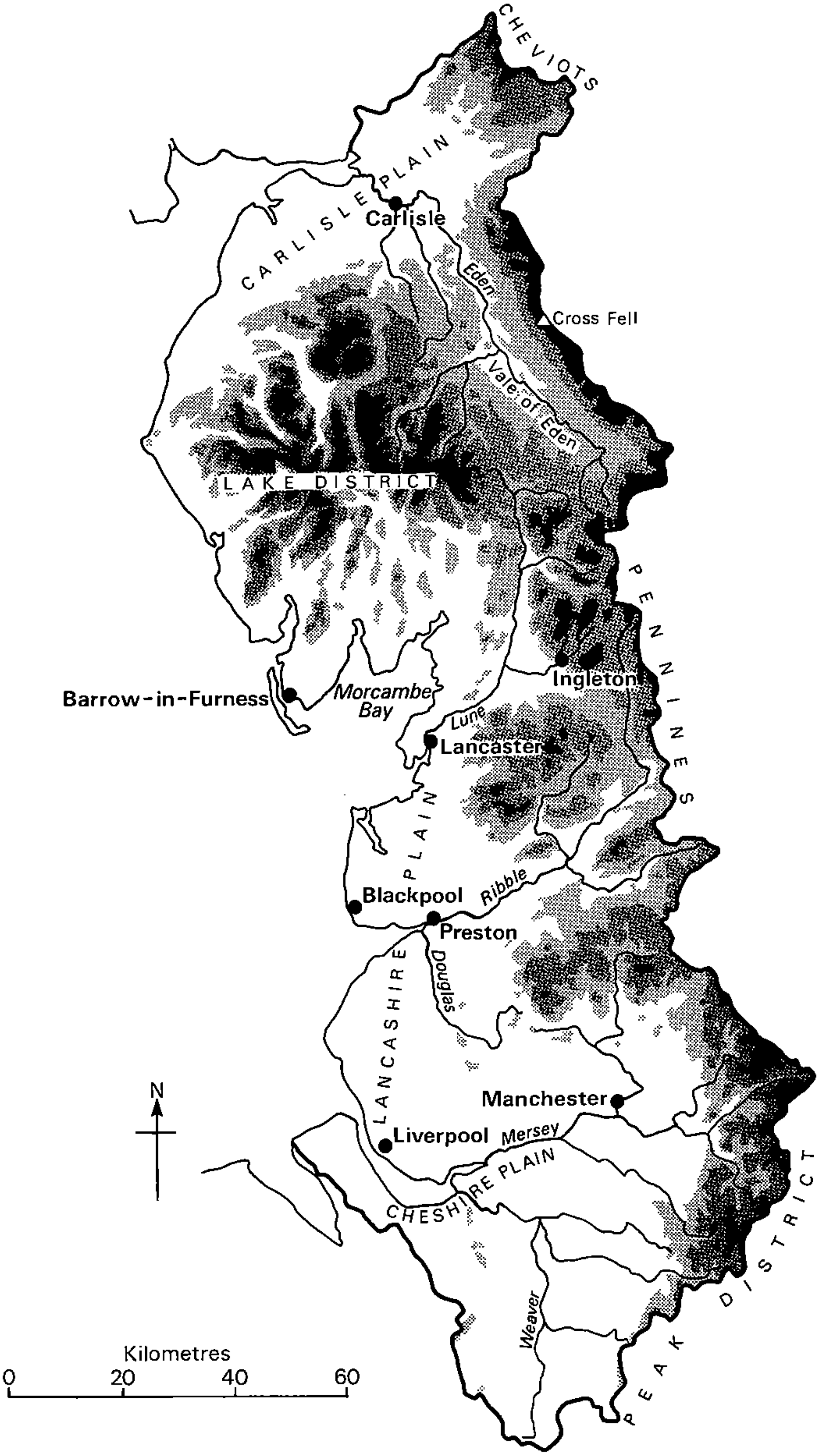

Fig: 5.4.1 Location map of the North West Water Authority

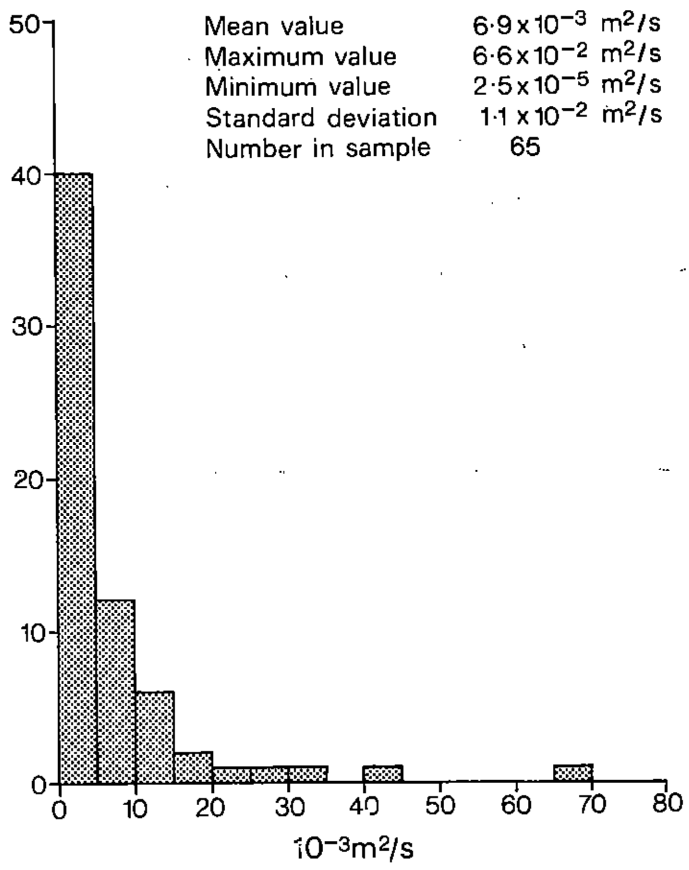

Fig: 5.4.2. Transmissivities of the Permo-Triassic sandstones aquifer in the North-West Water Authority (m^2/s)

Table 5.4.1. Transmissivities in the Permo-Triassic sandstones of the North West Water Authority

Unit	Number of determinations	Transmissivities (m^2/s) Mean	Maximum	Minimum	Mean as % of overall mean
1	1	7.0×10^{-3}	-	-	102
4	4	2.5×10^{-2}	6.6×10^{-2}	2.8×10^{-3}	356
5	1	5.9×10^{-3}	-	-	86
8	7	3.0×10^{-3}	6.6×10^{-3}	3.5×10^{-5}	43
9	29	5.8×10^{-3}	4.3×10^{-2}	2.3×10^{-5}	137
10	11	8.0×10^{-3}	1.7×10^{-2}	1.3×10^{-3}	70
16 + 17	4	4.5×10^{-3}	1.2×10^{-2}	1.1×10^{-3}	65
20	8	5.2×10^{-3}	2.2×10^{-2}	9.3×10^{-5}	75
All Units	65	6.9×10^{-3}	6.6×10^{-2}	2.3×10^{-5}	100

Table 5.4.2. Groundwater resources for Unit 1 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	12	200	525	116	1.7	1.4	0.0

Table 5.4.3. Abstraction of groundwater and balance of resources for Unit 1 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	2.5	2.1	0.0

Table 5.4.4. Groundwater resources for Unit 2 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	20	875	525	nk	0.8	0.5	0.0
Millstone Grit	59	875	525	nk	0.2	0.2	0.0
Permo-Triassic sandstones	6	875	525	196	3.0	2.2	-1.1
Total					4.0	2.9	-1.1

Table 5.4.5. Abstraction of groundwater and balance of resources for Unit 2 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	2.0	1.3	0.0
Millstone Grit	0.5	0.5	0.0
Permo-Triassic sandstones	7.6	5.6	-2.8
Total	10.1	7.4	-2.8

Table 5.4.6. Groundwater resources for Unit 4 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Permo-Triassic sandstones	226	707	513	136	39.6	24.1	6.7

Table 5.4.7. Abstraction of groundwater and balance of resources for Unit 4 of the North West Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	159.7	97.2	27.0

Table 5.4.8. Groundwater resources for Unit 5 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Permo-Triassic sandstones	169	812	487	111	38.2	26.0	-7.2

Table 5.4.9. Abstraction of groundwater and balance of resources for Unit 5 of the North West Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	191.0	130.0	-36.0

Table 5.4.10. Groundwater resources for Unit 6 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Millstone Grit	440	1200	475	nk	4.6	2.1	0.0

Table 5.4.11. Abstraction of groundwater and balance of resources for Unit 6 of the North West Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Millstone Grit	7.0	3.2	0.0

Table 5.4.12. Groundwater resources for Unit 7 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Millstone Grit	32	1356	447	nk	1.4	0.4	0.0
Coal Measures	423	985	465	nk	7.3	3.0	0.0
Total					8.7	3.4	0.0

Table 5.4.13. Abstraction of groundwater and balance of resources for Unit 7 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Millstone Grit	3.1	0.9	0.0
Coal Measures	16.0	6.6	0.0
Total	19.1	7.5	0.0

Table 5.4.14. Groundwater resources for Unit 8 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	416	897	470	65	40.9	19.6	7.4

Table 5.4.15. Abstraction of groundwater and balance of resources for Unit 8 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	74.2	35.6	13.4

Table 5.4.16. Groundwater resources for Unit 9 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	341	993	480	136	86.9	59.0	-12.6

Table 5.4.17. Abstraction of groundwater and balance of resources for Unit 9 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	182.6	123.9	-26.5

Table 5.4.18. Groundwater resources for Unit 10 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	365	840	560	105	48.1	33.3	4.9

Table 5.4.19. Abstraction of groundwater and balance of resources for Unit 10 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	81.4	56.3	8.3

Table 5.4.20. Groundwater resources for Unit 11 of the North West Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	$10^6\ m^3$	$10^6\ m^3$	$10^6\ m^3$
Millstone Grit	197	1153	447	nk	10.7	1.8	0.0
Coal Measures	790	1143	508	nk	8.3	5.3	0.0
Total					19.0	7.1	0.0

Table 5.4.21. Abstraction of groundwater and balance of resources for Unit 11 of the North West Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	$10^3\ m^3/km^2$	$10^3\ m^3/km^2$	$10^3\ m^3/km^2$
Millstone Grit	10.9	1.8	0.0
Coal Measures	8.4	5.4	0.0
Total	19.3	7.2	0.0

Table 5.4.22. Groundwater resources for Unit 12 of the North West Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	$10^6\ m^3$	$10^6\ m^3$	$10^6\ m^3$
Millstone Grit	215	1303	447	nk	1.6	0.6	0.0

Table 5.4.23. Abstraction of groundwater and balance of resources for Unit 12 of the North West Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	$10^3\ m^3/km^2$	$10^3\ m^3/km^2$	$10^3\ m^3/km^2$
Millstone Grit	2.6	1.0	0.0

Table 5.4.24. Groundwater resources for Unit 13 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	324	1067	514	176	76.7	14.4	42.6

Table 5.4.25. Abstraction of groundwater and balance of resources for Unit 13 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	135.5	25.4	75.3

Table 5.4.26. Groundwater resources for Unit 14 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Millstone Grit	740	1002	498	81	10.8	3.3	56.6

Table 5.4.27. Abstraction of groundwater and balance of resources for Unit 14 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Millstone Grit	7.2	2.2	37.9

Table 5.4.28. Groundwater resources for Unit 16 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	129	1100	400	114	1.2	1.0	13.7
Permo-Triassic sandstones	25	1100	400	84	7.1	2.8	-0.7
Total					8.3	3.8	13.0

Table 5.4.29. Abstraction of groundwater and balance of resources for Unit 16 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	6.3	5.3	72.5
Permo-Triassic sandstones	37.6	14.8	-3.7
Total	43.9	20.1	68.8

Table 5.4.30. Groundwater resources for Unit 17 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	305	933	420	36	0	0	11.0

Table 5.4.31. Abstraction of groundwater and balance of resources for Unit 17 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	0	0	36.1

Table 5.4.32. Groundwater resources for Unit 19 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	261	1150	450	nk	1.4	0.3	0.0

Table 5.4.33. Abstraction of groundwater and balance of resources for Unit 19 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	1.6	0.3	0.0

Table 5.4.34. Groundwater resources for Unit 20 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	900	850	426	108	11.7	4.0	93.3

Table 5.4.35. Abstraction of groundwater and balance of resources for Unit 20 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	5.8	2.0	48.5

Table 5.4.36. Groundwater resources for Unit 21 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	504	1450	425	nk	4.1	3.6	0.0

Table 5.4.37. Abstraction of groundwater and balance of resources for Unit 21 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	5.8	5.1	0.0

Table 5.4.38. Groundwater resources for Unit 22 of the North West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	533	1200	425	nk	4.3	3.8	0.0

Table 5.4.39. Abstraction of groundwater and balance of resources for Unit 22 of the North West Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	8.1	7.1	0.0

Table 5.4.40. Areas of Units in the North West Water Authority (km^2)

Unit	Area	Unit	Area
1	671	12	623
2	394	13	566
3	295	14	1494
4	248	15	1373
5	200	16	189
6	653	17	305
7	455	18	387
8	551	19	897
9	476	20	2006
10	591	21	704
11	987	22	533

5.5. Severn-Trent Water Authority

General Features

The Severn-Trent Water Authority covers an area of 21 451 km^2 in the centre of England (Fig 2.1), and includes a portion of the central part of Wales. High lands include the eastern side of Plynlimon in Wales where altitudes are attained in excess of 700 m above sea-level, and the Peak District at the southern end of the Pennines (Figure 5.5.1) with altitudes over 600 m. The remainder of the authority area is undulating with altitudes occasionally rising to 200 m but most below 80 m above sea-level. Two major river systems drain the area. The river Severn rises in the Welsh hills and flows east and south to the sea in the Bristol Channel. The river Trent rises in the low lands to the south-west of the Peak District and flows north-eastwards into the estuary of the Humber.

The total population in 1974 was of the order of 8.2 million. The major towns are Gloucester (population 90 000), Coventry (336 000), Birmingham (1 006 000), Leicester (281 000), Derby (220 000), Nottingham (294 000), Stoke on Trent (262 000), Shrewsbury (57 000) and Wolverhampton (269 000).

The area around Coventry, Birmingham, Leicester, Derby and Nottingham is heavily industrialised and coal is mined near Birmingham and to the north of Nottingham, but the remaining areas are largely agricultural.

Geologically, the area is floored for the most part by rocks of the Carboniferous and the Permo-Trias. Jurassic strata crop out along the eastern border. Lower Palaezoic rocks floor the headwaters of the river Severn. Superficial deposits overlie much of the solid geology, varying from sands and gravels to boulder clay, and reaching thicknesses in excess of 30 m.

Aquifers

The Carboniferous Limestone is not widespread in this area. The maximum thickness may be over 1 500 m, but much of the aquifer is covered by the unconformable Keuper Marl. Groundwater flow is through fissures, and these are relatively sparsely distributed through the aquifer. It is not unusual for a well to be dry due to failure to intersect suitable fissures.

The Millstone Grit also has a limited outcrop, although the maximum thickness may again exceed 1 500 m. The formation comprises a succession of sandstones, mudstones and shales, groundwater being found in the sandstone horizons. Groundwater flow is partly through fissures and partly intergranular. This aquifer is not considered important in this area.

The Coal Measures comprise a succession of sandstones, mudstones and shales with subordinate coals. The thickness varies, but at a maximum, in the north of the area, it exceeds 1 000 m. This aquifer is not considered important in this area.

The Permo-Triassic sandstones form the major aquifer in this area, comprising sandstones, often massive and dune-bedded, with subordinate mudstones and siltstones. This formation was deposited in large intermontane basins, and the thickness is very variable. Over 2 600 m are present in the Cheshire Basin (part of which touches upon the Severn-Trent Water Authority area), and 750 m in the Severn Basin.

The Magnesian Limestone crops out in the eastern part of this area. Two limestones are present, separated by marls, together making up some 40 m of limestone. The rock is not, as its name suggests, a pure dolomite, but is a mixture of calcium and magnesium carbonates. The groundwater flow is almost entirely through fissures which tend to be large but somewhat sparsely distributed, and wells which fail to intersect suitable fissures are generally dry.

Resources

Sites in the Carboniferous Limestone generally yield approximately 0.5 x 10^6 m^3/a or less. Larger yields are possible if suitable fissures are encountered, but there is some reluctance to construct wells in this aquifer since there is a possibility of failing to intersect fissures and hence having a dry well.

In the Millstone Grit, the average yield of a successful site is 0.5 to 1.0 x 10^6 m^3/a. A satisfactory yield is dependent upon intersecting a suitable sandstone horizon, and, in areas where the strata are faulted, natural replenishment may be limited. Consequently, even though wells may initially give a good yield, this may decrease significantly in time.

Yields of wells in the Coal Measures are not recorded as having exceeded 1.7 x 10^6 m^3/a. As with the Millstone Grit, successful wells depend upon the intersection of suitable fissures, and there may be restrictions upon natural replenishment. In the vicinity of disused coal workings, there is also a possibility of finding groundwater sufficiently mineralised so as to be non-potable.

The maximum yield recorded from a site in the Permo-Triassic sandstones is 6.2 x 10^6 m^3/a. However, the mean is between 0.5 and 1.5 x 10^6 m^3/a, depending upon the Unit concerned. Units 4, 5, 9 and 14 have yields higher than average, while Units 8, 11 and 13 have yields markedly lower than the average. It is very unusual to construct a well in this aquifer and not to obtain any yield at all.

The Magnesian Limestone has rather small yields to wells in this area, the mean abstraction being about 0.4 to 0.6 x 10^6 m^3/a. This is possibly due to a lack of development because of the presence of more prolific aquifers in the vicinity.

Wells constructed in the aquifers of this area normally require lining only near to the ground surface and in the mudstone and shale beds where a slow movement may in time cause collapse. The water-bearing strata usually stand without support.

Details of the resources for each unit are shown in Tables 5.5.1. to 5.5.26. There are no resources in Units 6, 12 and 16, and these are omitted from the tables.

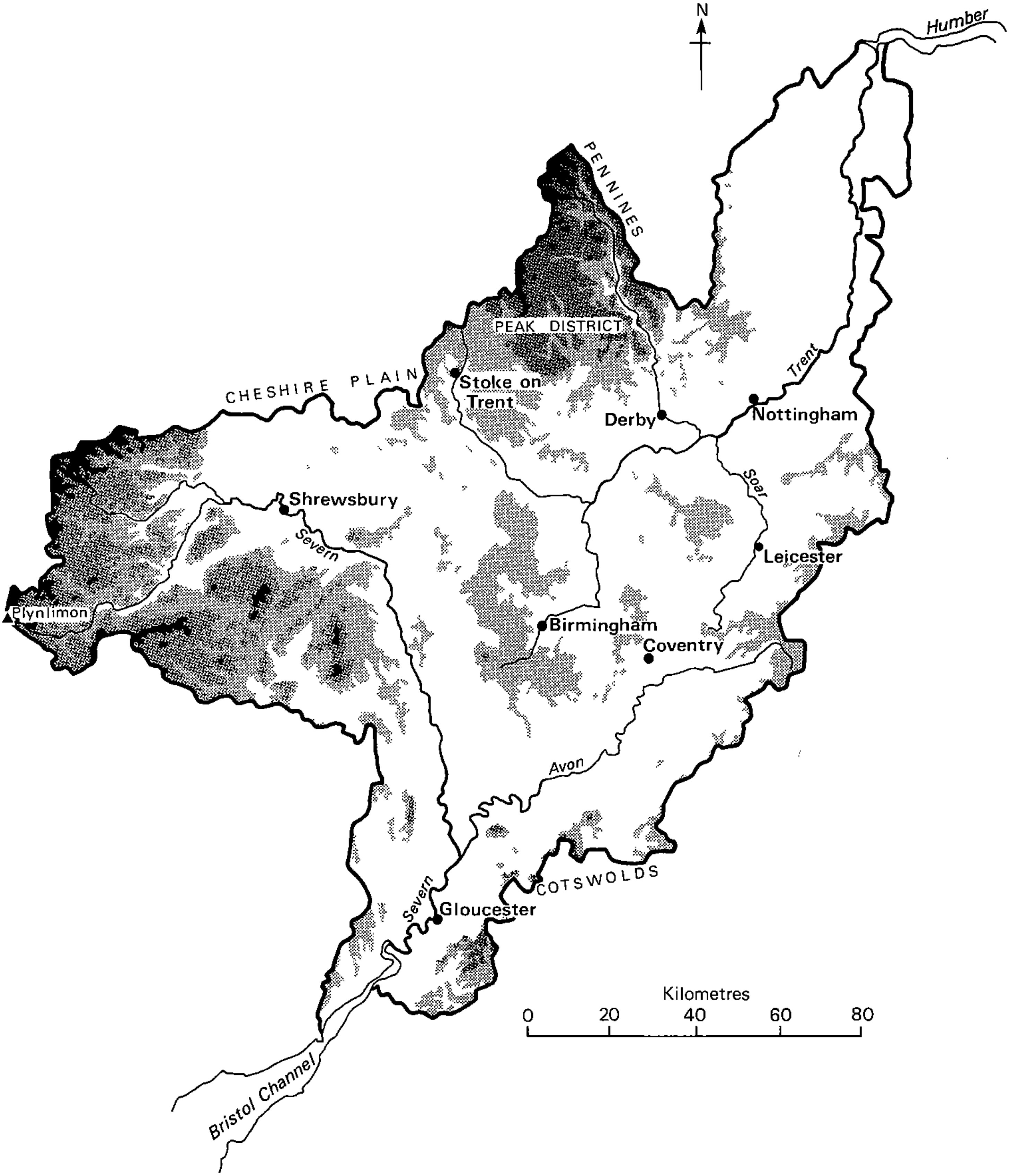

Fig 5.5.1 Location map of the Severn–Trent Water Authority

Table 5.5.1. Groundwater resources for Unit 1 of the Severn-Trent Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Carboniferous Limestone	260	1003	485	578	4.6	3.1	147.1

Table 5.5.2. Abstraction of groundwater and balance of resources for Unit 1 of the Severn-Trent Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	7.7	5.2	247.6

Table 5.5.3. Groundwater resources for Unit 2 of the Severn-Trent Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Permo-Triassic sandstones	107	862	483	379	18.9	10.7	29.7
Carboniferous Limestone	177	986	485	501	1.0	1.0	87.9
Total					19.9	11.7	117.6

Table 5.5.4. Abstraction of groundwater and balance of resources for Unit 2 of the Severn-Trent Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	16.5	9.3	25.9
Carboniferous Limestone	0.9	0.9	76.7
Total	17.4	10.2	102.4

Table 5.5.5. Groundwater resources for Unit 3 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Permo-Triassic sandstones	271	584	470	114	46.4	28.8	2.1
Magnesian Limestone	54	584	470	121	0.8	0.6	5.9
Total					47.2	29.4	8.0

Table 5.5.6. Abstraction of groundwater and balance of resources for Unit 3 of the Severn-Trent Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	74.1	46.0	3.3
Magnesian Limestone	1.3	1.0	9.5
Total	75.4	47.0	12.8

Table 5.5.7. Groundwater resources for Unit 4 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Permo-Triassic sandstones	250	615	470	145	34.1	25.4	10.9
Magnesian Limestone	126	620	470	150	3.9	2.0	16.9
Total					38.0	27.4	27.8

Table 5.5.8. Abstraction of groundwater and balance of resources for Unit 4 of the Severn-Trent Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	48.0	35.7	15.3
Magnesian Limestone	5.5	2.8	23.8
Total	53.5	38.5	39.1

Table 5.5.9. Groundwater resources for Unit 5 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Permo-Triassic sandstones	300	679	459	196	105.1	78.7	-20.0
Magnesian Limestone	90	662	438	165	1.4	0.9	14.0
Total					106.5	79.6	-6.0

Table 5.5.10. Abstraction of groundwater and balance of resources for Unit 5 of the Severn-Trent Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	86.9	65.0	-16.5
Magnesian Limestone	1.2	0.7	11.6
Total	88.1	65.7	-4.9

Table 5.5.11. Groundwater resources for Unit 7 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Permo-Triassic sandstones	11	724	483	241	0.0	0.0	2.7

Table 5.5.12. Abstraction of groundwater and balance of resources for Unit 7 of the Severn-Trent Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	0.0	0.0	2.0

Table 5.5.13. Groundwater resources for Unit 8 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Permo-Triassic sandstones	148	677	483	195	18.2	10.5	18.3

Table 5.5.14. Abstraction of groundwater and balance of resources for Unit 8 of the Severn-Trent Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	20.8	12.0	20.9

Table 5.5.15. Groundwater resources for Unit 9 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	315	764	482	264	61.9	47.3	35.9

Table 5.5.16. Abstraction of groundwater and balance of resources for Unit 9 of the Severn-Trent Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	37.3	28.5	21.6

Table 5.5.17. Groundwater resources for Unit 10 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	245	724	464	244	51.9	31.0	28.8

Table 5.5.18. Abstraction of groundwater and balance of resources for Unit 10 of the Severn-Trent Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	41.0	24.5	22.7

Table 5.5.19. Groundwater resources for Unit 11 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1972) 10^6 m^3	balance of resources (1972) 10^6 m^3
Permo-Triassic sandstones	nk	nk	nk	nk	0.0	0.3	0.0

Table 5.5.20. Abstraction of groundwater and balance of resources for Unit 11 of the Severn-Trent Water Authority (1972)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	0.0	0.2	0.0

Table 5.5.21. Groundwater resources for Unit 13 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1972) 10^6 m^3	balance of resources (1972) 10^6 m^3
Carboniferous Limestone	19	940	495	165	1.4	0.8	2.3
Permo-Triassic sandstones	829	720	516	125	22.7	10.8	92.8
Total					24.1	11.6	95.1

Table 5.5.22. Abstraction of groundwater and balance of resources for Unit 13 of the Severn-Trent Water Authority (1972)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Carboniferous Limestone	0.9	0.5	1.6
Permo-Triassic sandstones	15.3	7.3	62.7
Total	16.2	7.8	64.3

Table 5.5.23. Groundwater resources for Unit 14 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1972) $10^6\ m^3$	balance of resources (1972) $10^6\ m^3$
Permo-Triassic sandstones	646	707	509	125	134.7	97.7	-17.0

Table 5.2.24. Abstraction of groundwater and balance of resources for Unit 14 of the Severn-Trent Water Authority (1972)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	39.1	28.4	-4.9

Table 5.5.25. Groundwater resources for Unit 15 of the Severn-Trent Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1972) $10^6\ m^3$	balance of resources (1972) $10^6\ m^3$
Permo-Triassic sandstones	43	688	510	52	5.1	1.7	0.5

Table 5.5.26. Abstraction of groundwater and balance of resources for Unit 15 of the Severn-Trent Water Authority (1972)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	2.7	0.9	0.3

Table 5.5.27. Areas of Units in the Severn-Trent Water Authority (km^2)

Unit	Area
1	594
2	1147
3	626
4	711
5	1210
6	1045
7	1342
8	876
9	1659
10	1266
11	1951
12	1327
13	1480
14	3445
15	1873
16	899

5.6 Yorkshire Water Authority

General Features

The Yorkshire Water Authority covers an area of 13 488 km^2 in the north-east of England (Fig 2.1). The area is bounded to the east by the sea and to the west by the high ground of the Pennines, reaching 700 m above sea level at Buckden Pike and 545 m at Margery Hill (Fig 5.6.1). The Pennines fall eastwards to the low-lying Vale of York which does not exceed 60 m above sea level. Between the Vale of York and the sea is the higher land of the North Yorkshire Moors and the Yorkshire Wolds, these being separated by the basin of the Vale of Pickering. Finally, in the south-east of the area is the coastal plain of Holderness.

Drainage of the greater part of the Authority area is controlled by the river system of the Ouse draining to the Humber Estuary. The rivers Swale, Ure, Nidd, Wharfe, Aire and Don drain eastwards from the Pennines to the Vale of York where they form the river Ouse. The river Derwent drains the North Yorkshire Moors and the Vale of Pickering into the river Ouse. Most of the Wolds drains to the river Hull and part of the North Yorkshire Moors drains directly to the sea by the river Esk.

The total population in 1974 was of the order of 4.5 million. The principal towns include York (population 105 000), Kingston upon Hull (283 000), Sheffield (513 000), Huddersfield (130 000), Bradford (294 000) and Leeds (499 000).

Industrial areas are found from Sheffield northwards to Leeds and around Kingston upon Hull, which is also an important sea-port. Coal is extensively mined but the remainder of the area comprises agricultural land, generally of high quality on the lower ground.

The Pennines are formed of Carboniferous strata, mainly the Millstone Grit and Coal Measures, but with Carboniferous Limestone in the north-west of the Authority's area. The Carboniferous strata dip eastwards and are overlain by the outcrop of the Magnesian Limestone. The Vale of York is floored by the Permo-Triassic sandstones, generally below a cover of superficial drift, with the Keuper Marl overlying the sandstones on the eastern side. The North Yorkshire Moors are formed of rocks of Jurassic age, including limestones, sandstones and shales. The Vale of Pickering exploit this aquifer.

The average yield from wells in the Millstone Grit is approximately 0.5×10^6 m^3/a, although yields as high as 1.5×10^6 m^3/a have been recorded. Although generally unsuitable for the development of large sources, this aquifer is important for local supplies, particularly for industrial use and for small agricultural demands.

The major abstraction from the Coal Measures is in the form of mine drainage, and in 1977 a total of 51.5×10^6 m^3 was pumped. Of this, 27.4×10^6 m^3 came from Unit 8. The mean discharge in mine drainage abstraction is between 1.0 and 2.0×10^6 m^3/a. The quality of groundwater discharged from mines is usually poor and unsuitable for public supply. Yields from supply wells are generally lower, the mean being approximately 0.5×10^6 m^3/a.

The mean yield of wells in the Magnesian Limestone is of the order of 0.6×10^6 m^3/a. However, if suitable fissures are intersected, yields of as much as 1.5×10^6 m^3/a can be obtained.

The mean yield from wells in the Permo-Triassic sandstones is of the order of 2.0×10^6 m^3/a for large diameter public supply boreholes, and 1.0×10^6 m^3/a for smaller diameter industrial boreholes. Maximum yields exceed 3.0×10^6 m^3/a. This aquifer is usually reliable, but may present problems with water quality or running sand in some localities.

The mean yield of sites in the Corallian aquifer is between 0.5 and 0.8×10^6 m^3/a, but yields in excess of 3.0×10^6 m^3/a have been obtained. High yields are obtained adjacent to major springs, where fissure flow has been highly developed, and also adjacent to faults.

Yields from public supply boreholes in the Chalk average between 2.0 and 3.0×10^6 m^3/a, and the maximum is of the order of 4.0×10^6 m^3/a. Industrial sites usually yield less, in some areas less than 0.4×10^6 m^3/a where there is no choice of borehole location.

Most wells in the aquifers in this area will stand without support. However, where mudstones and shales are penetrated above the aquifer, it is advisable to line these out. Gravel packs and well screens may be needed in Permo-Triassic sandstone boreholes when the aquifer is

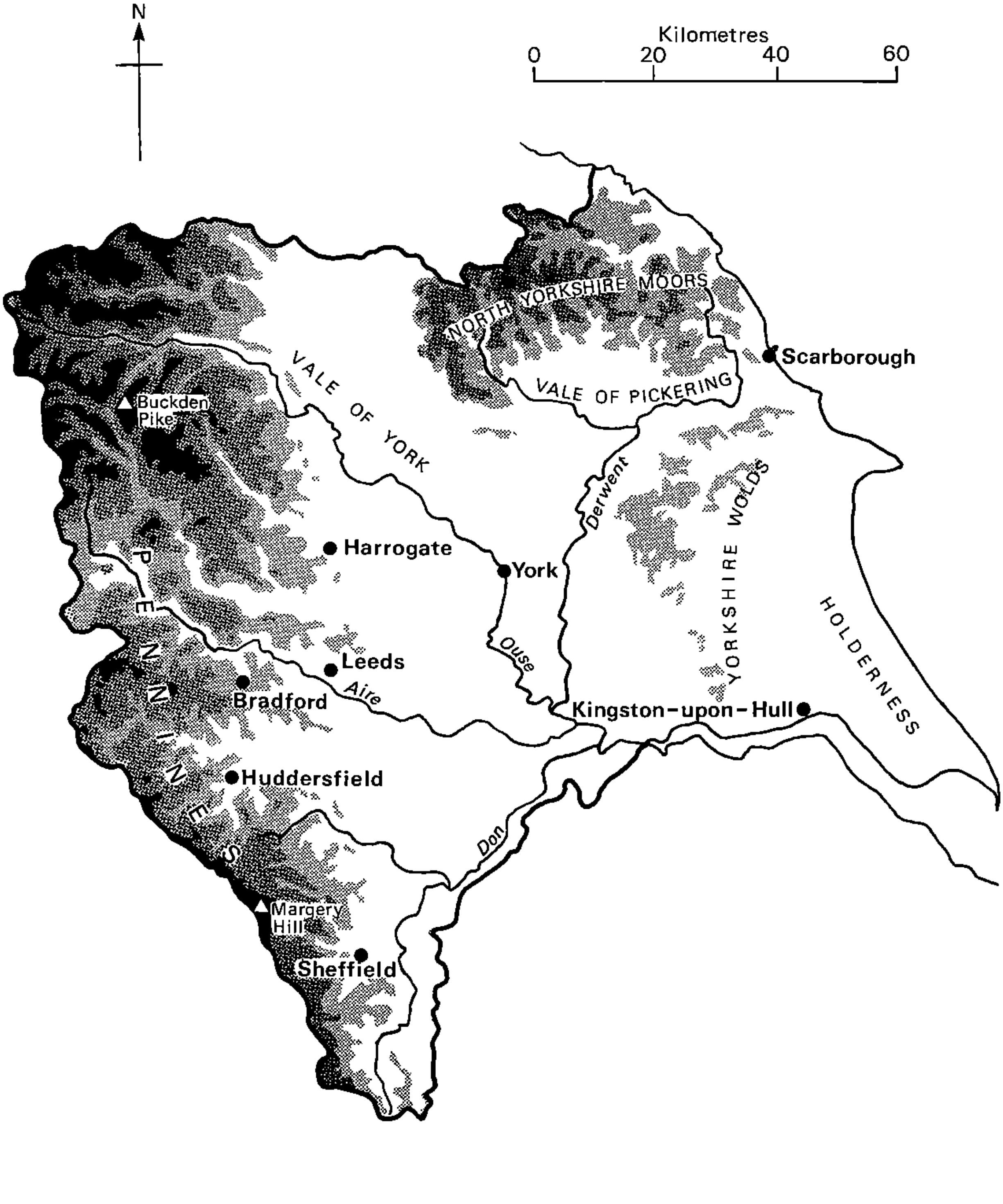

Fig: 5.6.1 Location map of the Yorkshire Water Authority

poorly cemented. In many parts of the area a considerable thickness of Superficial Deposits may overlie the aquifers, particularly the Permo-Triassic sandstones. Typically 30 m of plain lining may be required in boreholes in the area.

The resources for each Unit are shown in Tables 5.6.2 to 5.6.69. Actual abstractions from the Coal Measures may exceed the licensed amounts because it is not required that mine drainage be licensed by the Water Authority.

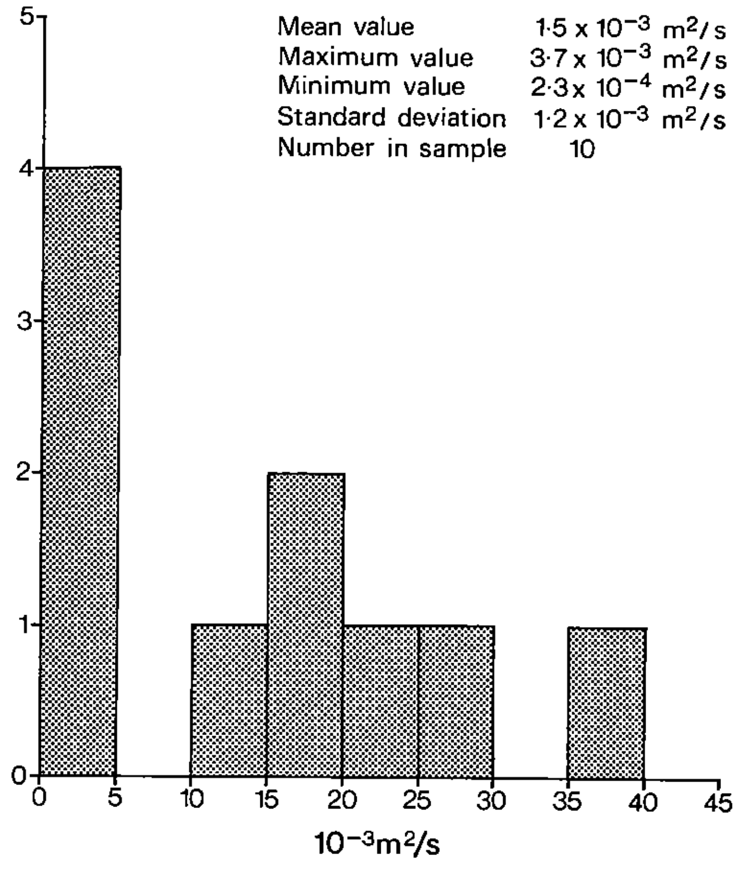

Fig: 5.6.2. Transmissivities of the Millstone Grit aquifer in the Yorkshire Water Authority (m^2/s)

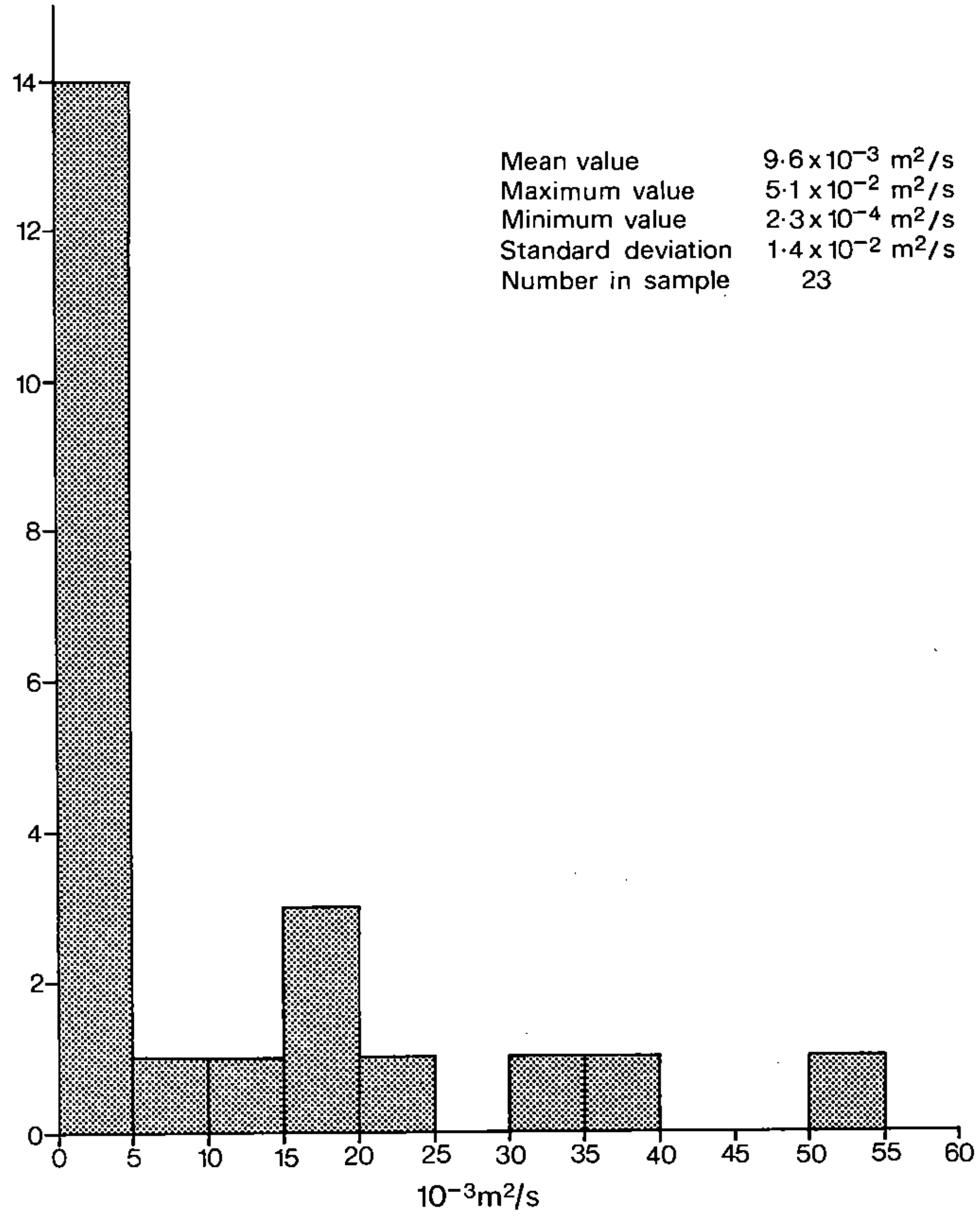

Fig: 5.6.3. Transmissivities of the Magnesian Limestone aquifer in the Yorkshire Water Authority (m^2/s)

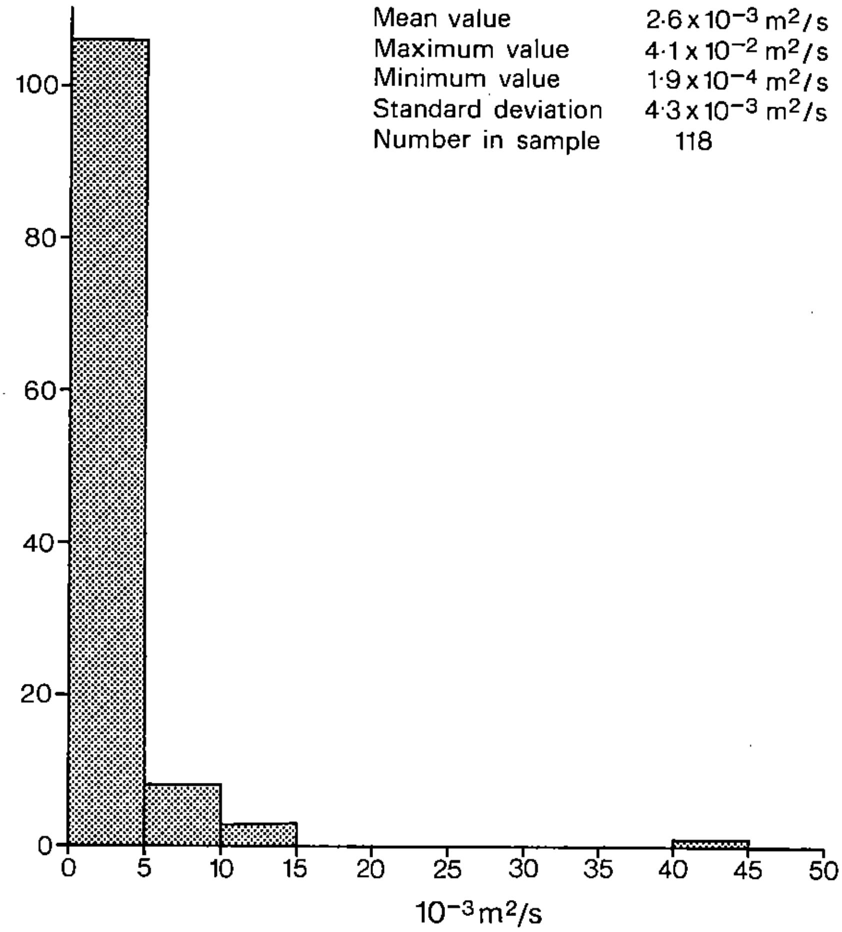

Fig: 5.6.4. Transmissivities of the Permo-Triassic sandstones aquifer in the Yorkshire Water Authority (m^2/s)

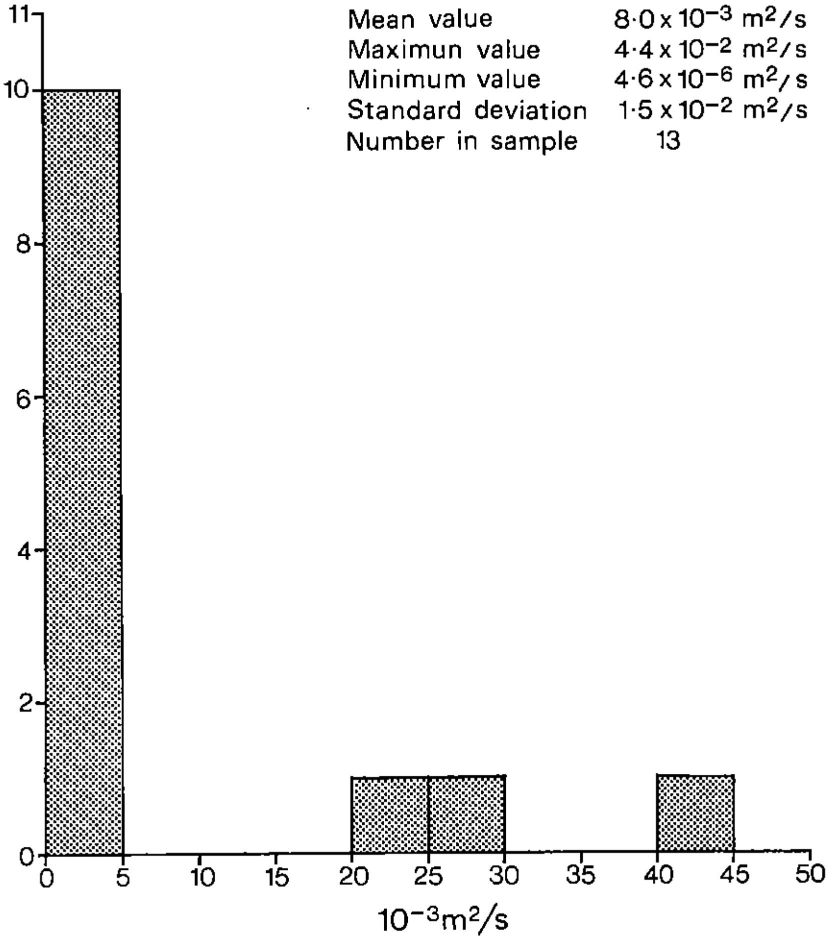

Fig: 5.6.5. Transmissivities of the Middle Jurassic aquifer in the Yorkshire Water Authority (m^2/s)

Table 5.6.1. Transmissivities in the Permo-Triassic sandstones aquifer of the Yorkshire Water Authority (m^2/s)

Unit	Number of determinations	Transmissivities (m^2/s) Mean	Minimum	Maximum	Mean as % of overall mean
7	2	5.2×10^{-4}	3.5×10^{-4}	6.9×10^{-4}	20
9	19	2.5×10^{-3}	4.6×10^{-4}	1.4×10^{-2}	96
18	14	1.8×10^{-3}	6.4×10^{-4}	6.4×10^{-3}	69
20	2	5.5×10^{-4}	4.1×10^{-4}	6.9×10^{-4}	21
22	27	2.9×10^{-3}	1.9×10^{-4}	1.2×10^{-2}	112
23	14	4.5×10^{-3}	3.5×10^{-4}	4.1×10^{-2}	173
24	38	2.2×10^{-3}	2.3×10^{-4}	1.4×10^{-2}	85
28	2	1.9×10^{-3}	1.0×10^{-3}	2.7×10^{-3}	73
All Units	118	2.6×10^{-3}	1.9×10^{-4}	4.1×10^{-2}	100

Table 5.6.2. Groundwater resources for Unit 1 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	61	710	430	147	0.5	1.0	8.0
Magnesian Limestone	11	710	430	257	0.0	0.0	2.8
Total					0.5	1.0	10.8

Table 5.6.3. Abstraction of groundwater and balance of resources for Unit 1 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	6.9	13.9	111.1
Magnesian Limestone	0.0	0.0	38.9
Total	6.9	13.9	150.0

Table 5.6.4. Groundwater resources for Unit 2 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	173	790	380	140	1.4	2.0	22.2
Millstone Grit	18	890	350	181	2.3	0.2	3.1
Total					3.7	2.2	25.3

Table 5.6.5. Abstraction of groundwater and balance of resources for Unit 2 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	7.3	10.5	116.2
Millstone Grit	12.0	1.0	16.2
Total	19.3	11.5	132.4

Table 5.6.6. Groundwater resources for Unit 3 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	136	710	405	97	0.0	5.1	8.1

Table 5.6.7. Abstraction of groundwater and balance of resources for Unit 3 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	0.0	37.5	59.6

Table 5.6.8. Groundwater resources for Unit 4 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	62	865	380	105	0.3	0.1	6.5
Millstone Grit	13	1015	380	151	0.0	0.0	1.9
Total					0.3	0.1	8.4

Table 5.6.9. Abstraction of groundwater and balance of resources for Unit 4 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	4.0	1.3	86.7
Millstone Grit	0.0	0.0	25.3
Total	4.0	1.3	112.0

Table 5.6.10. Groundwater resources for Unit 5 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	140	1065	430	133	6.6	1.4	17.1
Millstone Grit	143	1220	430	132	0.0	0.0	19.0
Total					6.6	1.4	36.1

Table 5.6.11. Abstraction of groundwater and balance of resources for Unit 5 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	23.2	4.9	60.4
Millstone Grit	0.0	0.0	67.1
Total	23.2	4.9	127.5

Table 5.6.12. Groundwater resources for Unit 6 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	82	735	430	75	0.0	2.0	4.1

Table 5.6.13. Abstraction of groundwater and balance of resources for Unit 6 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	0.0	24.4	51.2

Table 5.6.14. Groundwater resources for Unit 7 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	89	635	430	81	0.0	4.1	3.1
Magnesian Limestone	15	635	430	193	0.0	0.0	2.9
Permo-Triassic Sandstones	2	610	430	167	0.0	0.0	0.4
Total					0.0	4.1	6.4

Table 5.6.15. Abstraction of groundwater and balance of resources for Unit 7 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	0.0	38.7	29.2
Magnesian Limestone	0.0	0.0	27.4
Permo-Triassic Sandstones	0.0	0.0	3.8
Total	0.0	38.7	60.4

Table 5.6.16. Groundwater resources for Unit 8 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	326	660	430	110	0.0	30.7	5.2

Table 5.6.17. Abstraction of groundwater and balance of resources for Unit 8 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	0.0	94.2	16.0

Table 5.6.18. Groundwater resources for Unit 9 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	124	610	430	99	0.0	2.5	9.8
Permo-Triassic sandstones	213	610	430	150	3.7	2.2	29.8
Magnesian Limestone	125	610	430	168	2.2	1.2	19.7
Total					5.9	5.9	59.3

Table 5.6.19. Abstraction of groundwater and balance of resources for Unit 9 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	0.0	5.4	21.2
Permo-Triassic sandstones	8.0	4.8	64.5
Magnesian Limestone	4.8	2.6	42.6
Total	12.8	12.8	128.3

Table 5.6.20. Groundwater resources for Unit 10 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Millstone Grit	78	1270	430	130	0.0	0.0	10.2
Coal Measures	17	1040	430	88	0.0	0.0	1.5
Total					0.0	0.0	11.7

Table 5.6.21. Abstraction of groundwater and balance of resources for Unit 10 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Millstone Grit	0.0	0.0	106.3
Coal Measures	0.0	0.0	15.6
Total	0.0	0.0	121.9

Table 5.6.22. Groundwater resources for Unit 11 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	79	915	430	112	0.0	1.0	7.8
Millstone Grit	68	1195	430	135	5.1	0.7	8.5
Total					5.1	1.7	16.3

Table 5.6.23. Abstraction of groundwater and balance of resources for Unit 11 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	0.0	6.8	53.1
Millstone Grit	34.7	4.8	57.8
Total	34.7	11.6	110.9

Table 5.6.24. Groundwater resources for Unit 12 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	64	965	430	120	0.3	0.2	7.5
Millstone Grit	331	1270	430	126	1.6	0.2	41.5
Total					1.9	0.4	49.0

Table 5.6.25. Abstraction of groundwater and balance of resources for Unit 12 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	0.8	0.5	19.0
Millstone Grit	4.1	0.5	105.1
Total	4.9	1.0	124.1

Table 5.6.26. Groundwater resources for Unit 13 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	308	710	455	101	4.2	6.4	24.7

Table 5.6.27. Abstraction of groundwater and balance of resources for Unit 13 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	13.6	20.8	80.2

Table 5.6.28. Groundwater resources for Unit 14 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Millstone Grit	73	1195	430	84	0.0	0.0	6.1

Table 5.6.29. Abstraction of groundwater and balance of resources for Unit 14 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Millstone Grit	0.0	0.0	83.6

Table 5.6.30. Groundwater resources for Unit 15 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Millstone Grit	158	1040	405	66	2.8	0.6	9.8
Carboniferous Limestone	220	1195	405	107	0.0	0.0	23.5
Total					2.8	0.6	33.3

Table 5.6.31. Abstraction of groundwater and balance of resources for Unit 15 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Millstone Grit	7.4	1.6	25.8
Carboniferous Limestone	0.0	0.0	61.8
Total	7.4	1.6	87.6

Table 5.6.32. Groundwater resources for Unit 16 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Coal Measures	100	940	405	80	0.0	0.0	8.0
Millstone Grit	112	890	405	107	3.8	1.8	10.2
Total					3.8	1.8	18.2

Table 5.6.33. Abstraction of groundwater and balance of resources for Unit 16 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Coal Measures	0.0	0.0	37.6
Millstone Grit	17.8	8.5	47.9
Total	17.8	8.5	85.5

Table 5.6.34. Groundwater resources for Unit 17 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Coal Measures	241	710	430	97	0.0	1.7	21.7
Millstone Grit	38	760	430	122	2.7	0.8	3.9
Magnesian Limestone	23	635	430	195	0.0	0.0	4.5
Total					2.7	2.5	30.1

Table 5.6.35. Abstraction of groundwater and balance of resources for Unit 17 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Coal Measures	0.0	5.6	71.6
Millstone Grit	8.9	2.6	12.9
Magnesian Limestone	0.0	0.0	14.9
Total	8.9	8.2	99.4

Table 5.6.36. Groundwater resources for Unit 18 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Coal Measures	13	635	430	82	0.0	0.3	0.8
Permo-Triassic sandstones	89	635	430	177	24.0	13.2	2.5
Magnesian Limestone	39	635	430	201	2.1	0.3	7.5
Total					26.1	13.8	10.8

Table 5.6.37. Abstraction of groundwater and balance of resources for Unit 18 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Coal Measures	0.0	2.1	5.7
Permo-Triassic sandstones	170.2	93.6	17.7
Magnesian Limestone	14.9	2.1	53.2
Total	185.1	97.8	76.6

Table 5.6.38. Groundwater resources for Unit 19 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	278	1525	360	122	6.8	2.0	32.0
Millstone Grit	234	1145	380	90	0.0	0.0	21.1
Total					6.8	2.0	53.1

Table 5.6.39. Abstraction of groundwater and balance of resources for Unit 19 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	13.3	3.9	62.4
Millstone Grit	0.0	0.0	41.1
Total	13.3	3.9	103.5

Table 5.6.40. Groundwater resources for Unit 20 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual asbtraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	1	1170	405	125	0.0	0.0	0.1
Millstone Grit	200	810	405	72	2.5	0.2	14.1
Permo-Triassic sandstones	81	635	405	75	3.2	2.1	4.0
Magnesian Limestone	145	660	405	227	8.7	4.0	28.9
Coal Measures	69	710	405	69	0.0	0.0	4.8
Total					14.4	6.3	51.9

Table 5.6.41. Abstraction of groundwater and balance of resources for Unit 20 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	0.0	0.0	0.2
Millstone Grit	5.0	0.4	28.4
Permo-Triassic sandstones	6.5	4.2	8.1
Magnesian Limestone	17.5	8.1	58.3
Coal Measures	0.0	0.0	9.7
Total	29.0	12.7	104.5

Table 5.6.42. Groundwater resources for Unit 21 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	9	810	405	90	0.0	0.0	0.8
Millstone Grit	411	1065	405	98	0.0	0.0	40.2
Permo-Triassic sandstones	61	685	405	145	0.0	0.0	8.8
Magnesian Limestone	64	710	405	174	1.7	0.0	11.1
Total					1.7	0.0	60.9

Table 5.6.43. Abstraction of groundwater and balance of resources for Unit 21 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	0.0	0.0	1.5
Millstone Grit	0.0	0.0	73.8
Permo-Triassic sandstones	0.0	0.0	16.1
Magensian Limestone	3.1	0.0	20.4
Total	3.1	0.0	111.8

Table 5.6.44. Groundwater resources for Unit 22 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Millstone Grit	371	104	355	111	1.3	0.4	40.8
Permo-Triassic sandstones	122	685	355	165	1.7	0.8	19.4
Magnesian Limestone	109	760	355	155	0.3	0.1	16.7
Carboniferous Limestone	405	1475	355	96	0.0	0.0	38.9
Total					3.3	1.3	115.8

Table 5.6.45. Abstraction of groundwater and balance of resources for Unit 22 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Millstone Grit	1.3	0.4	40.5
Permo-Triassic sandstones	1.7	0.8	19.3
Magnesian Limestone	0.3	0.1	16.6
Carboniferous Limestone	0.0	0.0	38.6
Total	3.3	1.3	115.0

Table 5.6.46. Groundwater resources for Unit 23 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	308	685	355	183	2.6	0.7	55.7
Magnesian Limestone	102	685	355	136	1.3	1.0	12.9
Carboniferous Limestone	489	1195	355	127	1.7	0.3	61.8
Millstone Grit	150	1015	355	98	0.0	0.0	14.6
Middle Jurassic	72	790	355	142	0.0	0.0	10.2
Total					5.6	2.0	155.2

Table 5.6.47. Abstraction of groundwater and balance of resources for Unit 23 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	1.8	0.5	38.0
Magnesian Limestone	0.9	0.7	8.8
Carboniferous Limestone	1.1	0.2	42.1
Millstone Grit	0.0	0.0	10.0
Middle Jurassic	0.0	0.0	7.0
Total	3.8	1.4	105.9

Table 5.6.48. Groundwater resources for Unit 24 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	641	660	405	194	11.3	5.9	118.4
Magnesian Limestone	70	660	405	193	0.0	0.0	13.6
Middle Jurassic	14	710	405	148	0.0	0.0	2.1
Total					11.3	5.9	134.1

Table 5.6.49. Abstraction of groundwater and balance of resources for Unit 24 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	11.8	6.2	123.6
Magnesian Limestone	0.0	0.0	14.2
Middle Jurassic	0.0	0.0	2.2
Total	11.8	6.2	140.0

Table 5.6.50. Groundwater resources for Unit 25 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Middle Jurassic	225	835	380	137	0.0	0.0	34.9
Corallian	370	820	380	380	11.2	5.4	135.2
Total					11.2	5.4	170.1

Table 5.6.51. Abstraction of groundwater and balance of resources for Unit 25 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Middle Jurassic	0.0	0.0	41.1
Corallian	13.2	6.4	159.2
Total	13.2	6.4	200.3

Table 5.6.52. Groundwater resources for Unit 26 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Middle Jurassic	142	810	380	116	0.0	0.0	16.5
Corallian	41	810	380	360	0.0	0.0	14.8
Total					0.0	0.0	31.3

Table 5.6.53. Abstraction of groundwater and balance of resources for Unit 26 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Middle Jurassic	0.0	0.0	90.2
Corallian	0.0	0.0	80.9
Total	0.0	0.0	171.1

Table 5.6.54. Groundwater resources for Unit 27 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Corallian	152	740	405	300	15.5	7.5	38.1
Middle Jurassic	138	780	405	144	0.5	0.0	19.9
Chalk	82	710	405	252	0.0	0.0	20.7
Total					16.0	7.5	78.7

Table 5.6.55. Abstraction of groundwater and balance of resources for Unit 27 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Corallian	27.9	13.5	68.5
Middle Jurassic	0.0	0.0	35.8
Chalk	0.0	0.0	37.2
Total	27.9	13.5	141.5

Table 5.6.56. Groundwater resources for Unit 28 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Permo-Triassic sandstones	165	660	405	175	0.0	0.0	28.9
Middle Jurassic	13	710	405	146	0.0	0.0	1.9
Chalk	71	790	405	371	0.0	0.0	26.4
Total					0.0	0.0	57.2

Table 5.6.57. Abstraction of groundwater and balance of resources for Unit 28 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	0.0	0.0	52.0
Middle Jurassic	0.0	0.0	3.4
Chalk	0.0	0.0	47.5
Total	0.0	0.0	102.9

Table 5.6.58. Groundwater resources for Unit 29 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Middle Jurassic	394	890	430	42	0.0	0.0	16.5

Table 5.6.59. Abstraction of groundwater and balance of resources for Unit 29 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Middle Jurassic	0.0	0.0	33.2

Table 5.6.60. Groundwater resources for Unit 30 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	441	685	430	179	11.3	5.8	73.1

Table 5.6.61. Abstraction of groundwater and balance of resources for Unit 30 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	23.1	25.6	165.8

Table 5.6.62. Groundwater resources for Unit 31 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	414	735	430	201	3.9	2.4	80.8

Table 5.6.63. Abstraction of groundwater and balance of resources for Unit 31 of the Yorkshire Water Authority

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	9.4	5.8	195.2

Table 5.6.64. Groundwater resources for Unit 32 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	628	685	430	121	9.5	7.2	68.8
Middle Jurassic	1	635	430	125	2.2	2.2	-2.1
Total					11.7	9.4	66.7

Table 5.6.65. Abstraction of groundwater and balance of resources for Unit 32 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	15.1	11.4	109.2
Middle Jurassic	3.5	3.5	-3.3
Total	18.6	14.9	105.9

Table 5.6.66. Groundwater resources for Unit 33 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	329	610	430	52	0.1	0.0	17.0

Table 5.6.67. Abstraction of groundwater and balance of resources for Unit 33 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	0.3	0.0	51.7

Table 5.6.68. Groundwater resources for Unit 34 of the Yorkshire Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Permo-Triassic sandstones	53	635	430	166	0.2	0.0	8.8
Chalk	71	710	430	277	2.1	0.0	19.7
Middle Jurassic	23	685	430	121	0.2	0.0	2.8
Total					2.5	0.0	31.3

Table 5.6.69. Abstraction of groundwater and balance of resources for Unit 34 of the Yorkshire Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Permo-Triassic sandstones	0.6	0.0	27.4
Chalk	6.5	0.0	61.2
Middle Jurassic	0.6	0.0	8.7
Total	7.7	0.0	97.3

Table 5.6.70. Areas of Units in the Yorkshire Water Authority (km^2)

Unit	Area	Unit	Area
1	72	18	141
2	191	19	513
3	136	20	496
4	75	21	545
5	283	22	1007
6	82	23	1467
7	106	24	957
8	326	25	849
9	462	26	183
10	95	27	556
11	147	28	498
12	395	29	497
13	308	30	441
14	73	31	414
15	380	32	629
16	212	33	329
17	303	34	320

5.7. Anglian Water Authority

General Features

Anglian Water Authority covers an area of 27 063 km^2 in eastern England. Inland from The Wash, the country is very low-lying, much of it below sea-level over the area known as the Fens. To the north of the Wash is a low-lying coastal plain backed inland by a north-south range of low hills, the Lincolnshire Wolds, formed in the Chalk outcrop and rising to 150 m above sea-level. South of The Wash, the land is generally low-lying, occasionally rising to an altitude of 60 m or so above sea-level where the harder rocks crop out. The coast is exposed to storms, and harbours are relatively few. The major drainage is performed by rivers such as the Great Ouse, the Welland, the Nene and the Stour. In the Fens, much of the drainage is artificial and pumping is necessary to drain the lower areas.

The population in 1974 was 4.8 million. The major towns include Northampton, (population 148 000), Ipswich (123 000), Norwich (120 000), Bedford (108 000), Cambridge (100 000), Peterborough (71 000), Lincoln (74 000), and Chelmsford (58 000).
There was formerly a large fishing industry based on the east coast ports, particularly at Grimsby, Lowestoft and Yarmouth. Although somewhat reduced, this industry still thrives. The area is generally agricultural with industrial developments in the urban areas.
The geology is varied. On the coast, there are extensive outcrops of the Crag, with Tertiary strata appearing further south. Inland, there is a broad outcrop of the Chalk. Westwards again, strata of increasing age crop out, including the Lower Greensand, the Great Oolite limestone and the Lincolnshire Limestone.

Aquifers

The most important aquifers in the area are the Chalk and the Lincolnshire Limestone. Less important are the Crag, the Spilsby Sandstone, the Great Oolite, and the Lower Greensand.

The Crag crops out close to the east coast to the south of The Wash. The deposits are mainly shelly sands, pebbly gravels and sands. The maximum thickness is of the order of 85 m. Aquifer properties have been measured only at a single site at Billesford Hall (TM 437 601) where the transmissivity was 1.1×10^{-2} m^2/s and the specific yield was 5×10^{-3}.

The Chalk north of the Wash has a total thickness of about 100 m. To the south of The Wash, the thickness is barely 50 m, but the formation thickens steadily to about 280 m maximum further south. Transmissivities were measured at 103 sites and the mean value is 1.3×10^{-2} m^2/s (Figure 5.7.2). The values vary considerably from one Unit to another (Table 5.7.1), but with many Units having few determinations, this variation may be misleading. Specific yields are usually of the order of 1×10^{-2}, but, when the aquifer is confined, these values fall to about 1×10^{-4}.

The Spilsby Sandstone outcrops only in Unit 1. The maximum thickness is about 25 m, and the lithology is of soft, greenish-yellow sands with seams of light grey clay. There are no determinations available for the aquifer properties.

The Lower Greensand outcrop is not continuous but is found from the Wash southwards to a point south of Leighton Buzzard. The maximum thickness (between Cambridge and Leighton Buzzard) is about 65 m, but this thickness tends to vary since the sediments were deposited upon an eroded and irregular land surface. The transmissivity reaches some 1.1×10^{-2} m^2/s where the formation is at its greatest thickness, but to the east of Cambridge, where the thickness falls to 10 m or less, the transmissivity is less than 1×10^{-3} m^2/s. Most wells in this formation are in the confined aquifer and the coefficient of storage is generally about 1×10^{-4}.

The Great Oolite limestone is only some 5 m thick in the north of the area, increasing to about 10 m in the south. In the tables attached to this section, this formation is referred to as the Middle Jurassic since much of its water derives from the underlying Estuarine Beds, a succession of clays and clayey sands with occasional limestone. Although the Lincolnshire Limestone is stratigraphically of Middle Jurassic age, it is treated separately since it forms an important aquifer. The Great Oolite tends to contain saline water within a short distance of passing beneath confining beds, and consequently is not greatly developed. No determinations of aquifer properties are available.

The Lincolnshire Limestone is a hard, compact limestone with groundwater flow dominantly through fissures. The outcrop extends from the Humber

Estuary southwards to a point near Peterborough. The maximum thickness, near Grantham, is about 40 m but the formations thin both to the north and to the south and the mean thickness is of the order of 15 m to 20 m. The transmissivity has been determined at 9 sites, with a mean value of 3.3×10^{-2} m^2/s (Figure 5.7.3). These sites were within two Units only (Table 5.7.2), but Unit 3 has a higher mean value than Unit 1. The aquifer is most frequently pumped in the confined area, and the coefficient of storage is usually of the order of 1×10^{-4}. However, it should be noted that where larger fissures are intercepted, wells support large yields, but the density of fissuring is low and there is some risk of a well failing to yield useful supplies of groundwater.

Resources

Yields of wells from the Crag are usually small, rarely being sufficient to supply urban areas. The maximum yields are usually of the order of 0.4×10^6 m^3/a. Average yields are usually less than 0.1×10^6 m^3/a. The importance of the Crag as an aquifer to some extent rests in the fact that groundwater in the underlying Chalk is occasionally saline, leaving the Crag as the only available source.

Yields of wells in the Chalk are variable. Some wells have given yields in excess of 9.0×10^6 m^3/a, but these are exceptional. It is customary to assume that there is always a good chance of obtaining 2.0×10^6 m^3/a. However, particularly in East Anglia, there are areas where the transmissivity is low, and this is reflected in Table 5.7.1. There are also a number of deep channels scoured in the Chalk surface, often over 50 m in depth, which were subsequently filled with superficial sediments of low permeability. These channels are not visible on the present ground surface, but when intersected by a well, or when they are in close proximity to a well, they adversely affect the yield.

The yield from wells in the Spilsby Sandstone is usually fairly small, of the order of 1.0×10^6 m^3/a. Yields up to 3.7×10^6 m^3/a have been recorded.

The Lower Greensand generally yields reliable supplies. Wells of 250 to 300 mm diameter commonly give from 0.2×10^6 m^3/a to 0.5×10^6 m^3/a. With larger diameters, wells penetrating the thicker parts of the aquifer can yield about 2.0×10^6 m^3/a.

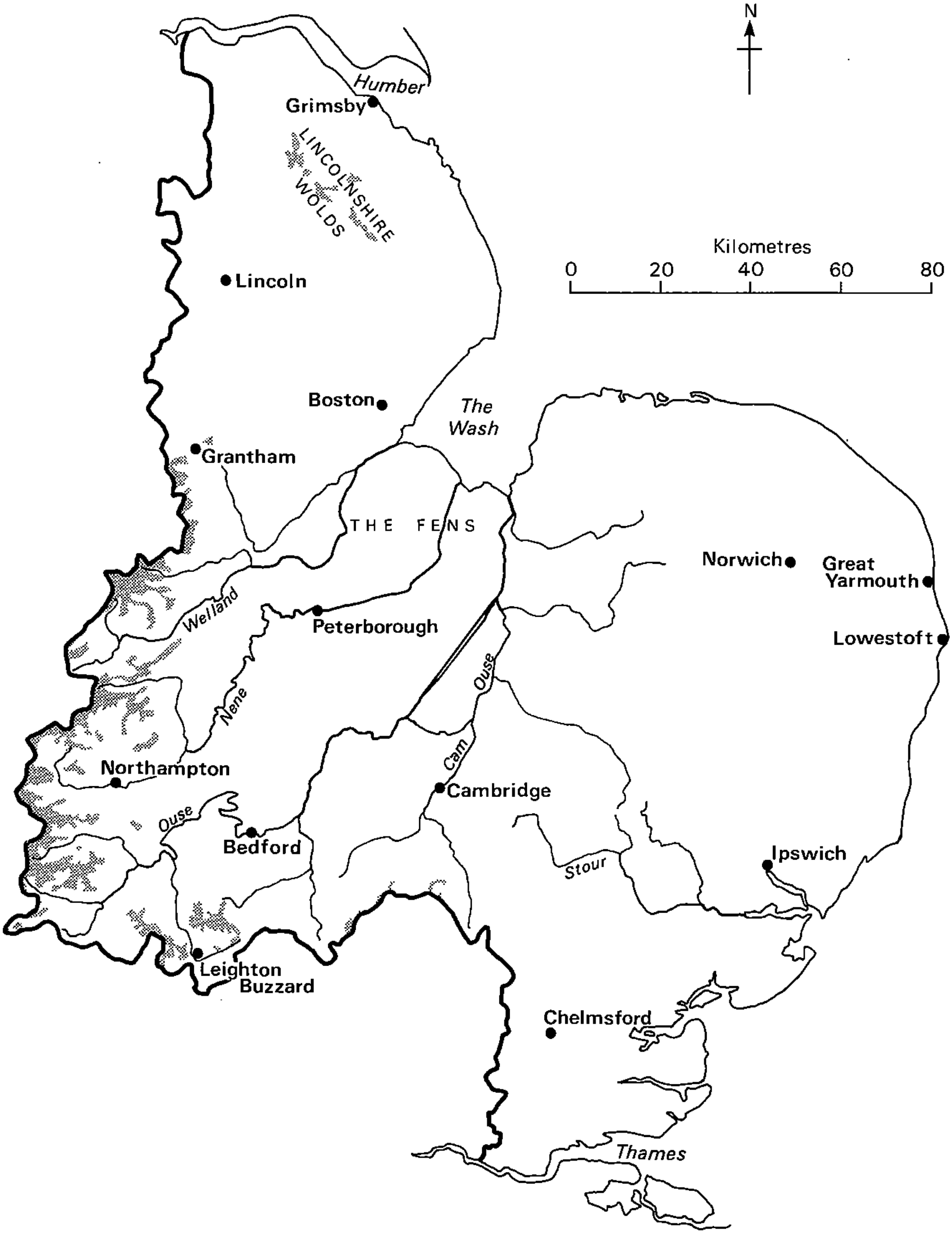

Fig 5.7.1 Location map of the Anglian Water Authority

Wells in the Great Oolite limestone (Middle Jurassic in the accompanying tables) may yield up to 0.4 x 10^6 m^3/a. However, the aquifer is thin, and in the confined areas the groundwater is often non-potable. In consequence, the aquifer is not greatly used.

The Lincolnshire Limestone can yield at very high rates. Single wells are known to have given yields in excess of 8.0 x 10^6 m^3/a and sites with 4 wells have yielded over 12.0 x 10^6 m^3/a. Yields are rather less in the northern half of the aquifer than in the southern. The mean yield in the northern half is about 1.0 x 10^6 m^3/a and in the southern half about 3.0 x 10^6 m^3/a.

Wells constructed in the Chalk, the Middle Jurassic and the Lincolnshire Limestone rarely need lining within the aquifer, the rock standing without support. A few metres only of lining tube is usually sufficient at the top of the well unless a thickness of confining strata is present. Wells in the Spilsby Sandstone, the Lower Greensand and the Crag require sand screens.

Details of the resources are given in Tables 5.7.3 to 5.7.87. In Unit 47 (Table 5.7.85), the details of outcrop area, rainfall, evaporation and infiltration are not known. The balance is shown as zero, assuming the replenishment to be equal to the abstraction. In reality, there may be a surplus. There are no significant resources in Units 4, 5, 6, 7 and 19, and tables for these are omitted.

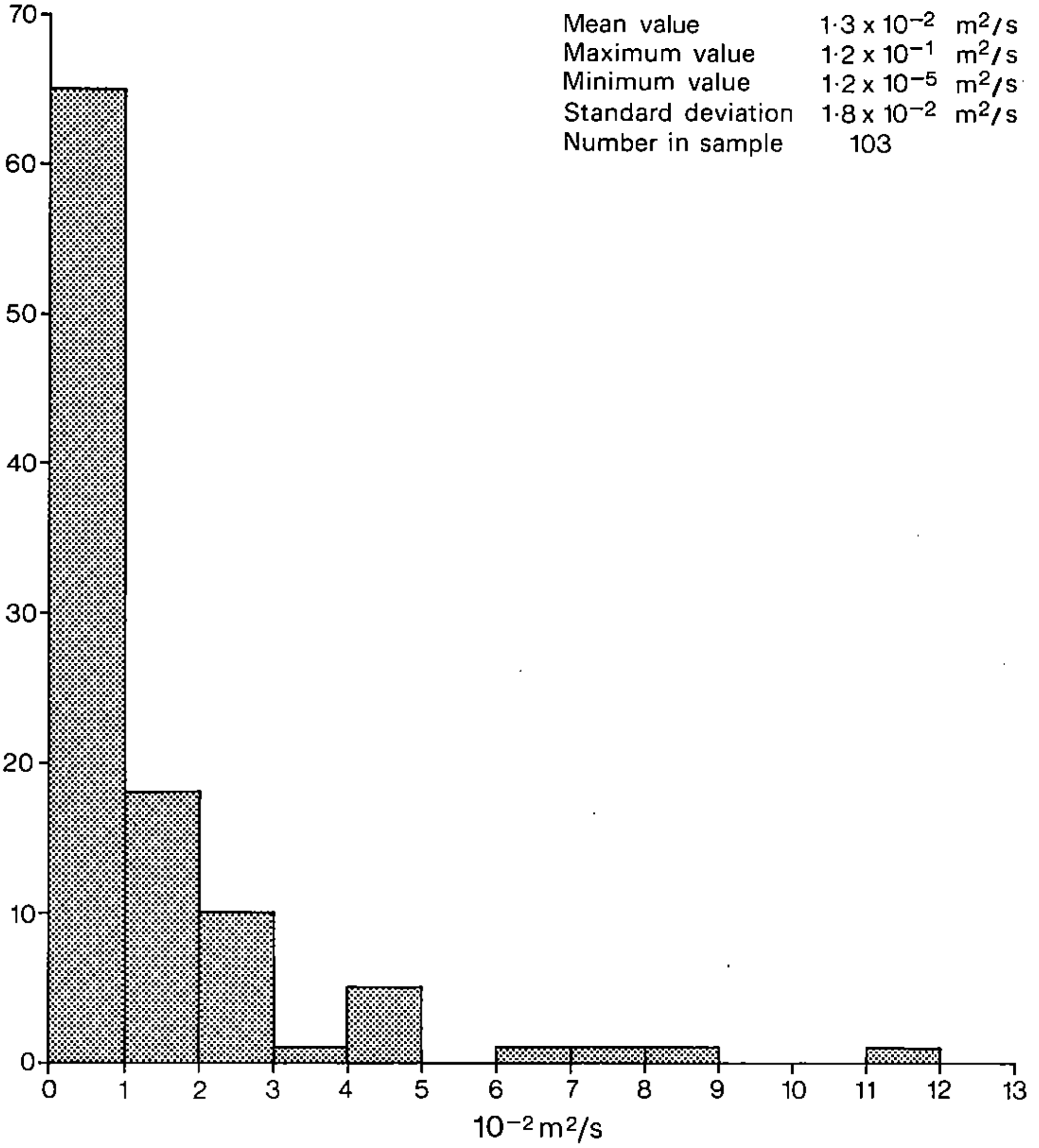

Fig:5.7.2. Transmissivities of the Chalk aquifer in the Anglian Water Authority (m^2/s)

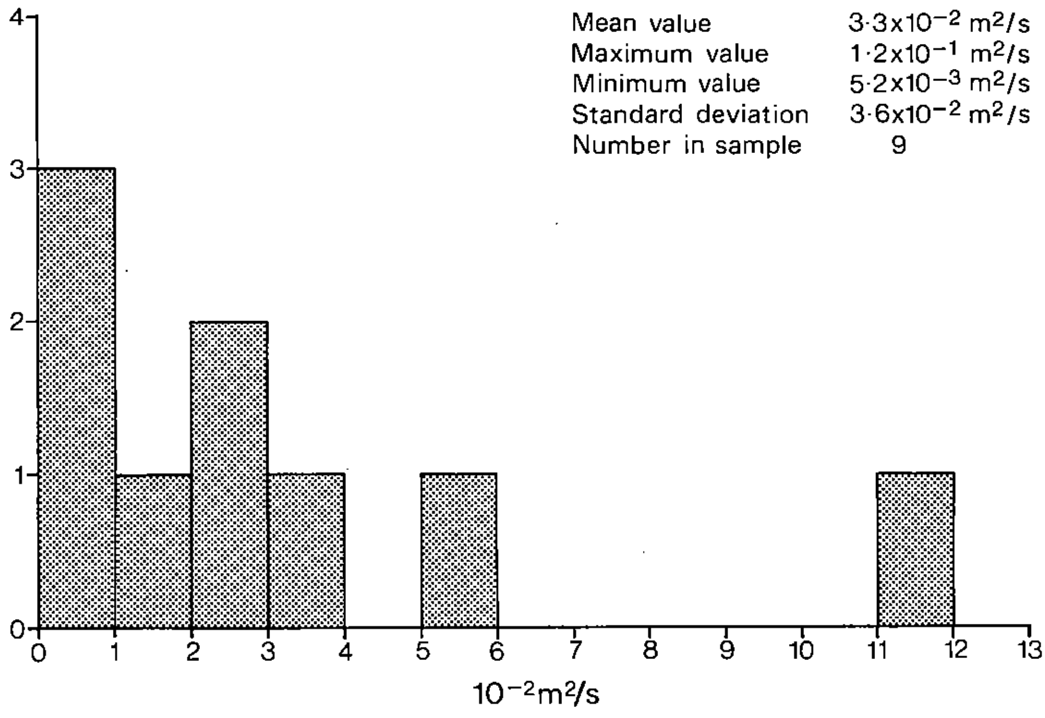

Fig: 5.7.3. Transmissivities of the Lincolnshire Limestone aquifer in the Anglian Water Authority (m^2/s)

Table 5.7.1. Transmissivities in the Chalk aquifer of the Anglian Water Authority

Unit	Number of determinations	Transmissivities (m^2/s) Mean	Maximum	Minimum	Mean as % of overall mean
1	8	4.6×10^{-2}	1.2×10^{-1}	9.4×10^{-3}	350
12	12	1.2×10^{-2}	2.8×10^{-2}	1.3×10^{-3}	92
13	1	1.2×10^{-2}	-	-	92
14	18	1.0×10^{-2}	2.4×10^{-2}	3.5×10^{-3}	77
21	3	2.5×10^{-2}	4.6×10^{-2}	8.8×10^{-3}	192
22	1	8.1×10^{-2}	-	-	623
24	3	3.1×10^{-2}	6.4×10^{-2}	7.0×10^{-3}	238
25	2	2.6×10^{-3}	2.9×10^{-3}	2.4×10^{-3}	20
26	1	3.5×10^{-3}	-	-	27
27	2	4.5×10^{-3}	4.6×10^{-2}	4.4×10^{-3}	35
28	4	7.3×10^{-3}	2.2×10^{-2}	9.5×10^{-4}	56
29	1	4.9×10^{-3}	-	-	38
30	6	3.6×10^{-3}	8.3×10^{-3}	1.0×10^{-3}	28
31	1	3.5×10^{-3}	-	-	27
32	2	1.2×10^{-2}	1.2×10^{-2}	1.2×10^{-2}	92
33	1	7.0×10^{-3}	-	-	54
34	3	4.6×10^{-3}	6.0×10^{-3}	3.5×10^{-3}	35
38	1	3.0×10^{-3}	-	-	23
44	18	7.4×10^{-3}	2.3×10^{-2}	3.5×10^{-4}	57
45	6	3.8×10^{-3}	6.9×10^{-3}	1.2×10^{-5}	29
46	6	4.5×10^{-3}	2.3×10^{-4}	2.3×10^{-4}	35
All Units	103	1.3×10^{-2}	1.2×10^{-1}	1.2×10^{-5}	100

Table 5.7.2. Transmissivities in the Lincolnshire Limestone aquifer of the Anglian Water Authority

Unit	Number of determinations	Transmissivities (m^2/s) Mean	Maximum	Minimum	Mean as % of overall mean
1	6	1.8×10^{-2}	5.3×10^{-2}	5.2×10^{-3}	55
3	3	6.1×10^{-2}	1.2×10^{-1}	3.0×10^{-2}	180
All Units	9	3.3×10^{-2}	1.2×10^{-1}	5.2×10^{-3}	100

Table 5.7.3. Groundwater resources for Unit 1 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	464	668	419	249	79.6	57.6	58.0
Spilsby Sandstone	79	659	419	240	10.9	8.3	10.6
Lincolnshire Limestone	176	629	437	192	14.2	8.4	25.4
Total					104.7	74.3	94.0

Table 5.7.4. Abstraction of groundwater and balance of resources for Unit 1 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	22.5	16.3	16.4
Spilsby Sandstone	3.1	2.3	3.0
Lincolnshire Limestone	4.0	2.4	7.2
Total	29.6	21.0	26.6

Table 5.7.5. Groundwater resources for Unit 2 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Lincolnshire Limestone	209	610	424	186	9.8	5.1	33.8

Table 5.7.6. Abstraction of groundwater and balance of resources for Unit 2 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Lincolnshire Limestone	7.4	3.8	25.5

Table 5.7.7. Groundwater resources for Unit 3 of the Anglian Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Lincolnshire Limestone	121	609	447	109	50.0	29.2	-16.0

Table 5.7.8. Abstraction of groundwater and balance of resources for Unit 3 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	10^3 m^3/km^2	10^3 m^3/km^2	10^3 m^3/km^2
Lincolnshire Limestone	57.0	33.3	-18.3

Table 5.7.9. Groundwater resources for Unit 8 of the Anglian Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Middle Jurassic	20	670	445	225	1.9	1.9	2.6

Table 5.7.10. Abstraction of groundwater and balance of resources for Unit 8 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	10^3 m^3/km^2	10^3 m^3/km^2	10^3 m^3/km^2
Middle Jurassic	2.3	2.3	3.2

Table 5.7.11. Groundwater resources for Unit 9 of the Anglian Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Middle Jurassic	1	670	445	225	0.0	0.0	0.2
Lower Greensand	53	622	460	116	10.3	7.4	-1.2
Chalk	70	663	434	229	0.1	0.0	16.1
Total					10.4	7.4	15.1

Table 5.7.12. Abstraction of groundwater and balance of resources for Unit 9 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	10^3 m^3/km^2	10^3 m^3/km^2	10^3 m^3/km^2
Middle Jurassic	0.0	0.0	0.5
Lower Greensand	27.6	19.8	-3.2
Chalk	0.3	0.0	43.2
Total	27.9	19.8	40.5

Table 5.7.13. Groundwater resources for Unit 10 of the Anglian Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Lower Greensand	124	577	456	90	6.9	5.0	6.1
Chalk	241	634	428	196	13.5	7.4	39.6
Total					20.4	12.4	45.7

Table 5.7.14. Abstraction of groundwater and balance of resources for Unit 10 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	10^3 m^3/km^2	10^3 m^3/km^2	10^3 m^3/km^2
Lower Greensand	11.5	8.3	10.2
Chalk	22.5	12.3	66.0
Total	34.0	20.6	76.2

Table 5.7.15. Groundwater resources for Unit 11 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Middle Jurassic	5	670	445	225	1.9	0.4	0.7
Lower Greensand	14	585	470	74	0.0	0.0	1.0
Total					1.9	0.4	1.7

Table 5.7.16. Abstraction of groundwater and balance of resources for Unit 11 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Middle Jurassic	1.3	0.3	0.5
Lower Greensand	0.0	0.0	0.7
Total	1.3	0.3	1.2

Table 5.7.17. Groundwater resources for Unit 12 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Lower Greensand	16	567	462	45	4.3	3.2	-2.5
Chalk	782	587	421	131	52.6	30.2	72.3
Total					56.9	33.4	69.8

Table 5.7.18. Abstraction of groundwater and balance of resources for Unit 12 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Lower Greensand	3.9	2.9	-2.3
Chalk	47.7	27.4	65.5
Total	51.6	30.3	63.2

Table 5.7.19. Groundwater resources for Unit 13 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	460	611	425	104	20.0	14.0	33.8

Table 5.7.20. Abstraction of groundwater and balance of resources for Unit 13 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	33.4	23.4	56.4

Table 5.7.21. Groundwater resources for Unit 14 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	735	626	427	85	12.6	6.5	56.0

Table 5.7.22. Abstraction of groundwater and balance of resources for Unit 14 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	14.2	7.3	63.3

Table 5.7.23. Groundwater resources for Unit 15 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Lower Greensand	2	635	443	115	0.0	0.0	0.2
Chalk	399	665	436	139	8.1	6.4	49.0
Total					8.1	6.4	49.2

Table 5.7.24. Abstraction of groundwater and balance of resources for Unit 15 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Lower Greensand	0.0	0.0	0.4
Chalk	16.4	13.0	99.2
Total	16.4	13.0	99.6

Table 5.7.25. Groundwater resources for Unit 16 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Lower Greensand	26	537	439	86	0.3	0.3	2.0
Chalk	73	592	422	129	0.5	0.3	9.1
Total					0.8	0.6	11.1

Table 5.7.26. Abstraction of groundwater and balance of resources for Unit 16 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Lower Greensand	0.7	0.7	4.7
Chalk	1.2	0.7	21.4
Total	1.9	1.4	26.1

Table 5.7.27. Groundwater resources for Unit 17 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Lower Greensand	26	672	443	212	1.0	0.4	5.1
Chalk	189	687	440	161	0.8	0.2	30.2
Total					1.8	0.6	35.3

Table 5.7.28. Abstraction of groundwater and balance of resources for Unit 17 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Lower Greensand	4.3	1.7	22.1
Chalk	3.5	0.9	130.7
Total	7.8	2.6	152.8

Table 5.7.29. Groundwater resources for Unit 18 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Lower Greensand	170	616	443	134	0.1	0.0	22.8
Chalk	332	635	429	171	26.0	15.6	41.1
Total					26.1	15.6	63.9

Table 5.7.30. Abstraction of groundwater and balance of resources for Unit 18 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Lower Greensand	0.2	0.0	36.5
Chalk	41.6	25.0	65.8
Total	41.8	25.0	102.3

Table 5.7.31. Groundwater resources for Unit 20 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	160	641	488	92	0.4	0.9	13.8

Table 5.7.32. Abstraction of groundwater and balance of resources for Unit 20 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	1.4	3.2	48.5

Table 5.7.33. Groundwater resources for Unit 21 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	142	648	478	100	25.9	1.7	12.6

Table 5.7.34. Abstraction of groundwater and balance of resources for Unit 21 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	175.0	11.5	85.1

Table 5.7.35. Groundwater resources for Unit 22 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	115	670	470	120	0.4	0.1	13.8

Table 5.7.36. Abstraction of groundwater and balance of resources for Unit 22 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	3.5	0.9	120.0

Table 5.7.37. Groundwater resources for Unit 23 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	77	645	460	100	1.5	1.0	6.7

Table 5.7.38. Abstraction of groundwater and balance of resources for Unit 23 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	11.8	7.9	52.9

Table 5.7.39. Groundwater resources for Unit 24 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	331	690	475	120	3.0	2.2	37.9

Table 5.7.40. Abstraction of groundwater and balance of resources for Unit 24 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	8.8	6.5	110.1

Table 5.7.41. Groundwater resources for Unit 25 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	62	660	475	100	1.0	0.5	5.7

Table 5.7.42. Abstraction of groundwater and balance of resources for Unit 25 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	16.1	8.1	91.9

Table 5.7.43. Groundwater resources for Unit 26 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	49	648	455	140	1.2	0.3	6.6
Crag	74	630	470	50	0.0	0.0	3.7
Total					1.2	0.3	10.3

Table 5.7.44. Abstraction of groundwater and balance of resources for Unit 26 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	9.8	2.4	53.7
Crag	0.0	0.0	30.1
Total	9.8	2.4	83.8

Table 5.7.45. Groundwater resources for Unit 27 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	164	625	463	76	2.7	2.4	10.1
Crag	104	630	470	50	0.0	0.0	5.2
Total					2.7	2.4	15.3

Table 5.7.46. Abstraction of groundwater and balance of resources for Unit 27 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	10.1	9.0	37.7
Crag	0.0	0.0	19.4
Total	10.1	9.0	57.1

Table 5.7.47. Groundwater resources for Unit 28 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	560	685	465	133	7.2	3.7	70.8

Table 5.7.48. Abstraction of groundwater and balance of resources for Unit 28 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	12.9	6.6	126.4

Table 5.7.49. Groundwater resources for Unit 29 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	77	681	481	64	0.5	0.0	4.9

Table 5.7.50. Abstraction of groundwater and balance of resources for Unit 29 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	6.5	0.0	63.6

Table 5.7.51. Groundwater resources for Unit 30 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	280	682	471	94	6.1	2.7	23.6

Table 5.7.52. Abstraction of groundwater and balance of resources for Unit 30 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	21.7	9.6	84.1

Table 5.7.53. Groundwater resources for Unit 31 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	186	673	468	76	1.3	0.1	14.0

Table 5.7.54. Abstraction of groundwater and balance of resources for Unit 31 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	7.0	0.5	75.3

Table 5.7.55. Groundwater resources for Unit 32 of the Anglian Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	306	641	479	39	8.2	2.7	9.2

Table 5.7.56. Abstraction of groundwater and balance of resources for Unit 32 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	26.3	8.7	29.5

Table 5.7.57. Groundwater resources for Unit 33 of the Anglian Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	153	678	498	43	4.6	3.5	3.1

Table 5.7.58. Abstraction of groundwater and balance of resources for Unit 33 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	30.1	22.9	20.3

Table 5.7.59. Groundwater resources for Unit 34 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	200	648	483	43	1.2	0.9	7.7

Table 5.7.60. Abstraction of groundwater and balance of resources for Unit 34 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	5.4	4.0	34.6

Table 5.7.61. Groundwater resources for Unit 35 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	318	648	473	43	4.1	4.6	9.1

Table 5.7.62. Abstraction of groundwater and balance of resources for Unit 35 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	10.4	11.6	23.0

Table 5.7.63. Groundwater resources for Unit 36 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	219	629	476	52	7.0	3.5	7.9

Table 5.7.64. Abstraction of groundwater and balance of resources for Unit 36 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	32.0	16.0	36.1

Table 5.7.65. Groundwater resources for Unit 37 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Crag	103	630	470	50	0.4	0.3	4.9

Table 5.7.66. Abstraction of groundwater and balance of resources for Unit 37 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Crag	3.9	2.9	47.6

Table 5.7.67. Groundwater resources for Unit 38 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	211	615	483	53	4.2	2.8	8.5

Table 5.7.68. Abstraction of groundwater and balance of resources for Unit 38 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	18.5	12.3	37.4

Table 5.7.69. Groundwater resources for Unit 39 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	172	631	479	60	2.0	1.8	8.5

Table 5.7.70. Abstraction of groundwater and balance of resources for Unit 39 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	11.3	10.2	48.1

Table 5.7.71. Groundwater resources for Unit 40 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Crag	109	612	482	56	0.5	0.4	5.8

Table 5.7.72. Abstraction of groundwater and balance of resources for Unit 40 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Crag	4.6	3.7	53.2

Table 5.7.73. Groundwater resources for Unit 41 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Crag	112	610	490	55	0.7	0.4	5.8

Table 5.7.74. Abstraction of groundwater and balance of resources for Unit 41 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Crag	6.1	3.5	50.4

Table 5.7.75. Groundwater resources for Unit 42 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Crag	145	610	485	78	1.2	0.6	10.7

Table 5.7.76. Abstraction of groundwater and balance of resources for Unit 42 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Crag	7.3	3.6	64.8

Table 5.7.77. Groundwater resources for Unit 43 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	763	611	469	62	30.8	20.4	26.9

Table 5.7.78. Abstraction of groundwater and balance of resources for Unit 43 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	36.9	24.5	32.3

Table 5.7.79. Groundwater resources for Unit 44 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	556	566	450	71	53.4	22.9	16.7

Table 5.7.80. Abstraction of groundwater and balance of resources for Unit 44 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	54.6	23.4	17.1

Table 5.7.81. Groundwater resources for Unit 45 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	38	545	438	47	12.5	3.7	-1.9

Table 5.7.82. Abstraction of groundwater and balance of resources for Unit 45 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	18.1	5.4	-2.75

Table 5.7.83. Groundwater resources for Unit 46 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	64	568	437	121	10.6	6.0	1.8

Table 5.7.84. Abstraction of groundwater and balance of resources for Unit 46 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	8.8	5.0	1.5

Table 5.7.85. Groundwater resources for Unit 47 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	nk	nk	nk	nk	1.6	1.5	0.0

Table 5.7.86. Abstraction of groundwater and balance of resources for Unit 47 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	3.1	2.9	0.0

Table 5.7.87. Groundwater resources for Unit 48 of the Anglian Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	31	559	435	112	13.2	9.2	-5.7

Table 5.7.88. Abstraction of groundwater and balance of resources for Unit 48 of the Anglian Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	63.2	44.1	-27.3

The Lower Greensand is absent beneath the Chalk of the central London Basin, but is present to the west where 60 m occurs at depth beneath Slough. It is difficult to apply the classical divisions of Folkestone Beds, Sandgate Beds and Hythe Beds, except in the south along the border with the Southern Water Authority. The outcrop on the north side of the London Basin is discontinuous, and the formation tends to thicken beneath cover. The transmissivity was determined at one site in Unit 21 where a value of 2.5×10^{-3} m^2/s was obtained, with a coefficient of storage of 4.0×10^{-4}.

The Upper Greensand aquifer comprises medium- to fine-grained glauconitic sands, and immediately underlies the Chalk, with which it is in hydraulic continuity. The maximum thickness is approximately 30 m at Calne but often falls to 3 or 4 m in the east. A single transmissivity determination in Unit 11 gave a value of 2.5×10^{-3} m^2/s and a coefficient of storage of 8.0×10^{-4}. However, because of its hydraulic continuity with the Chalk and its thinness relative to that aquifer, the Upper Greensand is included with the Chalk and is not credited in the resource tables with a separate identity.

The Chalk has its maximum thickness on the south side of the London Basin where it reaches approximately 245 m. On the north side of the Basin, the thickness reaches 200 m, while westwards the thickness falls to 180 m. However, groundwater flows through the Chalk through fissures, and the density of these decreases with depth. The effective saturated thickness is usually between 50 and 75 m, and drilling to greater depths rarely provides a well with a greater yield. The transmissivity as determined at 16 sites is shown on Figure 5.8.2. The mean transmissivity is 6.8×10^{-3} m^2/s, ranging from 3.0×10^{-4} to 2.0×10^{-2} m^2/s. There is some variation between Units (Table 5.8.1), but there are too few determinations in some Units to put great reliance on the values. The mean specific yield in the unconfined aquifer is 1.4×10^{-2}, while the mean coefficient of storage in the confined aquifer is 4.5×10^{-4}.

There are other, lesser aquifers in the upper Tertiary and in the Middle Lias (of the Lower Jurassic). However, these have not been extensively studied, and are not included in this report.

Resources

Wells in the Middle Jurassic aquifer can give very large yields, the maximum recorded in 1977 was 8.5 x 10^6 m^3 in Unit 9. The normal yield is between 0.4 and 1.0 x 10^6 m^3/a. In the more massive limestones, the fissures may be sparsely distributed and it is possible for a well to fail to intersect them and therefore to be dry. Beneath cover, the groundwater quickly becomes saline, and it is speculative to drill wells more than 3 km from the outcrop.

Wells in the Lower Greensand can yield over 5.0 x 10^6 m^3/a, but the usual yield is of the order of 1.0 x 10^6 m^3/a. The volume of groundwater in storage can be very large, and wells in the Slough area have been pumped at high rates for many years despite a very limited recharge.

In the Chalk, many hand-dug wells have been constructed comprising shafts with horizontal adits driven for distances of several kilometres. In more recent times, it has proved more economic to construct wells by boring with machinery. Yields from a single site can be large, the greatest recorded in 1977 being 9.5 x 10^6 m^3. Yields in excess of 1.0 x 10^6 m^3/a can usually be obtained unless the well is constructed on high ground remote from valleys. Experience has shown that the best yields are obtained where wells are constructed on the lower ground where the fissuring is better developed.

Wells in the Upper Greensand are usually constructed only where the Chalk is absent or contains no groundwater. Yields are usually small, less than 0.2 x 10^6 m^3/a, and the maximum is unlikely to exceed 0.5 x 10^6 m^3/a.

Wells in the upper Tertiary beds or in the Lias have usually a very small yield, suitable for isolated domestic supplies or for small agricultural requirements.

Wells constructed in the Middle Jurassic limestones or in the Chalk rarely require support other than a few metres of lining tubes near to the ground surface. Where they are overlain by drift, or by clays and sands, these require lining tubes. Wells constructed in the Upper Greensand, the Lower Greensand and the Tertiary beds require lining throughout with sand screens within the aquifer. The Lias also requires lining throughout.

The resources of the individual Units are shown in Tables 5.8.2 to 5.8.47. In a few Units, parameters such as outcrop area, rainfall, evaporation and infiltration are inadequately known, and in these cases the balance is shown as zero, assuming the replenishment to be equal to the abstraction. In reality there is surplus, although a small one. The Chalk in Units in the central part of the London Basin is totally confined, and the balance is shown in these cases as a deficiency. Replenishment is afforded by groundwater flow from Units where the Chalk is present in outcrop, and these movements are indicated on the accompanying maps (see Chapter 4). A large surplus in one of these latter Units will not, therefore, necessarily be available for exploitation, but must be considered together with the deficiences of the confined aquifer.

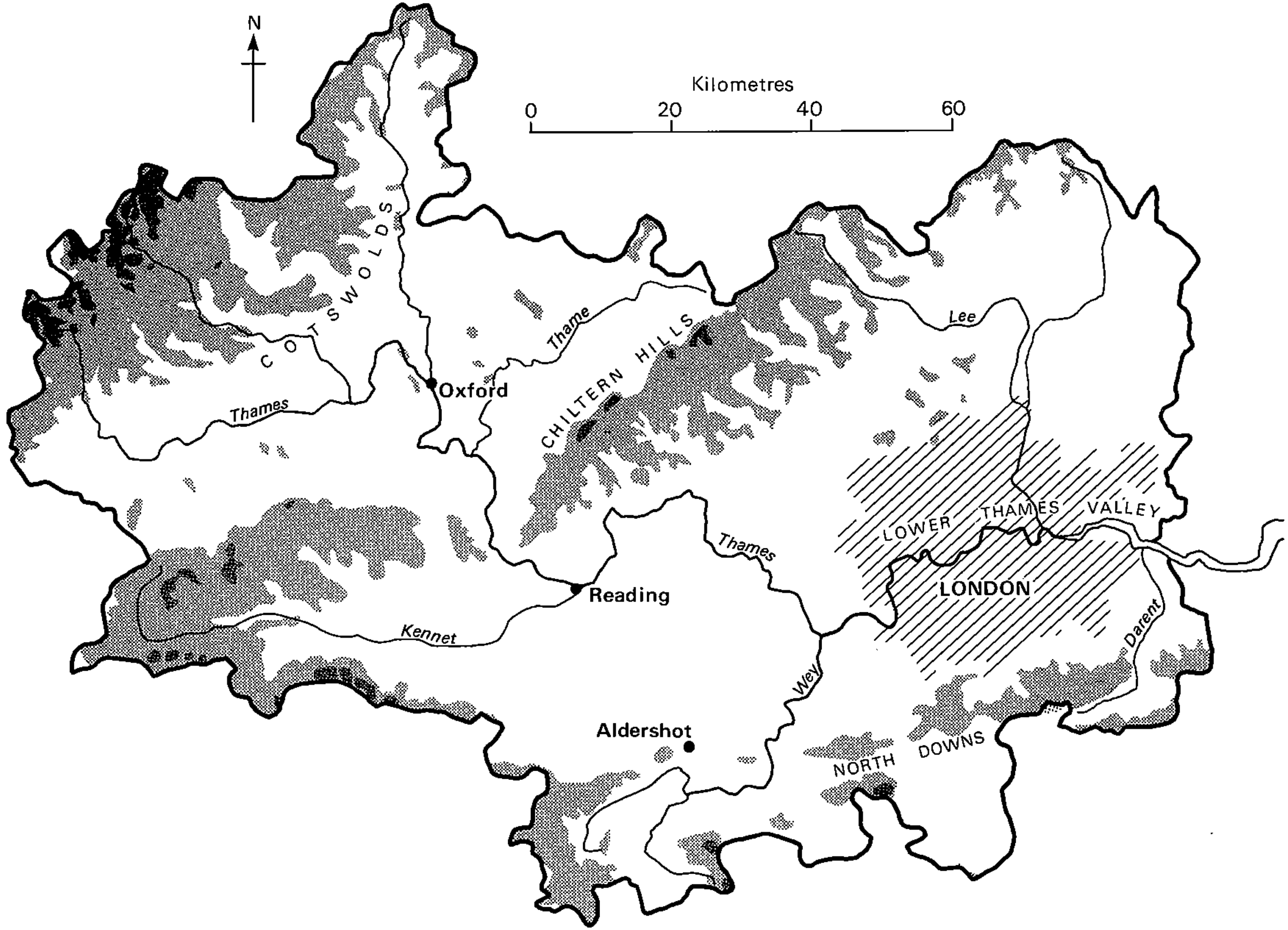

Fig 5.8.1 Location map of the Thames Water Authority

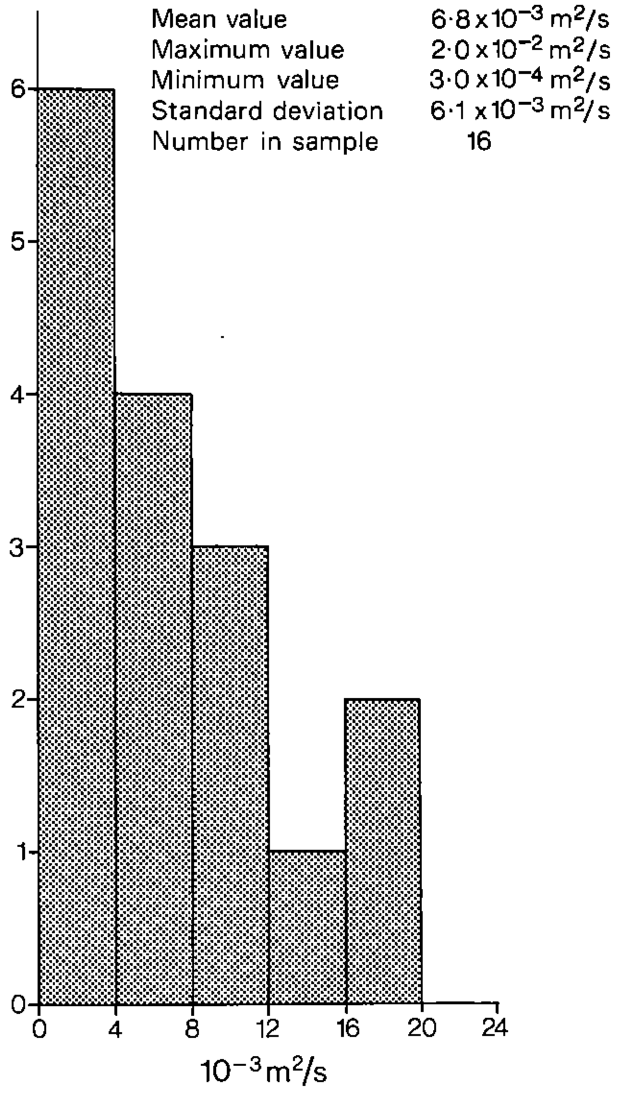

Fig: 5.8.2. Transmissivities of the Chalk aquifer in the Thames Water Authority (m^2/s)

Table 5.8.1. Transmissivities in the Chalk aquifer of the Thames Water Authority (m^2/s)

Unit	Number of determinations	Mean	Minimum	Maximum	Mean as % of overall mean
7	6	3.0×10^{-3}	3.0×10^{-4}	8.2×10^{-3}	44
12	7	7.6×10^{-3}	1.7×10^{-3}	1.4×10^{-2}	111
13	2	9.0×10^{-3}	5.8×10^{-4}	1.7×10^{-2}	132
22	1	2.0×10^{-2}	-	-	294
All Units	16	6.8×10^{-3}	3.0×10^{-4}	2.0×10^{-2}	100

Table 5.8.2. Groundwater resources for Unit 1 of the Thames Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	$10^6\ m^3$	$10^6\ m^3$	$10^6\ m^3$
Chalk	103	663	457	206	63.2	43.9	-22.7

Table 5.8.3. Abstraction of groundwater and balance of resources for Unit 1of the Thames Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	$10^3\ m^3/km^2$	$10^3\ m^3/km^2$	$10^3\ m^3/km^2$
Chalk	330.9	229.8	-118.8

Table 5.8.4. Groundwater resources for Unit 2 of the Thames Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	$10^6\ m^3$	$10^6\ m^3$	$10^6\ m^3$
Chalk	110	660	457	203	12.0	6.2	16.2

Table 5.8.5. Abstraction of groundwater and balance of resources for Unit 2 of the Thames Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	$10^3\ m^3/km^2$	$10^3\ m^3/km^2$	$10^3\ m^3/km^2$
Chalk	100.0	51.7	135.0

Table 5.8.6. Groundwater resources for Unit 3 of the Thames Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	92	658	462	196	16.6	13.7	4.4

Table 5.8.7. Abstraction of Groundwater and balance of resources for Unit 3 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	100.6	83.0	26.7

Table 5.8.8. Groundwater resources for Unit 4 of the Thames Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	60	653	455	198	9.0	6.7	5.2

Table 5.8.9. Abstraction of groundwater and balance of resources for Unit 4 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	64.7	48.2	37.4

Table 5.8.10. Groundwater resources for Unit 5 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	49	645	462	183	1.7	0.8	8.1

Table 5.8.11. Abstraction of groundwater and balance of resources for Unit 5 of the Thames Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	19.5	9.2	93.1

Table 5.8.12. Groundwater resources for Unit 6 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	22	643	447	196	14.1	8.9	-4.6

Table 5.8.13. Abstraction of groundwater and balance of resources for Unit 6 of the Thames Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	52.8	33.3	-17.2

Table 5.8.14. Groundwater resources for Unit 7 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	11	649	444	205	74.5	17.2	-14.9

Table 5.8.15. Abstraction of groundwater and balance of resources for Unit 7 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	182.2	42.1	-36.4

Table 5.8.16. Groundwater resources for Unit 8 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	0	0	0	0	14.3	10.7	-10.7

Table 5.8.17. Abstraction of groundwater and balance of resources for Unit 8 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	25.3	18.9	-18.9

Table 5.8.18. Groundwater resources for Unit 9 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Middle Jurassic	801	805	467	304	17.2	18.7	224.8

Table 5.8.19. Abstraction of groundwater and balance of resources for Unit 9 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Middle Jurassic	13.3	14.4	173.2

Table 5.8.20. Groundwater resources for Unit 10 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Middle Jurassic	140	734	475	233	0.7	0.4	32.2

Table 5.8.21. Abstraction of groundwater and balance of resources for Unit 10 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Middle Jurassic	0.5	0.3	22.8

Table 5.8.22. Groundwater resources for Unit 11 of the Thames Water Authority

Aquifer	outcrop area (km^2)	mean annual rainfall (mm)	mean annual evaporation (mm)	mean annual infiltration (mm)	licensed abstraction (annual) (10^6 m^3)	actual abstraction (1977) (10^6 m^3)	balance of resources (1977) (10^6 m^3)
Chalk	282	708	478	207	9.6	6.2	52.2

Table 5.8.23. Abstraction of groundwater and balance of resources for Unit 11 of the Thames Water Authority (1977)

Aquifer	licensed abstraction (10^3 m^3/km^2)	actual abstraction (10^3 m^3/km^2)	balance of resources (10^3 m^3/km^2)
Chalk	6.5	4.2	35.2

Table 5.8.24. Groundwater resources for Unit 12 of the Thames Water Authority

Aquifer	outcrop area (km^2)	mean annual rainfall (mm)	mean annual evaporation (mm)	mean annual infiltration (mm)	licensed abstraction (annual) (10^6 m^3)	actual abstraction (1977) (10^6 m^3)	balance of resources (1977) (10^6 m^3)
Chalk	789	779	480	270	38.2	20.2	192.8

Table 5.8.25. Abstraction of groundwater and balance of resources for Unit 12 of the Thames Water Authority (1977)

Aquifer	licensed abstraction (10^3 m^3/km^2)	actual abstraction (10^3 m^3/km^2)	balance of resources (10^3 m^3/km^2)
Chalk	33.0	17.5	166.8

Table 5.8.26. Groundwater resources for Unit 13 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	135	779	480	270	20.6	13.8	22.7

Table 5.8.27. Abstraction of groundwater and balance of resources for Unit 13 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	113.8	76.2	125.4

Table 5.8.28. Groundwater resources for Unit 14 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	117	737	488	224	8.0	2.6	23.6

Table 5.8.29. Abstraction of groundwater and balance of resources for Unit 14 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	30.0	9.7	88.4

Table 5.8.30. Groundwater resources for Unit 15 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	335	737	488	224	38.9	19.8	55.2

Table 5.8.31. Abstraction of groundwater and balance of resources for Unit 15 of the Thames Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	104.3	53.1	148.0

Table 5.8.32. Groundwater resources for Unit 16 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	133	737	488	224	27.8	14.9	14.9

Table 5.8.33. Abstraction of groundwater and balance of resources for Unit 16 of the Thames Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	209.0	112.0	112.0

Table 5.8.34. Groundwater resources for Unit 17 of the Thames Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	$10^6\ m^3$	$10^6\ m^3$	$10^6\ m^3$
Chalk	692	729	467	236	207.7	141.1	22.2

Table 5.8.35. Abstraction of groundwater and balance of resources for Unit 17 of the Thames Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	198.8	135.0	21.2

Table 5.8.36. Groundwater resources for Unit 18 of the Thames Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	$10^6\ m^3$	$10^6\ m^3$	$10^6\ m^3$
Lower Greensand	nk	nk	nk	nk	2.3	1.7	0.0
Chalk	145	818	480	304	26.2	20.1	24.0
Total					28.5	21.8	24.0

Table 5.8.37. Abstraction of groundwater and balance of resources for Unit 18 of the Thames Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Lower Greensand	3.5	2.6	0.0
Chalk	40.1	30.8	36.8
Total	43.6	33.4	36.8

Table 5.8.38. Groundwater resources for Unit 19 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	85	737	488	224	4.1	59.2	-40.2

Table 5.8.39. Abstraction of groundwater and balance of resources for Unit 19 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	20.5	296.0	-201.0

Table 5.8.40. Groundwater resources for Unit 20 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Lower Greensand	nk	nk	nk	nk	5.1	4.6	0.0
Chalk	8	756	474	254	18.2	35.5	-33.5
Total					23.3	40.1	-33.5

Table 5.8.41. Abstraction of groundwater and balance of resources for Unit 20 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Lower Greensand	7.0	6.3	0.0
Chalk	25.1	48.9	-46.1
Total	32.1	55.2	-46.1

Table 5.8.42. Groundwater resources for Unit 21 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Lower Greensand	361	826	483	309	31.5	17.7	93.8
Chalk	228	818	480	304	16.8	13.0	56.3
Total					48.3	30.7	150.1

Table 5.8.43. Abstraction of groundwater and balance of resources for Unit 21 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Lower Greensand	29.2	16.4	86.9
Chalk	15.6	12.0	52.1
Total	44.8	28.4	139.0

Table 5.8.44. Groundwater resources for Unit 22 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Lower Greensand	44	818	483	302	9.0	5.7	7.6
Chalk	277	799	456	308	95.3	61.3	24.0
Total					104.3	67.0	31.6

Table 5.8.45. Abstraction of groundwater and balance of resources for Unit 22 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Lower Greensand	8.5	5.4	7.2
Chalk	90.1	57.9	22.7
Total	98.6	63.3	29.9

Table 5.8.46. Groundwater resources for Unit 23 of the Thames Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Lower Greensand	55	801	472	329	20.8	14.7	3.5
Chalk	268	694	450	244	92.8	63.9	1.5
Total					113.6	78.6	5.0

Table 5.8.47. Abstraction of groundwater and balance of resources for Unit 23 of the Thames Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Lower Greensand	51.4	36.3	8.6
Chalk	229.1	157.8	3.7
Total	280.5	194.1	12.3

Table 5.8.48. Areas of Units in the Thames Water Authority (km^2)

Unit	Area	Unit	Area
1	191	13	181
2	120	14	267
3	165	15	373
4	139	16	133
5	87	17	1045
6	267	18	653
7	409	19	200
8	565	20	726
9	1298	21	1080
10	1415	22	1058
11	1482	23	405
12	1156		

5.9 Southern Water Authority

General Features

The Southern Water Authority covers an area of 10 588 km^2 along the southern coast of England, from the border with the Wessex Water Authority in the west to the headland of the North Foreland in the east (Fig 2.1). To the east and to the south, this area is bounded by the sea. High ground is restricted to the North Downs, the South Downs, to a lesser extent the centre of the Weald (Figure 5.9.1), and to the Hampshire Downs in the west. However, altitudes of 240 m are rarely exceeded. Low-lying areas comprise Romney Marsh in the east, the Vale of Kent, the Vale of Sussex, and the coastal plain around Portsmouth.

Numerous short rivers drain the area, many of these being typical "Chalk streams", with a large base flow (groundwater component) and consequently small variations in seasonal flow.

The total population in 1974 was of the order of 3.8 million, although there is a large influx of tourists during the summer months. The principal towns include Southampton (population 214 000), Portsmouth (207 000), Winchester (32 000), Worthing (89 000), Brighton (164 000), Eastbourne (70 000), Tunbridge Wells (45 000) and Canterbury (36 000).

Industrial areas, mostly in cement manufacture, are located near Chatham, and other industrial areas are found in Brighton, Portsmouth and Southampton. Some coal is mined in the country south of Canterbury but most of the remaining area is agricultural. There is a major seaport at Southampton, major cross-Channel ports at Dover and Folkestone and large naval dockyards at Portsmouth and Chatham.

The geology is dominated by an upfold of Lower Cretaceous strata in the Weald. Surrounding this is an extensive outcrop of the Chalk which forms the most important aquifer in the authority area. Around Southampton and Portsmouth, a downfold structure contains Tertiary strata.

Aquifers

The maximum thickness of the Hastings Beds is of the order of 425 m. The full succession comprises:

Tunbridge Wells Sand	55 to 120 m thick

Wadhurst Clay(aquiclude)	70 m thick
Ashdown Sand	50 to 150 m thick

The Ashdown Sand consists of fine-grained, silty sandstones and siltstones with subordinate amounts of mudstone and shale. The Lower Tunbridge Wells Sand comprises interbedded silts and fine, silty sandstones, while the Upper Tunbridge Wells Sand consists of a series of lenticular and interbedded mudstones, silts, sandstones and occasionally clay ironstones. The intervening argillaceous beds, the Grinstead and Wadhurst clays, comprise shales and mudstones, often fairly well fissured, and form only a moderate barrier to the passage of groundwater between the sandy horizons. Aquifer properties have been determined at only one site, in Unit 4, where a transmissivity of 4.6×10^{-4} m^2/s and a coefficient of storage of 1×10^{-4} were obtained.

At its maximum, the Lower Greensand attains a thickness of approximately 200 m, but the thickness is variable, and in many areas, particularly to the south, it falls below 50 m. The Lower Greensand is divided where possible into four lithological divisions:

Folkestone Beds	0 to 60 m thick
Sandgate Beds	15 to 40 m thick
Hythe Beds	10 to 110 m thick
Atherfield Clay	5 to 15 m thick

The Atherfield Clay consists of clay and soft mudstone and does not form an aquifer. The Hythe Beds have a variable lithology, but comprise generally a succession of calcareous and argillaceous sandstones. In the east, thin sandy limestones are found.

The Sandgate Beds consist of interbedded argillaceous sands and silty mudstones, and form a poor aquifer. The Folkestone Beds consist predominantly of poorly consolidated sands with seams of clay and occasional iron-cemented "doggers". The transmissivity in the Lower Greensand has been determined at three sites (in Units 24, 26 and 36), where values ranging from 1.3×10^{-4} m^2/s to 3.1×10^{-3} m^2/s have been obtained. In the Hythe Beds in particular, fissuring may increase transmissivity values to the order of 1.4×10^{-2} m^2/s. In outcrop, specific yields as high as 1×10^{-1} can be found. In the confined aquifer, the coefficient of storage is usually of the order of 1×10^{-4}.

At the eastern end of the area, the maximum thickness of the Chalk is of the order of 280 m. Westwards, the formation thins to about 250 m but then thickens into the Hampshire Basin (in the Southampton area) to approximately 330 m. In the Isle of Wight, the thickness is nearly 500 m, but the strata are steeply dipping in parts, and the full thickness is greater than the area of outcrop suggests. The density of fissuring decreases with depth, and the effective saturated thickness is usually some 60 m, and rarely more than 100 m. The transmissivity has been determined at 11 sites with a mean value of 4.3×10^{-2} m^2/s, ranging from 1.9×10^{-3} to 1.6×10^{-1} m^2/s (Figure 5.9.2). Transmissivity appears to vary considerably from one Unit to the next (Table 5.9.1), but this may not be a true picture since relatively few determinations have been made. The specific yield as determined at the same sites is very low, with a mean of 2.0×10^{-4}. Fluctuations in groundwater levels over long periods suggest that this value is too low by two orders of magnitude and that the true value is approximately 2.0×10^{-2}. The low values obtained during pumping tests may be due to a short-term reluctance of the aquifer to yield from storage.

Sandy strata in the Tertiary succession, particularly in Units 35 and 36, do contain useable groundwater. The Bracklesham and Bagshot beds in particular are used to satisfy small demands. However, too little is known about these strata for a useful assessment of their resources to be made.

Resources

At several sites in this area, individual wells intersect, and take water from, more than one aquifer. For the purposes of this report, it is assumed that in such a case each aquifer contributes equally to the yield of the well. The maximum yield recorded from the Hasting Beds aquifer in 1977 was 2.5×10^6 m^3. The more usual value is between 0.3 and 0.6×10^6 m^3/a. A considerable number of small abstractions for small agricultural and domestic requirements are made.

In the Lower Greensand, a mean yield of between 0.5 and 0.8×10^6 m^3/a can be obtained. In 1977, the maximum yield was 2.6×10^6 m^3.

The Chalk is the major aquifer in the area, and the maximum yield from a

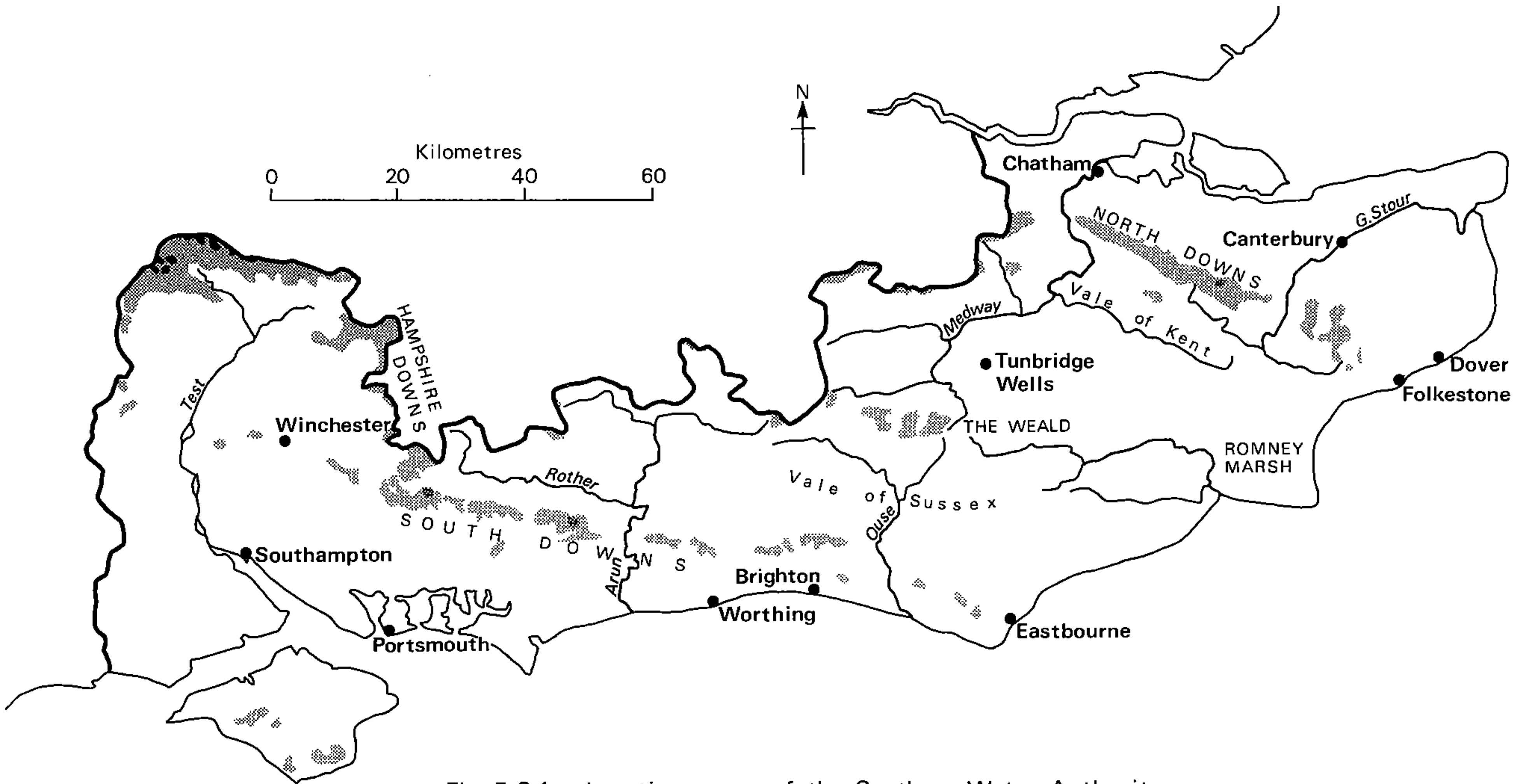

Fig 5.9.1 Location map of the Southern Water Authority

single site in 1977 was 12.8×10^6 m^3. A mean yield of approximately 1.5×10^6 m^3/a seems to be taken, but in many locations 3.0×10^6 m^3/a can be obtained. The actual yield at a given site is dependent more upon the overall management policy for the aquifer rather than the ability of the wells at that site to support a high pumping rate.

Wells in the Tertiary beds rarely yield more than 0.2×10^6 m^3/a, and most abstractions are much less than this.

Wells constructed in the Chalk aquifer will normally stand without support other than a few metres of lining tubes near to the ground surface. In the other aquifers, sand screens and full lining of the well is essential as the sands will rarely stand without support. It is the normal practice to drill the well over-size so as to allow for the introduction of an artificial filter pack and yet to retain a sufficient internal diameter to accommodate the pumping plant. Development of the well is necessary to, and preferably beyond, the expected rate of pumping to be used when the well is in service since failure to do this encourages clogging with subsequent failure of the well.

Details of the resources from the individual Units are given in Tables 5.9.2 to 5.9.65. Units 6, 9 and 20 support limited groundwater abstraction only, and are therefore omitted. The resources in Unit 35 are wholly within the Tertiary and the Table is also omitted. In several Units, the parameters of outcrop area, rainfall, evaporation and infiltration are inadequately known. In these cases, the balance is shown as zero, assuming the replenishment to be equal to the abstraction. In reality, there may be a surplus in these instances.

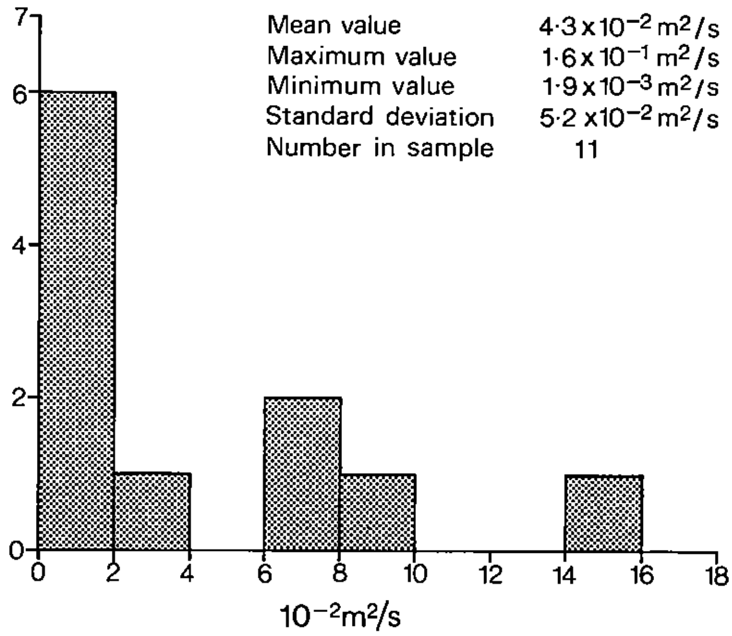

Fig: 5.9.2. Transmissivities of the Chalk aquifer in the Southern Water Authority (m^2/s)

Table 5.9.1. Transmissivities in the Chalk aquifer of the Southern Water Authority (m^2/s)

Unit	Number of determinations	Mean	Minimum	Maximum	Mean as % of overall mean
12	1	1.2×10^{-2}	-	-	28
22	3	2.7×10^{-2}	1.9×10^{-3}	7.5×10^{-2}	63
24	1	2.6×10^{-3}	-	-	6
31	1	9.5×10^{-2}	-	-	220
32	3	9.1×10^{-2}	3.7×10^{-2}	1.6×10^{-1}	210
33	1	2.8×10^{-3}	-	-	7
34	1	4.9×10^{-3}	-	-	11
All Units	11	4.3×10^{-2}	1.9×10^{-3}	1.6×10^{-1}	100

Table 5.9.2. Groundwater resources for Unit 1 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	175	635	460	166	44.1	11.8	17.3
Lower Greensand	185	635	460	79	33.4	8.7	5.9
Total					77.5	20.5	23.2

Table 5.9.3. Abstraction of groundwater and balance of resources for Unit 1 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	109.7	29.4	43.0
Lower Greensand	83.1	21.6	14.7
Total	192.8	51.0	57.7

Table 5.9.4. Groundwater resources for Unit 2 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	28	728	489	94	0.8	0.4	2.2
Lower Greensand	100	728	489	108	9.2	6.7	4.1
Hastings Beds	210	728	489	94	9.1	7.8	11.9
Total					19.1	14.9	18.2

Table 5.9.5. Abstraction of groundwater and balance of resources for Unit 2 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	2.2	1.1	6.1
Lower Greensand	25.6	18.7	11.4
Hastings Beds	25.3	21.7	33.1
Total	53.1	41.5	50.6

Table 5.9.6. Groundwater resources for Unit 3 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	120	808	545	250	1.0	2.5	27.5
Hastings Beds	97	808	545	118	5.4	nk	11.4
Total					6.4	2.5	38.9

Table 5.9.7. Abstraction of groundwater and balance of resources for Unit 3 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	4.5	11.2	122.8
Hastings Beds	24.1	nk	50.9
Total	28.6	11.2	173.7

Table 5.9.8. Groundwater resources for Unit 4 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Hastings Beds	218	891	545	156	4.2	1.8	32.2

Table 5.9.9. Abstraction of groundwater and balance of resources for Unit 4 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Hastings Beds	16.3	7.0	125.3

Table 5.9.10. Groundwater resources for Unit 5 of the Southern Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Hastings Beds	142	790	535	115	5.1	2.5	13.8

Table 5.9.11. Abstraction of groundwater and balance of resources for Unit 5 of the Southern Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	10^3 m^3/km^2	10^3 m^3/km^2	10^3 m^3/km^2
Hastings Beds	23.0	11.3	62.2

Table 5.9.12. Groundwater resources for Unit 7 of the Southern Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	67	636	459	168	19.2	9.1	2.2

Table 5.9.13. Abstraction of groundwater and balance of resources for Unit 7 of the Southern Water Authority (1977)

Aquifer	licensed abstraction	actual abstraction	balance of resources
	10^3 m^3/km^2	10^3 m^3/km^2	10^3 m^3/km^2
Chalk	124.7	59.1	14.3

Table 5.9.14. Groundwater resources for Unit 8 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	155	677	468	199	37.1	20.0	10.8

Table 5.9.15. Abstraction of groundwater and balance of resources for Unit 8 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	101.4	54.6	29.5

Table 5.9.16. Groundwater resources for Unit 10 of the Southern Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	140	740	478	249	23.5	14.5	20.4

Table 5.9.17. Abstraction of groundwater and balance of resources for Unit 10 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	136.6	84.3	118.6

Table 5.9.18. Groundwater resources for Unit 11 of the Southern Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	56	767	507	247	0.3	1.2	12.6
Lower Greensand	90	767	507	117	3.3	1.6	8.9
Total					3.6	2.8	21.5

Table 5.9.19. Abstraction of groundwater and balance of resources for Unit 11 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	1.3	5.2	54.8
Lower Greensand	14.3	7.0	38.7
Total	15.6	12.2	93.5

Table 5.9.20. Groundwater resources for Unit 12 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	251	752	484	255	29.1	11.5	52.5

Table 5.9.21. Abstraction of groundwater and balance of resources for Unit 12 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	102.5	40.5	184.9

Table 5.9.22. Groundwater resources for Unit 13 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	68	596	444	144	7.4	4.6	5.2

Table 5.9.23. Abstraction of groundwater and balance of resources for Unit 13 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	97.4	60.5	68.4

Table 5.9.24. Groundwater resources for Unit 14 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	124	813	491	306	29.6	11.6	26.3

Table 5.9.25. Abstraction of groundwater and balance of resources for Unit 14 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	217.6	85.3	193.4

Table 5.9.26. Groundwater resources for Unit 15 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Hastings Beds *	172	692	501	86	10.0	1.4	13.4
Chalk	5	692	501	181	2.8	1.7	-0.8
Total					12.8	3.1	12.6

*including gravels of Denge Beach area

Table 5.9.27. Abstraction of groundwater and balance of resources for Unit 15 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Hastings Beds	46.1	6.5	61.8
Chalk	12.9	7.8	3.7
Total	59.0	14.3	58.1

Table 5.9.28. Groundwater resources for Unit 16 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Hastings Beds*	475	772	539	105	6.4	0.7	49.2

*includes gravels of Denge Beach area

Table 5.9.29. Abstraction of groundwater and balance of resources for Unit 16 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Hastings Beds	11.4	1.3	87.9

Table 5.9.30. Groundwater resources for Unit 17 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Hastings Beds	117	865	521	155	3.1	1.8	16.3

Table 5.9.31. Abstraction of groundwater and balance of resources for Unit 17 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Hastings Beds	15.8	9.2	83.2

Table 5.9.32. Groundwater resources for Unit 18 of the Southern Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	5	749	431	302	3.0	1.8	-0.3
Hastings Beds	199	749	431	143	10.0	1.4	27.1
Total					13.0	3.2	26.8

Table 5.9.33. Abstraction of groundwater and balance of resources for Unit 18 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	10.9	6.5	-1.1
Hastings Beds	36.2	5.0	98.2
Total	47.1	11.5	97.1

Table 5.9.34. Groundwater resources for Unit 19 of the Southern Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	115	815	483	315	16.3	10.3	25.9

Table 5.9.35. Abstraction of groundwater and balance of resources for Unit 19 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	129.4	81.7	205.6

Table 5.9.36. Groundwater resources for Unit 21 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	19	775	382	342	1.0	0.3	5.9
Hastings Beds	234	775	382	153	2.2	1.0	34.8
Total					3.2	1.3	40.7

Table 5.9.37. Abstraction of groundwater and balance of resources for Unit 21 of the Southern Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	2.5	0.8	15.0
Hastings Beds	5.6	2.5	88.5
Total	8.1	3.3	103.5

Table 5.9.38. Groundwater resources for Unit 22 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	193	865	484	362	35.0	26.3	43.6

Table 5.9.39. Abstraction of groundwater and balance of resources for Unit 22 of the Southern Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	175.0	131.5	218.0

Table 5.9.40. Groundwater resources for Unit 23 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	19	775	441	317	1.2	1.0	5.0
Hastings Beds*	70	775	441	150	1.1	0.2	10.3
Total					2.3	1.2	15.3

*includes some Lower Greensand

Table 5.9.41. Abstraction of groundwater and balance of resources for Unit 23 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	3.7	3.1	15.5
Hastings Beds	3.4	0.6	32.0
Total	7.1	3.7	47.5

Table 5.9.42. Groundwater resources for Unit 24 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	143	813	484	313	30.4	17.8	27.0

Table 5.9.43. Abstraction of groundwater and balance of resources for Unit 24 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	174.7	102.3	155.2

Table 5.9.44. Groundwater resources for Unit 25 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Lower Greensand*	86	762	438	146	16.3	3.1	9.5

*includes some Hastings Beds

Table 5.9.45. Abstraction of groundwater and balance of resources for Unit 25 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Lower Greensand	29.0	5.5	16.9

Table 5.9.46. Groundwater resources for Unit 26 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	66	922	505	396	4.0	0.5	25.6
Lower Greensand	156	922	505	156	4.1	4.1	20.2
Total					8.1	4.6	45.8

Table 5.9.47. Abstraction of groundwater and balance of resources for Unit 26 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	11.8	1.5	75.7
Lower Greensand	12.1	12.1	59.8
Total	23.9	13.6	135.5

Table 5.9.48. Groundwater resources for Unit 27 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	331	839	484	337	51.9	31.4	80.1

Table 5.9.49. Abstraction of groundwater and balance of resources for Unit 27 of the Southern Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	107.5	65.0	165.8

Table 5.9.50. Groundwater resources for Unit 28 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	182	827	473	336	62.1	33.4	27.8

Table 5.9.51. Abstraction of groundwater and balance of resources for Unit 28 of the Southern Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	205.0	110.2	91.7

Table 5.9.52. Groundwater resources for Unit 29 of the Southern Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	96	899	482	395	15.9	4.8	33.1

Table 5.9.53. Abstraction of groundwater and balance of resources for Unit 29 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	120.5	36.4	250.8

Table 5.9.54. Groundwater resources for Unit 30 of the Southern Water Authority

Aquifer	outcrop area	mean annual rainfall	mean annual evaporation	mean annual infiltration	licensed abstraction (annual)	actual abstraction (1977)	balance of resources (1977)
	km^2	mm	mm	mm	10^6 m^3	10^6 m^3	10^6 m^3
Chalk	34	837	481	338	11.5	6.4	5.1

Table 5.9.55. Abstraction of groundwater and balance of resources for Unit 30 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	81.0	45.1	35.9

Table 5.9.56. Groundwater resources for Unit 31 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	259	836	466	352	49.7	24.7	66.5

Table 5.9.57. Abstraction of groundwater and balance of resources for Unit 31 of the Southern Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	133.6	66.4	178.8

Table 5.9.58. Groundwater resources for Unit 32 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Chalk	292	914	466	426	40.3	6.3	118.1

Table 5.9.59. Abstraction of groundwater and balance of resources for Unit 32 of the Southern Water Auhtority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Chalk	138.0	21.6	404.7

Table 5.9.60. Groundwater resources for Unit 33 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	305	822	485	320	8.5	4.1	93.5

Table 5.9.61. Abstraction of groundwater and balance of resources for Unit 33 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	13.7	6.6	150.8

Table 5.9.62. Groundwater resources for Unit 34 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	625	823	456	349	70.9	5.5	212.6

Table 5.9.63. Abstraction of groundwater and balance of resources for Unit 34 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	113.4	8.8	340.2

Table 5.9.64. Groundwater resources for Unit 36 of the Southern Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	63	850	489	343	12.0	8.7	12.9
Lower Greensand	60	850	489	163	4.8	1.3	8.5
Total					16.8	10.1	21.4

Table 5.9.65. Abstraction of groundwater and balance of resources for Unit 36 of the Southern Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	31.5	22.8	33.9
Lower Greensand	12.6	3.4	22.3
Total	44.1	26.2	56.2

Table 5.9.68. Areas of Units in the Southern Water Authority (km^2)

Unit	Area	Unit	Area
1	402	19	126
2	359	20	135
3	224	21	393
4	257	22	200
5	222	23	322
6	280	24	174
7	154	25	562
8	366	26	338
9	173	27	483
10	172	28	303
11	230	29	132
12	284	30	142
13	76	31	372
14	136	32	292
15	217	33	620
16	560	34	625
17	196	35	404
18	276	36	381

5.10. Wessex Water Authority

General Features

The Wessex Water Authority covers an area of 9 918 km^2 in the south-west of England (Fig 2.1). The high lands are represented by the Quantocks (up to 380 m above sea-level), the Mendip Hills (up to 325 m), and the Dorset Downs (up to 270 m). The remaining areas fall generally into two categories (Figure 5.10.1). The first comprises the gently undulating country of Salisbury Plain and Cranborne Chase, at about 200 m above sea-level; the second consists of the extensive Sedgemoor area of low-lying ground near to sea-level, and south of the Mendip Hills.

Natural drainage flows into four river systems, the Hampshire Avon, the Stour, the Parrett and the Bristol Avon.

The total population in 1974 was about 2.2 million. The principal towns include Bristol (population 421000), Bath (85 000) Weston-super-Mare (51 000), Bridgewater (27 000), Taunton (38 000), Yeovil (26 000), Salisbury (36 000), Bournemouth (149 000) and Weymouth (41 000).

Almost the whole of the authority area is agricultural and major industries are confined to Bristol, which is also a major sea port.

The areas of Salisbury Plain and Cranborne Chase are floored by the Chalk and Sedgemoor by Keuper Marl and Liassic strata, the latter formations being of little use as aquifers. Jurassic strata occur in a band crossing the authority area from north to south and Carboniferous strata occur in the Mendips and Bristol areas.

Aquifers

The Carboniferous Limestone reaches a maximum thickness of approximately 1 500 m to the south of Bristol, and approximately 1 400 m in the Mendip Hills. In the classic section of the Avon Gorge, immediately to the west of Bristol, the thickness is only about 670 m, indicating a thinning westwards and northwards, the thicknesses across the river Severn falling to 100 m and less. The limestones tend to be massive, and groundwater flow is entirely through fissures. The latter are often large, and karst features are developed in the Mendip Hills. The throughput of groundwater tends to be extremely rapid in the karst areas, and the natural replenishment is very quickly discharged. No data are available concerning the aquifer properties.

The outcrop of the Permo-Triassic sandstones is restricted to Unit 6. The maximum thickness is of the order of 100 m. However, the major part of the aquifer is overlain by the Keuper Marl which attain a thickness in excess of 450 m, and it is not uncommon for the groundwater in the sandstones beneath the Keuper Marl to be saline. No data are available concerning aquifer properties.

The Middle Jurassic aquifer, comprising the limestones and marls of the Inferior and Great Oolite series, does not exceed a thickness of 80 m, and thins westwards against the Mendip Hills. The limestones are usually well bedded, occasionally massive, sometimes fissile. The transmissivity has been determined at 19 sites, giving a mean value of 1.8×10^{-2} m^2/s and a range of 1.8×10^{-3} m^2/s to 6.2×10^{-3} m^2/s (Figure 5.10.2). The mean transmissvity in each of the two Units in which determinations were carried out varies little from the overall mean (Table 5.10.1). The mean value for the coefficient of storage was 3.4×10^{-4}, determined at 12 sites.

The maximum thickness of the Chalk is of the order of 290 m, but the formation thins to the west and south to less than half this thickness. The Chalk is underlain by approximately 10 m of micaceous sand and sandstone of the Upper Greensand, which is considered to form a single aquifer with the Chalk, the two being in hydraulic continuity. However, the Upper Greensand frequently has a very small mean grain size and a large silt fraction may be present, thus seriously reducing the ability of the sands to yield groundwater to wells. The transmissivity was determined at 15 sites in the Chalk with a mean value of 2.4×10^{-2} m^2/s, and a range of 8.0×10^{-6} m^2/s to 9.5×10^{-2} m^2/s (Figure 5.10.3). There is a considerable variation in the mean value for the different Units (Table 5.10.2), but this should be treated with caution due to the small number of determinations. The mean value for the specific yield was 2.2×10^{-2}, the highest value being 5.6×10^{-2}. Under confined conditions, the mean coefficient of storage is of the order of 2.0×10^{-4}.

Resources

Yields from wells in the Carboniferous Limestone can be large if suitable fissures are intersected, and one site in Unit 6 is recorded as having yielded 5.4 x 10^6 m^3 in 1977. The average yield is nearer to 0.8 x 10^6 m^3/a. However, with the generally sparse distribution of fissures, there is a possibility of constructing a dry well. Due to the rapid discharge after replenishment, wells sited at the higher topographic levels may require to be drilled to considerable depths to pump from levels beneath that of the natural discharges.

The Permo-Triassic sandstones aquifer is not well-developed in this area, and in 1977 the total abstraction was only 1.1 x 10^6 m^3. The largest single abstraction in the same period was 0.2 x 10^6 m^3. It seems, however, that larger yields could be obtained but this is a matter of speculation.

Wells in the Middle Jurassic yield on average of the order of 0.8 x 10^6 m^3/a. The maximum yield recorded for a single site is 5.7 x 10^6 m^3/a. In the more fissile limestones, failures are rare, but in the more massive limestones, particularly in the Great Oolite Limestone, it is possible for a well to fail to intersect suitable fissures and thus have either a poor yield or no yield at all.

The mean yield of wells in the Chalk is approximately 0.7 x 10^6 m^3/a, and a maximum was recorded for a single site in 1977 of 6.5 x 10^6 m^3. The Chalk is normally a reliable aquifer for the smaller yields, but larger yields may not always be obtained, particularly in the Lower Chalk which contains a larger proportion of argillaceous matter.

Wells constructed in the aquifers discussed above do not require sandscreens, and rarely require the support of lining tubes except near to the ground surface.

Details for the resources of the different Units are shown in Tables 5.10.3 to 5.10.16.

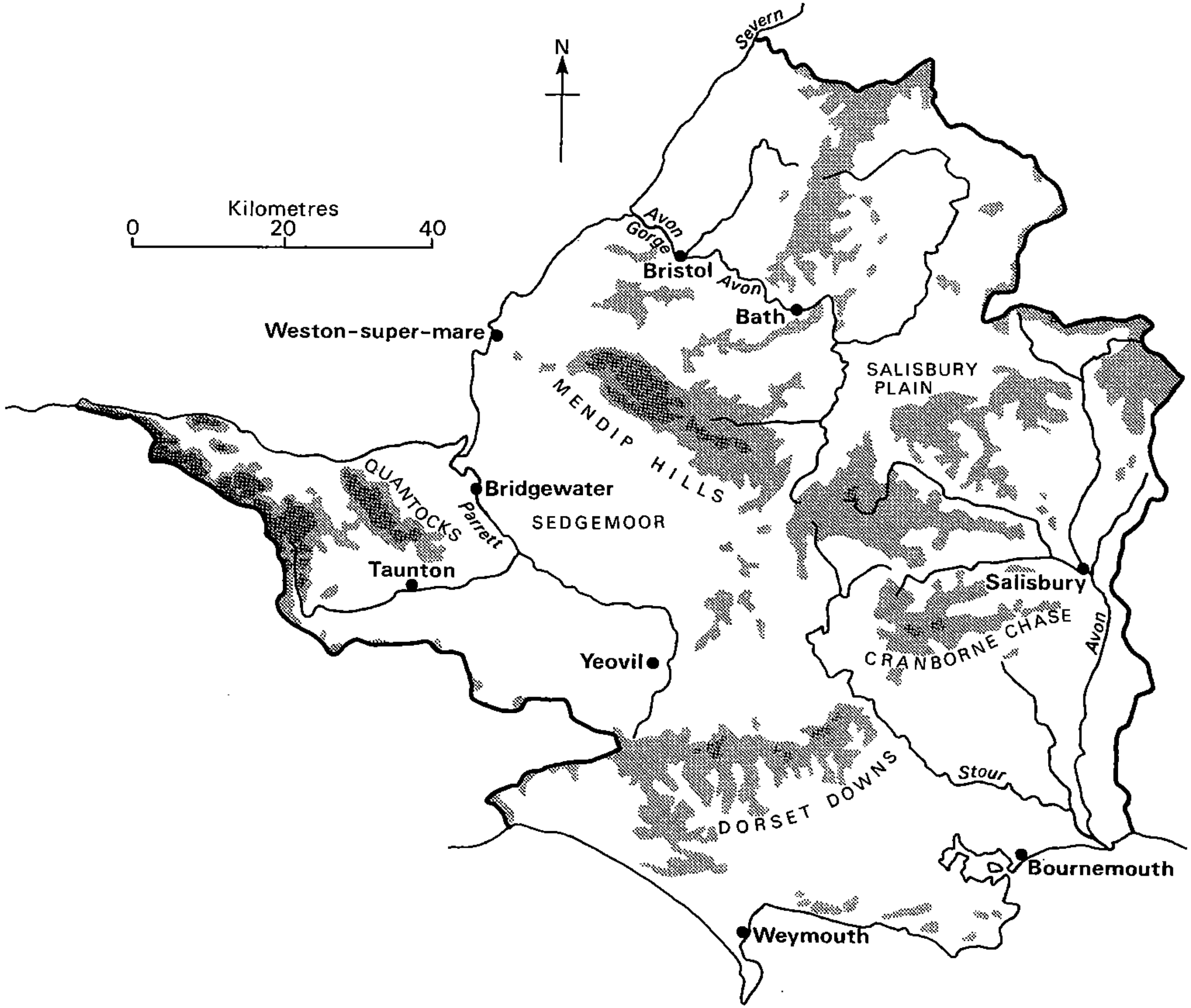

Fig: 5.10.1 Location map of the Wessex Water Authority

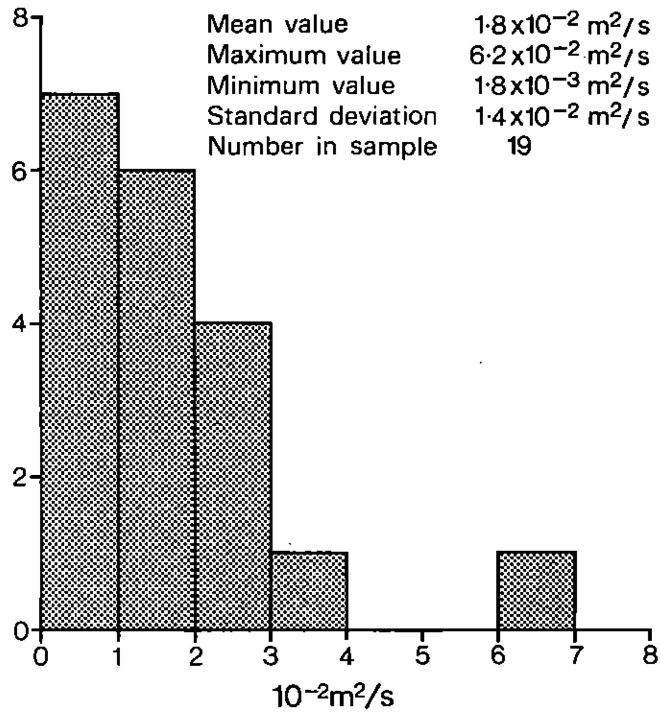

Fig: 5.10.2. Transmissivities of the Middle Jurassic aquifer in the Wessex Water Authority (m^2/s)

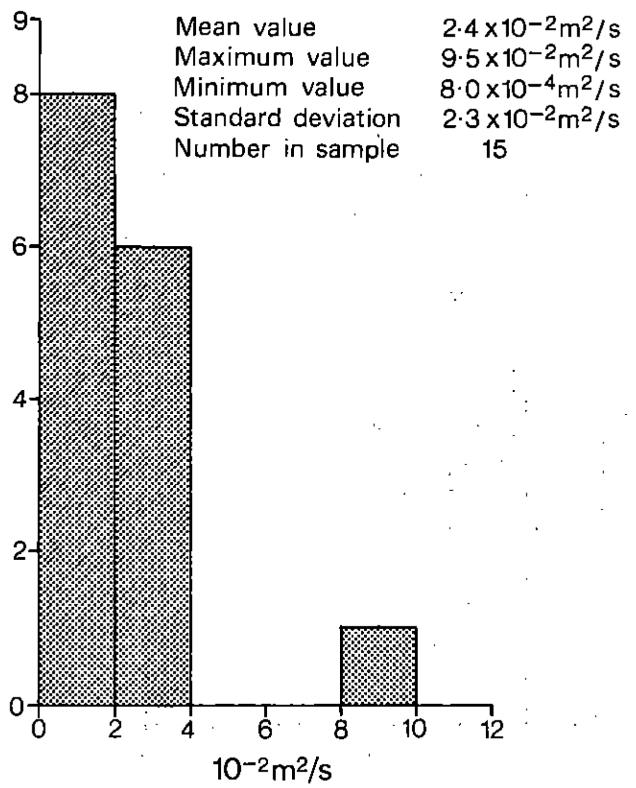

Fig: 5.10.3. Transmissivities of the Chalk aquifer in the Wessex Water Authority (m^2/s)

Table 5.10.1. Transmissivities in the Middle Jurassic aquifer of the Wessex Water Authority (m^2/s)

Unit	Number of determinations	Mean	Minimum	Maximum	Mean as % of overall mean
6	3	1.7×10^{-2}	9.3×10^{-3}	2.5×10^{-2}	94
7	16	1.8×10^{-2}	1.8×10^{-3}	6.2×10^{-2}	100
All Units	19	1.8×10^{-2}	1.8×10^{-3}	6.2×10^{-2}	100

Table 5.10.2. Transmissivities in the Chalk aquifer of the Wessex Water Authority (m^2/s)

Unit	Number of determinations	Mean	Minimum	Maximum	Mean as % of overall mean
1	1	1.2×10^{-2}	-	-	50
2	5	3.3×10^{-2}	8.0×10^{-4}	9.5×10^{-2}	140
3	1	6.0×10^{-3}	-	-	25
4	2	3.4×10^{-2}	3.1×10^{-2}	3.7×10^{-2}	140
5	6	1.7×10^{-2}	3.4×10^{-3}	2.8×10^{-2}	71
All Units	15	2.4×10^{-2}	8.0×10^{-4}	9.5×10^{-2}	100

Table 5.10.3. Groundwater resources for Unit 1 of the Wessex Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	320	719	450	269	14.2	9.7	76.4

Table 5.10.4. Abstraction of groundwater and balance of resources for Unit 1 of the Wessex Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	25.1	17.2	135.2

Table 5.10.5. Groundwater resources for Unit 2 of the Wessex Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	402	784	450	334	28.1	19.3	115.0

Table 5.10.6. Abstraction of groundwater and balance of resources for Unit 2 of the Wessex Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	63.7	43.8	260.8

Table 5.10.7. Groundwater resources for Unit 3 of the Wessex Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	471	860	450	410	39.8	27.3	165.8

Table 5.10.8. Abstraction of groundwater and balance of resources for Unit 3 of the Wessex Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	55.4	38.0	230.9

Table 5.10.9. Groundwater resources for Unit 4 of the Wessex Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	508	888	450	438	57.3	39.3	183.2

Table 5.10.10. Abstraction of groundwater and balance of resources for Unit 4 of the Wessex Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	41.7	28.6	133.4

Table 5.10.11. Groundwater resources for Unit 5 of the Wessex Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Chalk	500	963	450	513	64.6	44.3	212.2
Middle Jurassic	167	865	450	415	5.5	4.4	64.9
Total					70.1	48.7	277.1

Table 5.10.12. Abstraction of groundwater and balance of resources for Unit 5 of the Wessex Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Chalk	54.7	37.5	179.5
Middle Jurassic	4.7	3.7	54.9
Total	59.4	41.2	234.4

Table 5.10.13. Groundwater resources for Unit 6 of the Wessex Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Middle Jurassic	265	812	450	362	7.3	6.6	89.3
Carboniferous Limestone	170	896	450	446	44.5	31.0	44.8
Permo-Triassic sandstones	96	852	450	402	1.8	1.1	37.5
Chalk	38	870	450	420	4.0	3.1	13.0
Total					56.7	41.8	184.6

Table 5.10.14. Abstraction of groundwater and balance of resources for Unit 6 of the Wessex Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Middle Jurassic	2.3	2.1	28.8
Carboniferous Limestone	14.4	10.0	14.5
Permo-Triassic Sandstone	0.6	0.4	12.1
Chalk	1.3	1.0	4.2
Total	18.6	13.5	59.6

Table 5.10.15. Groundwater resources for Unit 7 of the Wessex Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Middle Jurassic	199	827	450	377	33.6	30.0	45.0
Carboniferous Limestone	98	941	450	491	10.9	5.8	42.3
Chalk	124	762	450	312	7.7	2.9	35.8
Total					52.2	38.7	123.1

Table 5.10.16. Abstraction of groundwater and balance of resources for Unit 7 of the Wessex Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Middle Jurassic	13.2	11.8	17.7
Carboniferous Limestone	4.3	2.3	16.7
Chalk	3.0	1.1	14.1
Total	20.5	15.2	48.5

Table 5.10.17. Areas of Units in the Wessex Water Authority (km^2)

Unit	Area
1	565
2	441
3	718
4	1373
5	1182
6	3099
7	2540

5.11. South West Water Authority

General Features

The South West Water Authority covers an area of 10 847 km^2 in the south-west of England (Fig 2.1). The landscape is undulating, rising to heights in excess of 500 m above sea-level on Exmoor and Dartmoor, but elsewhere commonly lying below 120 m (Figure 5.11.1). The coastline is generally rugged and stormswept with a few good harbours. Drainage is performed by numerous small rivers flowing directly to the sea.

The total population in 1974 was of the order of 1.3 million. The major towns include Exeter (population 96 000) and Plymouth (252 000). There is a large influx of tourists during the summer season, particularly along the southern coast.

The area is largely agricultural, with industry largely confined to the Exeter and Plymouth areas.

Geologically, the South West Water Authority area is dominated by an east-west downfold structure. On the flanks are strata of Devonian age, these being of Old Red Sandstone facies on the north coast, but containing marine horizons to the south. Neither are important as aquifers although small yields of less than 10 m^3/d are commonly obtained from boreholes to meet domestic and small agricultural demands.

The centre of the trough is dominated by Carboniferous strata, these comprising a series of mudstones, grits and turbidities known collectively as Culm Measures. As with Old Red Sandstone, small yields are obtained from boreholes, but sources suitable for public supply cannot be developed.

Both the Devonian and the Carboniferous strata are intruded by granitic bodies and the country rock has been extensively metamorphosed and mineralised. Groundwater present in the weathered zone can, in some areas, be seriously contaminated, notably by arsenic and copper.

Aquifers

At the eastern end of the downfold are located the main aquifers of the authority area, the Permo-Triassic sandstones and the Chalk and Upper Greensand. With the latter aquifer, the Upper Greensand facies is dominant in this area, and the Chalk occurs as isolated outliers.

The Permo-Triassic sandstones tend to be finer-grained and rather better cemented than their chronological equivalents in the Midlands and North of England. The basal beds are mainly coarse to fine clayey breccias, and the succeeding strata red and grey sandstones, often current-bedded. A thick sequence of marls, over 200 m, interrupts the sandstone succession. There are also developments of pebble beds as at Budleigh Salterton. On the South Devonshire coast, the total thickness of the Permo-Triassic may exceed 2 000 m, but this thickness diminishes rapidly inland and near Crediton is probably less than 450 m. Since these rocks were deposited in hollows in a pre-existing land surface, thicknesses may vary rapidly, and the outcrop areas are not extensive.

Aquifer properties have been calculated at 5 well sites, all in the Permo-Triassic sandstones, and all in Unit 1. Transmissivity ranges from 6.9×10^{-4} to 4.1×10^{-3} m^2/s with a mean of 2.1×10^{-3} m^3/s and a standard deviation of 1.4×10^{-3} m^2/s.

The coefficient of storage varies from 2.2 10^{-3} to 3.0 10^{-4}, with a mean of 1.5 10^{-3}.

Resources

Only in Unit 1 are significant groundwater resources present. These are shown in Table 5.11.1. The total area of the Unit is 3907 km^2 and the total resources are 408.8 10^6 m^3/a, giving a resource figure of 0.10 10^6 m^3/a, per square kilometre.

The Chalk and Upper Greensand have been dissected by erosion into numerous small separated catchments, and in consequence large sources cannot be readily developed.

Licensed abstraction from the Permo-Triassic sandstone is at present 21.3 10^6 m^3/a. This represents only 10% of the resources of this aquifer. Actual abstraction in 1976, the latest year for which data are available, was 16.4 10^6 m^3, representing 8% of the total theoretical resources.

Licensed abstraction from the Chalk and Upper Greensand amounts to 9.3 10^6 m^3/a, 5% of the total resources. Actual abstraction in 1976 was 4.0 10^6 m^3, 2% of the total resources.

The licensed abstraction, the actual abstraction and the balance of resources for 1976 have been calculated and are shown in Table 5.11.2

expressed as 10^3 m^3 per square kilometre of total catchment area.

The well sites in the Permo-Triassic sandstone yield from 0.1 to 3.0 10^6 m^3/a, with a mean of about 1.0 10^6 m^3/a. In the Chalk and Upper Greensand, yields are less, ranging from less than 0.1 to 0.3 10^6 m^3/a, with a mean of 0.2 10^6 m^3/a.

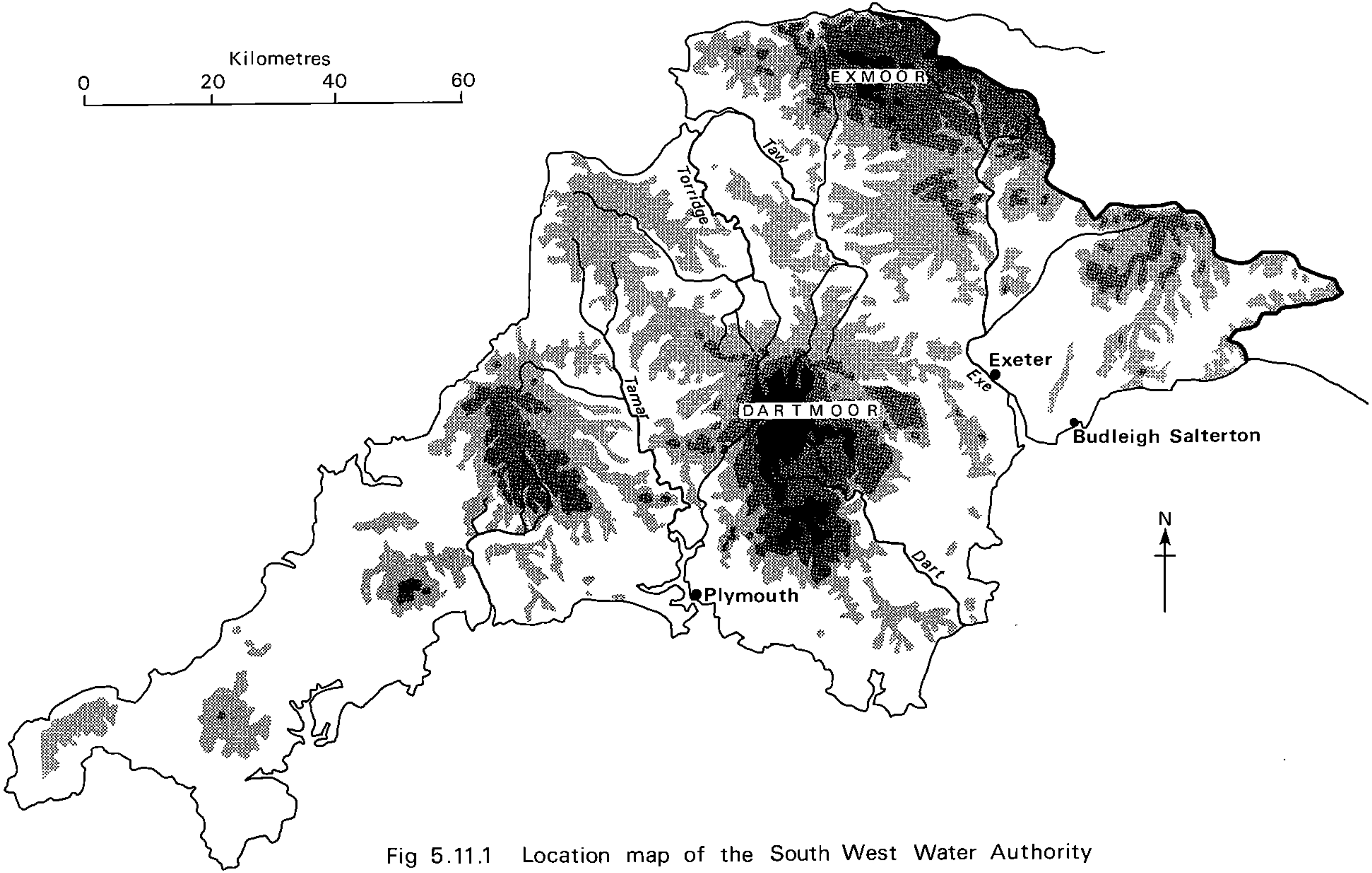

Fig 5.11.1 Location map of the South West Water Authority

Table 5.11.1. Groundwater resources for Unit 1 of the South West Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1976) 10^6 m^3	balance of resources (1976) 10^6 m^3
Permo-Triassic sandstones	529	925	540	388	21.3	16.4	188.9
Chalk and Upper Greensand	371	1065	520	545	9.3	4.0	198.2
Total					30.6	20.4	387.1

Table 5.11.2. Abstraction of groundwater and balance of resources for Unit 1 of the South West Water Authority (1976)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Permo-Triassic sandstones	5.5	4.2	48.4
Chalk and Upper Greensand	2.4	1.0	50.8
Total	7.9	5.2	99.2

Table 5.11.3. Areas of Units in the South West Water Authority (km^2)

Unit	Area
1	3907
2	1765
3	1570
4	1202
5	2193
6	210

5.12. Welsh Water Authority

General Features

The Welsh Water Authority covers an area of 20 704 km^2, mainly within the Principality of Wales (Fig 2.1). To the north, the west and the south, the authority area is bounded by the sea. The area is mountainous in the north where it is dominated by the Snowdon range, rising in Snowdon itself to 1085 m above sea level. In the south, there are a number of more or less discrete high lands, comprising the Plynlimon area (up to 750 m above sea level), Mynydd Eppynt (475 m), Mynydd Du (802 m), the Brecon Beacons (885 m) and the Black Mountains (810 m). The locations of these high lands are shown on Figure 5.12.1.

There are many rivers draining the area, the longest being the Wye and the Usk in South Wales, and the Dee in North Wales.

The total population in 1974 was of the order of 3.0 million. The principal towns include Cardiff (population 275 000), Newport (111 000), Swansea (171 000), Aberystwth (11 000), Chester (61 000) and Hereford (47 000).

The coastal area in the south is heavily industrialised. Coal is extensively mined, and there are several major steel works. The remaining area is largely agricultural, with a large number of hill farms dependent mainly upon sheep. There is a large seasonal influx of tourists.

Permo-Triassic rocks outcrop in the Vale of Clwyd in North Wales, together with some Carboniferous Limestone. Along the southern edge of the authority area, there is a synclinal structure containing Carboniferous Limestone, Millstone Grit and Coal Measures. The remainder of the area is floored almost exclusively by strata of Cambrian, Ordovician and Silurian age, mainly mudstones, shales and slates with extensive volcanic rocks, and by the Old Red Sandstone.

Aquifers

The Old Red Sandstone crops out over a large area of South Wales. The maximum thickness is in excess of 2 000 m. The strata comprise marls and sandstones with occasional mudstones. Transmissivity was determined at 3 sites, and a mean value of 1×10^{-3} m^2/s was obtained. The 3 sites are all in Unit 2, but this value may generally hold throughout the aquifer. No data are available concerning the specific yield, but this is probably of the order of 1×10^{-2}.

The Carboniferous Limestone has its major outcrops in the south of the area, with smaller outcrops near the north coast and in Anglesey. The maximum thickness is in excess of 900 m in the north and over 1 200 m in the south. Groundwater flow through this aquifer is through fissures, and these tend to be large but relatively sparsely distributed through the rock. It is not unusual for wells to be dry due to failure to intersect suitable fissures. No data are available concerning aquifer properties.

The Millstone Grit comprises a series of sandstones, grits and shales, the sandstones being rather more dominant in the south. The maximum thickness is of the order of 300 m. Although this aquifer does not yield large supplies to wells, it is considered particularly important in South Wales since groundwater percolates downwards into the underlying Carboniferous Limestone. No data are available concerning aquifer properties.

The Coal Measures in South Wales have a maximum thickness of some 2 500 m. The lowest division, varying from 430 to 900 m thick, is predominantly shaly with subordinate sandstones and coals. These rocks are extensively mined for coal, and large discharges of groundwater take place from the mines. The middle division of the Coal Measures is predominantly arenaceous, containing massive sandstones (Pennant Sandstone), and these beds are succeeded by an upper division of shales with coals. No data are available concerning aquifer properties.

The Permo-Triassic sandstones are found in North Wales only, the main outcrop being in the Vale of Clwyd where it comprises 400 m thickness of fine to medium-grained sandstones. The transmissivity has been determined at 8 sites in this region, and a mean value of 4.7×10^{-3} m^2/s was obtained. Values varied from 2.3×10^{-4} to 1.4×10^{-2} m^2/s, and this has been interpreted as relating to the degree of fissuring present at each site. The coefficient of storage is of the order of 4×10^{-4}, indicating that the aquifer is largely confined, in this area by boulder clay.

Large areas of Wales are floored by impervious shales and slates, and superficial deposits are therefore important as aquifers even though the resources are not large. These deposits comprise boulder clay and river silts, which are relatively impervious, and sands and gravels, which form aquifers. Transmissivities have been determined for 5 sites in Unit 1, where a mean value of 1.6×10^{-2} m^2/s was obtained. The mean specific yield was 2.1×10^{-1}. The aquifer properties have not been determined in other Units, but similar values might be expected.

Resources

Yields from the wells in the Old Red Sandstone are small, almost always less than 0.5×10^6 m^3/a. Although the extent of the outcrop is large, and the total storage therefore also large, the aquifer is not suitable for developing large resources. It is, however, very suitable for small supplies, and has provided numerous sources for small farms and for domestic requirements.

Yields from wells in the Carboniferous Limestone are usually of the order of 1.0×10^6 m^3/a or less. However, much larger yields are possible if suitable fissures are intersected, and an abstraction is recorded for 1977 of 8.9×10^6 m^3/a for a single site.

Wells in the Millstone Grit obtain water from the sandstone horizons. Yields are usually small, and unsuitable for large requirements.

The Coal Measures have some potential for large supplies. Yields of $4.0 \times 10^6 m^3/a$ are possible from wells, although $2.0 \times 10^6 m^3/a$ is closer to the normal expected discharge. The waste water pumped from coal mines in South Wales is often of reasonably good quality, and the mean rate of those discharges lies between 2.0 and $3.0 \times 10^6 m^3/a$.

Wells in the Permo-Triassic sandstones have an average yield of approximately $1.0 \times 10^6 m^3/a$, although yields in excess of $2.6 \times 10^6 m^3/a$ have been obtained.

It is not easy to indicate the reliable yield that can be obtained from superficial deposits since the amount pumped at a given site depends more upon the available resources than upon the actual rate at which a well can be pumped. Yields are generally less than $0.5 \times 10^6 m^3/a$, and often less than $0.2 \times 10^6 m^3/a$.

Wells constructed in the superficial deposits require supporting throughout, and the emplacement of sand screens is necessary. In all the other aquifers, the well will usually stand without support and a few metres of casing is normally used to prevent collapse in the weathered zone near to the ground surface.

The details of the resources for each Unit are shown in tables 5.12.1. to 5.12.30. Estimates of the balance available in the Carboniferous Limestone in Units 1 to 7 may be less than the real value due to the unknown contributions from the Millstone Grit. Investigations are being carried out in an attempt to quantify this. In some units, the actual abstraction from the Coal Measures is considerably greater than that licensed. This is due to the inclusion of mine-drainage to which the normal licensing conditions do not apply and this is not included in the licensed amount. Also included in this category is drainage from the railway tunnel under the river Severn.

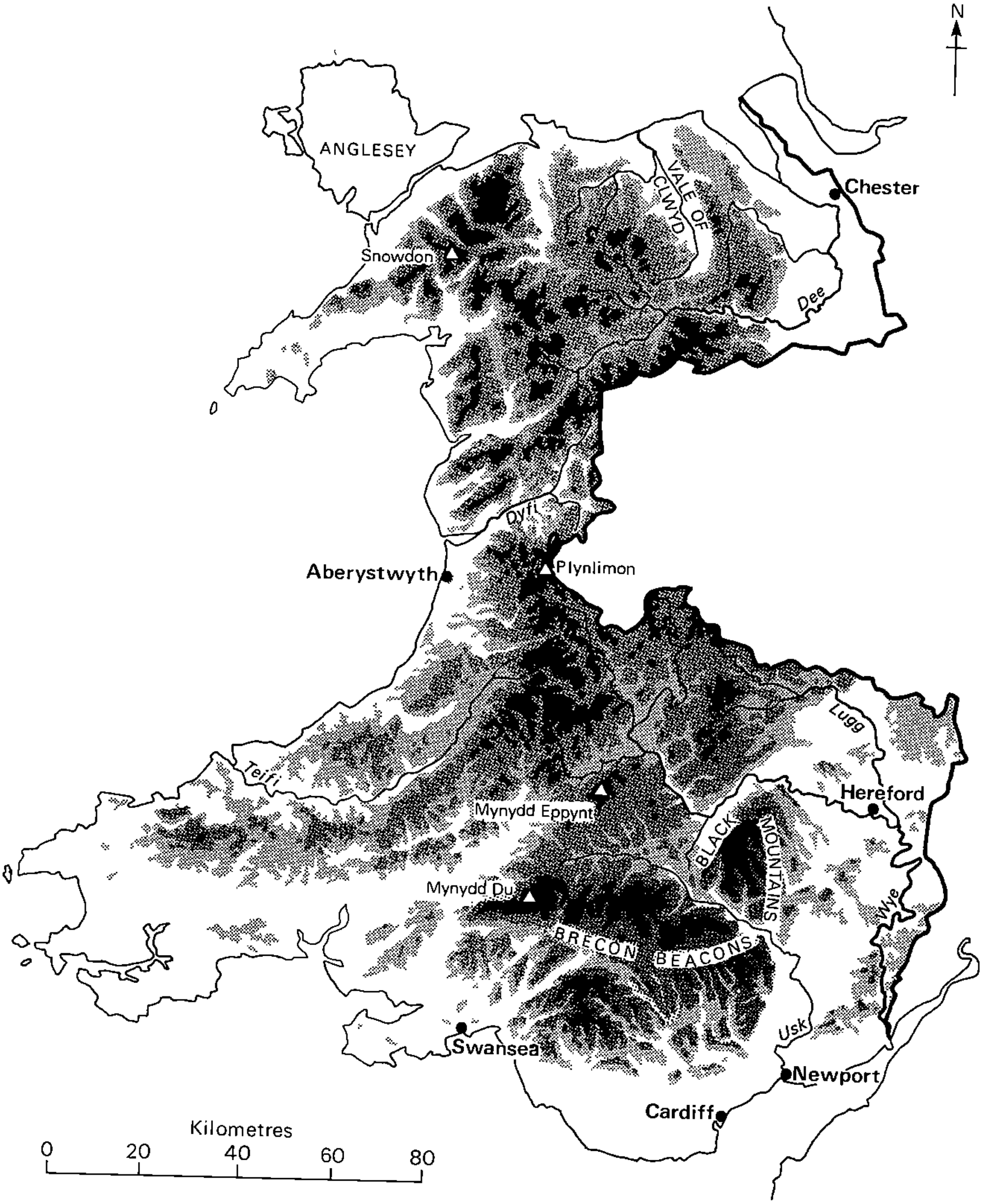

Fig 5.12.1 Location map of the Welsh Water Authority

Table 5.12.1. Groundwater resources for Unit 1 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Old Red Sandstone	1942	800	450	100	5.5	4.0	190.2
Carboniferous Limestone	80	850	450	400	0.0	16.1	15.9
Coal Measures	32	700	450	200	0.0	0.0	6.4
Superficial	358	799	450	138	7.9	2.8	46.6
Total					13.4	6.8	259.1

Table 5.12.2. Abstraction of groundwater and balance of resources for Unit 1 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Old Red Sandstone	1.3	0.9	44.5
Carboniferous Limestone	0.0	3.8	3.7
Coal Measures	0.0	0.0	1.5
Superficial	1.9	0.7	10.9
Total	3.2	5.4	60.6

Table 5.12.3. Groundwater resources for Unit 2 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Old Red Sandstone	1067	1400	450	100	0.1	0.0	106.7
Carboniferous Limestone	65	1300	450	850	2.4	1.0	54.3
Millstone Grit	32	1500	450	50	0.0	0.0	1.6
Coal Measures	225	1500	450	200	7.0	17.8	27.2
Superficial	267	1099	450	383	0.8	0.3	102.0
Total					10.3	19.1	291.8

Table 5.12.4. Abstraction of groundwater and balance of resources for Unit 2 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Old Red Sandstone	0.1	0.0	58.6
Carboniferous Limestone	1.3	0.5	29.8
Millstone Grit	0.0	0.0	0.9
Coal Measures	3.8	9.8	14.9
Superficial	0.4	0.2	56.0
Total	5.6	10.5	160.2

Table 5.12.5. Groundwater resources for Unit 3 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Old Red Sandstone	156	2100	450	100	0.1	0.0	15.6
Carboniferous Limestone	51	1300	450	850	1.6	1.0	42.4
Millstone Grit	55	1600	450	50	0.0	0.0	2.8
Coal Measures	472	2000	450	200	0.3	13.1	114.1
Superficial	12	1100	450	494	6.0	3.1	2.8
Total					8.0	17.2	177.7

Table 5.12.6. Abstraction of groundwater and balance of resources for Unit 3 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Old Red Sandstone	0.1	0.0	16.5
Carboniferous Limestone	1.7	1.1	44.9
Millstone Grit	0.0	0.0	3.0
Coal Measures	0.3	13.9	120.7
Superficial	6.3	3.3	3.0
Total	8.4	18.3	188.1

Table 5.12.7. Groundwater resources for Unit 4 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Old Red Sandstone	40	2200	450	100	0.0	0.0	4.0
Carboniferous Limestone	88	1200	450	750	10.5	10.0	56.0
Millstone Grit	58	1800	450	50	0.0	0.0	2.9
Coal Measures	472	2000	450	200	0.0	2.2	92.2
Superficial	7	1100	450	204	4.7	2.9	-1.5
Total					15.2	15.1	153.6

Table 5.12.8. Abstraction of groundwater and balance of resources for Unit 4 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Old Red Sandstone	0.0	0.0	4.0
Carboniferous Limestone	10.5	10.0	55.9
Millstone Grit	0.0	0.0	2.9
Coal Measures	0.0	2.2	92.0
Superficial	4.7	2.9	-1.5
Total	15.2	15.1	153.3

Table 5.12.9. Groundwater resources for Unit 5 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Old Red Sandstone	55	1900	450	100	1.0	0.6	4.9
Carboniferous Limestone	84	1200	450	750	1.0	0.6	62.4
Millstone Grit	111	1800	450	50	0.8	0.6	5.0
Coal Measures	528	1500	450	200	1.1	4.0	101.6
Superficial	84	1288	450	133	0.0	0.0	11.2
Total					3.9	5.8	185.1

Table 5.12.10. Abstraction of groundwater and balance of resources for Unit 5 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Old Red Sandstone	1.1	0.7	5.5
Carboniferous Limestone	1.1	0.7	70.4
Millstone Grit	0.9	0.7	5.6
Coal Measures	1.2	4.5	114.6
Superficial	0.0	0.0	12.6
Total	4.3	6.6	208.7

Table 5.12.11. Groundwater resources for Unit 6 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) $10^6\ m^3$	actual abstraction (1977) $10^6\ m^3$	balance of resources (1977) $10^6\ m^3$
Old Red Sandstone	300	1500	450	100	0.0	0.0	30.0
Carboniferous Limestone	20	1700	450	1250	0.0	0.0	25.0
Millstone Grit	34	1500	450	50	0.3	0.2	1.5
Coal Measures	55	1300	450	200	0.0	0.0	11.0
Superficial	123	1206	450	96	1.8	1.4	10.4
Total					2.1	1.6	77.9

Table 5.12.12. Abstraction of groundwater and balance of resources for Unit 6 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction $10^3\ m^3/km^2$	actual abstraction $10^3\ m^3/km^2$	balance of resources $10^3\ m^3/km^2$
Old Red Sandstone	0.0	0.0	14.1
Carboniferous Limestone	0.0	0.0	11.8
Millstone Grit	0.1	0.1	0.7
Coal Measures	0.0	0.0	5.2
Superficial	0.8	0.7	4.9
Total	0.9	0.8	36.7

Table 5.12.13. Groundwater resources for Unit 7 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Old Red Sandstone	225	1100	450	100	0.0	0.0	22.5
Carboniferous Limestone	88	1100	450	650	0.0	0.0	57.2
Millstone Grit	84	1200	450	50	0.0	0.0	4.2
Coal Measures	134	1200	450	200	0.0	0.0	26.8
Total					0.0	0.0	110.7

Table 5.12.14. Abstraction of groundwater and balance of resources for Unit 7 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Old Red Sandstone	0.0	0.0	15.1
Carboniferous Limestone	0.0	0.0	38.4
Millstone Grit	0.0	0.0	2.8
Coal Measures	0.0	0.0	18.0
Total	0.0	0.0	74.3

Table 5.12.15. Groundwater resources for Unit 8 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Superficial	32	1200	450	50	0.3	0.1	1.5

Table 5.12.16. Abstraction of groundwater and balance of resources for Unit 8 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Superficial	0.3	0.1	1.6

Table 5.12.17. Groundwater resources for Unit 9 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Superficial	8	1200	450	50	0.3	0.2	0.2

Table 5.12.18. Abstraction of groundwater and balance of resources for Unit 9 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Superficial	0.4	0.3	0.3

Table 5.12.19. Groundwater resources for Unit 10 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Superficial	4	1200	450	50	0.0	0.0	0.2

Table 5.12.20. Abstraction of groundwater and balance of resources for Unit 10 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Superficial	0.0	0.0	0.1

Table 5.12.21. Groundwater resources for Unit 11 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Superficial	2	1300	450	50	0.0	0.0	0.1

Table 5.12.22. Abstraction of groundwater and balance of resources for Unit 11 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Superficial	0.0	0.0	0.1

Table 5.12.23. Groundwater resources for Unit 12 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	1	800	450	350	0.0	0.0	0.4
Superficial	1	1100	450	50	0.0	0.0	0.1
Total					0.0	0.0	0.5

Table 5.12.24. Abstraction of groundwater and balance of resources for Unit 12 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	0.0	0.0	6.0
Superficial	0.0	0.0	1.5
Total	0.0	0.0	7.5

Table 5.12.25. Groundwater resources for Unit 13 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	41	800	450	350	0.7	0.0	14.4
Millstone Grit	10	700	450	50	0.0	0.0	0.5
Coal Measures	1	700	450	200	0.0	0.0	0.2
Permo-Triassic Sandstones	7	750	450	300	5.1	1.4	0.7
Superficial	46	700	450	76	0.0	0.0	3.5
Total					5.8	1.4	19.3

Table 5.12.26. Abstraction of groundwater and balance of resources for Unit 13 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	0.9	0.0	17.6
Millstone Grit	0.0	0.0	0.6
Coal Measures	0.0	0.0	0.2
Permo-Triassic sandstones	6.2	1.7	0.9
Superficial	0.0	0.0	4.3
Total	7.1	1.7	23.6

Table 5.12.27. Groundwater resources for Unit 14 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	51	900	450	450	4.9	17.0	6.0
Millstone Grit	55	900	450	50	0.5	0.0	2.8
Coal Measures	40	800	450	200	0.1	0.0	8.0
Permo-Triassic sandstones	100	700	450	250	15.3	10.1	14.9
Superficial	100	760	450	230	1.0	0.0	23.0
Total					21.8	27.1	54.7

Table 5.12.28. Abstraction of groundwater and balance of resources for Unit 14 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	2.2	7.8	2.7
Millstone Grit	0.2	0.0	1.3
Coal Measures	0.0	0.0	3.7
Permo-Triassic sandstones	7.0	4.6	6.8
Superficial	0.5	0.0	10.5
Total	9.9	12.4	25.0

Table 5.12.29. Groundwater resources for Unit 15 of the Welsh Water Authority

Aquifer	outcrop area km^2	mean annual rainfall mm	mean annual evaporation mm	mean annual infiltration mm	licensed abstraction (annual) 10^6 m^3	actual abstraction (1977) 10^6 m^3	balance of resources (1977) 10^6 m^3
Carboniferous Limestone	80	1000	450	550	0.0	0.0	44.0
Superficial	25	900	450	50	0.0	0.0	1.3
Total					0.0	0.0	45.3

Table 5.12.30. Abstraction of groundwater and balance of resources for Unit 15 of the Welsh Water Authority (1977)

Aquifer	licensed abstraction 10^3 m^3/km^2	actual abstraction 10^3 m^3/km^2	balance of resources 10^3 m^3/km^2
Carboniferous Limestone	0.0	0.0	61.0
Superficial	0.0	0.0	1.8
Total	0.0	0.0	62.8

Table 5.12.31. Areas of Units in the Welsh Water Authority (km^2)

Unit	Area
1	4270
2	1821
3	945
4	1002
5	887
6	2124
7	1489
8	930
9	786
10	1352
11	1310
12	67
13	817
14	2183
15	721

6. TRENDS IN GROUNDWATER ABSTRACTION

Under Section 6 of the Water Act 1945 returns of groundwater abstractions had to be made by public water supply authorities and private users during the period 1948 to 1963. This requirement applied to England and Wales only, and no returns were made for Scotland and Northern Ireland. Returns were required if (1) the capacity to abstract equalled or exceeded 230 m^3/d, or (2) abstraction exceeding 230 m^3/d took place on 7 days or more in the one year. Approximately 7 000 groundwater sources were covered in the returns, which were very detailed and included data on location, aquifer, hydrometric area and annual abstraction by use in one of twenty categories of an industrial classification system.

The Water Act 1945 was partially superseded by the Water Resources Act 1963. This new Act created 29 river authorities (the Thames Conservancy and the Lee Conservancy Catchment Board are included since they were the equivalents of a river authority) based on long-established Hydrometric Areas in England and Wales. In Section 114, the river authorities were empowered to obtain information from both groundwater and surface water abstractors. The new arrangements were not brought into operation until 1968 and the format of the returns was changed. Returns were required from all users licensed to abstract more than 60 000 m^3/a from groundwater sources, the classification of water use was reduced to 6 main categories and the returns made by the River Authorities to Central Government were generally only summaries of the individual returns by hydrometric areas. Subsequent analysis revealed that the data prior to 1973 were incomplete and unreliable.

This chapter considers the trends in groundwater abstraction demonstrated by the Section 6 returns from 1948 to 1963 and the Section 114 returns from 1973 to 1977. Table 6.1 shows the total abstractions of groundwater over these periods. The difference in the minimum quantity for which returns were required is not considered to be significant. Analysis of the distribution of groundwater abstractions for 1963 illustrated quite clearly that small abstractors contributed very little to the total demand. Thus for both Section 6 and Section 114 returns the contribution by small users who did not make returns is assumed to be similar and negligible in national terms. However, the discontinuity in the record and the change of classification of use makes comparison and analysis of the two sets of data less useful.

The data was analysed by a simple linear regression and a good correlation was obtained between abstraction rate and time in years with a coefficient of 0.976. The results are plotted on Figure 6.1. It was thought that the minor aberrations during the period 1948 to 1963 might be related to rainfall since the groundwater abstraction tends to increase in dry years to make up the shortfall in surface supplies. However, a multiple regression analysis bringing in either annual rainfall or summer rainfall as an additional parameter brought no improvement to the correlation coefficient.

The average annual growth indicated by the trend line in Figure 6.1 is approximately 33 x $10^6 m^3$/a. But from analysis of all the data it is clear that, although groundwater abstraction has risen consistently throughout the period of the record, the increase has been entirely due to groundwater development for public water supply which now accounts for over 75% of the total. Groundwater abstraction by industry has remained relatively constant since 1954. Within this overall picture most industries have exhibited declines or lack of growth whilst the building, chemical and food industries have shown the only significant growth rate.

The lack of growth in industrial abstraction is in contrast to the steady growth of 2% a year, until very recently, in the growth of public water supplies to industrial metered consumers. This may indicate a trend for industrial consumers to seek their supplies from the public water supply system rather than by developing their own resources.

It is also of interest that the ratio of groundwater abstracted for public water supplies to the total public water supply abstraction appears to have remained nearly constant over the last 16 years indicating that groundwater has been developed at a similar rate to surface water for public supply purposes since 1961.

Figure 6.1 indicates marked falls in abstractions in 1975 and 1976 which persisted to a lesser extent in 1977 all of which are attributable to the severe drought of 1975/76 which affected practically the whole of England and Wales. The period May 1975 to August 1976 was the driest 16 month period over England and Wales as a whole since records began in 1727. A relatively dry summer in 1975 was followed by a dry winter resulting in very low ground water levels at the end of the year. Supplies were restricted in some areas and prudent use of the depleted groundwater resources by the public supply undertakings, the major abstractors, resulted in a reduction in total abstractions of 5% of the 1974 figure. The summer of 1976 was exceptionally dry until the drought broke at the end of August. Restrictions were widespread and every effort was made to conserve supplies by reducing consumption. This was accomplished by restricting non-essential uses, by reducing wastage generally and in industry by re-cycling or the elimination of wasteful water using processes. The overall result was a further reduction of 7% of the 1974 total abstraction. The effects of the measures adopted during the drought appear to have continued to affect abstractions in 1977 and it is possible that part at least of the reduction may be permanent.

It would be inadvisable to project the trend shown in Figure 6.1 into the future. In the first place the trend is determined largely by the data for the period 1948 to 1963 which was one of sustained growth in total water supply consumption and present forecasts suggest that growth of demand over the next two decades will be slower than in the past. In addition, the growth in groundwater abstraction occurred over a period when resources were considered to be abundant and, prior to 1963, development was uncontrolled. The combination of a slower growth in demand, appreciation of the limit of available groundwater resources and effective control of development would suggest a much slower growth in groundwater abstraction than in the period of record.

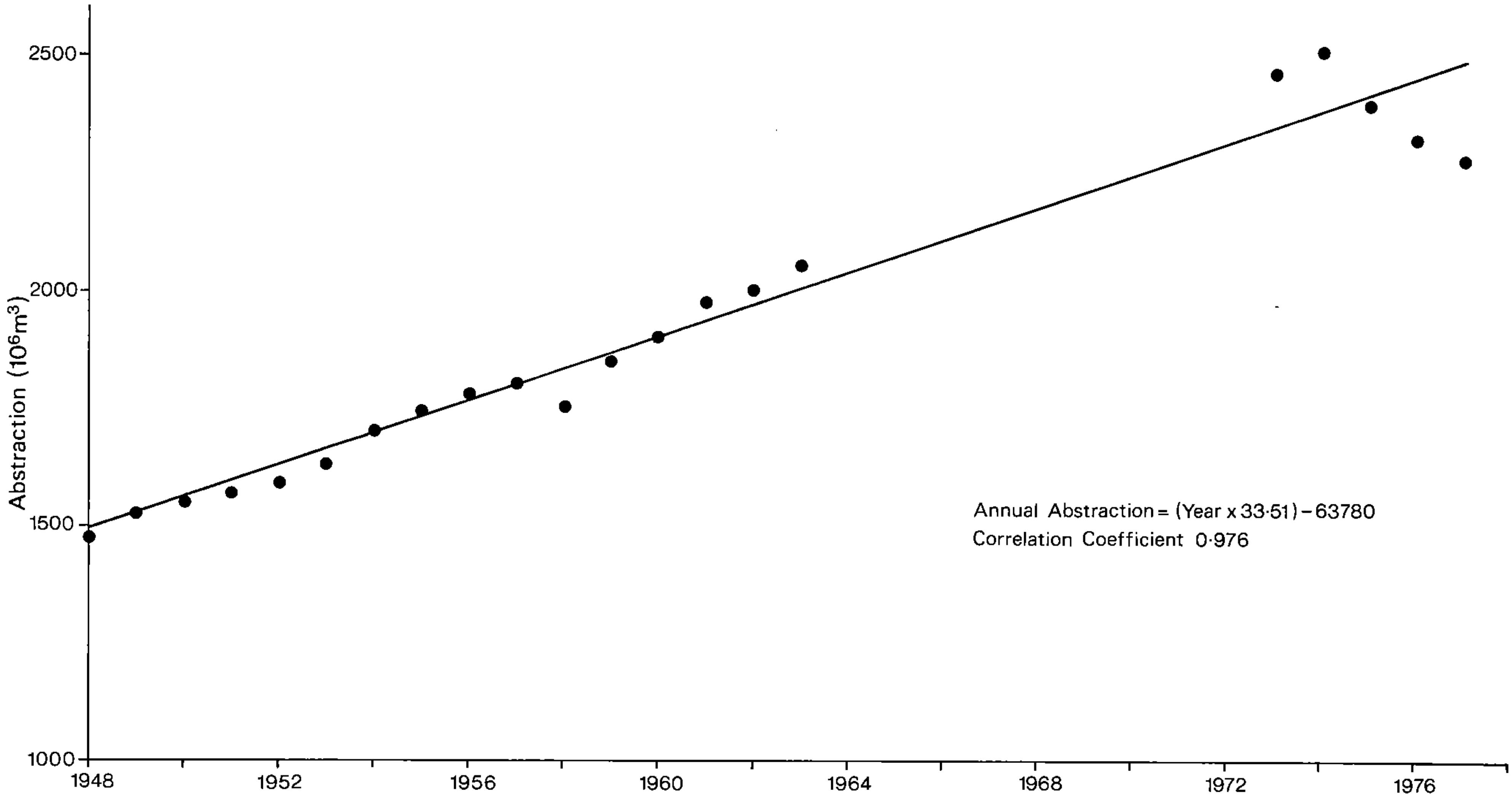

Fig: 6.1. Groundwater Abstraction in England and Wales, 1948 – 1977

Table 6.1. Groundwater abstraction in England and Wales during the years 1948 to 1963 and 1973 to 1975

Year	Total Abstraction (10^6 m^3)	Total Public Supply (10^6 m^3)	Total Industrial (10^6 m^3)	Total Other Uses (10^6 m^3)
1948	1475	986	431	58
1949	1522	995	461	66
1950	1554	1002	484	68
1951	1570	1006	487	77
1952	1592	1046	484	62
1953	1636	1063	503	70
1954	1702	1099	531	72
1955	1749	1136	538	75
1956	1782	1173	534	75
1957	1801	1191	533	77
1958	1753	1182	503	68
1959	1852	1252	526	74
1960	1902	1288	539	75
1961	1976	1361	539	76
1962	2002	1404	523	75
1963	2058	1459	526	73
1973	2462	1874	530	58
1974	2509	1953	501	55
1975	2391	1830	501	60
1976	2325	1770	514	41
1977	2280	1739	497	44

Note "Other uses" include such abstractions as those for agriculture, horticulture, and so forth.

7. GROUNDWATER DEVELOPMENT METHODS

In recent years techniques for developing aquifers in the United Kingdom have included abstractions of relatively constant supplies from boreholes (the water being pumped directly into supply), the combined use of surface and groundwater resources and the regulation of river flow from ground water storage.

In the early stages of development groundwater is abstracted from direct supply boreholes near to the demand centre which is commonly close to a river. The pumping rate is increased over the years until groundwater levels fall sufficiently to intercept base flow to the river and hence cause a diminution in river flow. Ultimately, induced recharge of river water into the aquifer may occur, further reducing river flow, and also leading to a possible deterioration in groundwater quality. In an attempt to alleviate this situation, new wells may be sited at greater distances from the river. However, it is inevitable that, if abstraction rates continue to rise, base flow to the river will eventually be intercepted and induced recharge from the river will take place.

An obvious alternative is to satisfy the demand from a river intake (or other surface source) whenever the river flow is sufficient, and to make up any shortfall during periods of inadequate flow by pumping ground water into supply. However, almost without exception, river water requires treatment to potable standards before being put into supply, while groundwater in general does not. The natural river flow varies seasonally and the permissible abstraction, and hence the volume of water passing through the treatment works, varies in proportion. Major problems in schemes which combine the use of surface and groundwater in an integrated water supply system are the difficulties of efficient control of water treatment works with a widely varying output, the cost of duplication of source works, the possibility of pipe erosion, quality deterioration from disturbance of accumulated pipe deposits and industrial and private consumers' intolerance to the markedly different qualities of water from the surface and groundwater resources.

Nevertheless major combined use schemes have been implemented and others are being planned. A notable example is the combined use of an impounding reservoir, groundwater supplies and abstractions from the river Lune in North Lancashire. Known as the Lancashire Conjunctive Use Scheme it is described below.

As demand on the combined use scheme increases, the pumping of groundwater during periods of reduced river flow may intercept base flow, or even induce recharge from the river, reducing the flow of the latter still further. This may in turn lead to a requirement for compensation water to be pumped into the river to maintain a prescribed minimum flow, thus reducing further the volume available for supply.

The final solution is to abstract the full requirement from the river, but to regulate the flow of the latter by pumping groundwater into the river. The installed abstraction capacity from the aquifer must be sufficient to maintain river flow at the required level during those periods when the natural flow is inadequate, and may be determined from a study of the flow frequency graph of the river concerned.

The location of abstraction wells is an economic compromise between the aims of maximising net gain to river flow by siting boreholes some distance from the river, to limit the possibility of intercepting a significant portion of the base flow, and of keeping the pipe lines connecting the boreholes to the river as short as possible to minimise costs. The river itself performs the function of a main aqueduct to convey the water to an intake downstream. The treatment works operates at a more or less constant rate (depending upon the seasonal variations in demand) and the water quality problems are reduced to treatment of a water whose quality varies relatively slowly and seasonally with increasing proportions of groundwater in the regulated flow. Ecological problems arising from changes in river regime and quality are a separate issue and may necessitate extensive investigations.

In Figure 7.1, the location of three such regulation schemes are shown, involving the rivers Tern and Perry in north Shropshire, tributaries of the river Severn; the river Thet in Norfolk, a tributary of the river Great Ouse; and the river Lambourn in Berkshire, a tributary of the river Thames.

The Lancashire Conjunctive Use Scheme

The Lancashire Conjunctive Use Scheme is the gradual development, over a number of years, of the concept that a number of resources, with different hydrological characteristics, operated together can yield more water than the sum of their independent yields. The concept was implemented in the late 1950s by the then Fylde Water Board in North Lancashire who combined the use of surface water supplies from a direct supply reservoir with abstractions from the Triassic sandstones.

More recently the scheme has been extended to include abstractions from the river Lune near Lancaster, in quantities up to 280 000 m^3/d, pumped through a pipeline and tunnel aqueduct to augment the flow of the river Wyre. Water is abstracted from the river Wyre and delivered to a nearby treatment plant which has separate facilities for treating river and borehole water. Groundwater is provided from 41 boreholes with a maximum authorised abstraction of 195 000 m^3/d.

Supplies from the river, groundwater and existing direct supply reservoirs are linked by a system of interconnecting trunk mains to provide 130 000 m^3/d of additional supplies.

The Shropshire regulation scheme

The river Severn is already regulated from an upstream impounding reservoir. Further regulation is proposed from groundwater storage. The aquifer involved is the Permo-Triassic sandstones, the pilot area investigated being within the catchments of the tributary rivers Tern and Perry.

The annual natural recharge of the whole of the aquifer is estimated at approximately 200 x $10^6 m^3$/a. Approximately 40% of the natural recharge is at present taken directly into supply and it is estimated that by the year 2001 a further 20% will be so used. The remaining 40%, equivalent to approximately 80 000 m^3/d is available for river regulation.

Work has been carried out to the point of testing two pilot areas, one in each tributary catchment. Each of the two pilot areas comprises approximately 80 km^2 and contains 7 abstraction wells and a number of observation wells. The mean yield of each abstraction well is of the order of 4 000 m^3/d, and the net gain to the rivers Perry and Tern appears to be between 65% and 70% of the water pumped.

In the first stage development it is intended to drill up to 60 abstraction boreholes to further regulate the river Severn via the rivers

Tern and Perry to support additional continuous abstractions of 225 000 m^3/d from the river Severn. It is expected that the groundwater will be pumped in one year in three and for continuous periods ranging between 20 and 115 days. The long term demand on aquifer storage is estimated at approximately 7 000 m^3/d. A further 73 000 m^3/d remains available either for direct supply or for further regulation.

At the present time the pilot studies have been completed and application has been made for the development of the first stage of the operational scheme.

The Thames groundwater scheme

The major demands in the river Thames basin arise in the London conurbation which is supplied largely from pumped storage reservoirs near to the tidal limit supplemented by direct groundwater abstractions. The objective of the groundwater scheme is the augmentation of river flow from groundwater storage as an alternative to further surface storage developments.

Four areas have been identified within the basin where groundwater resources are available and are relatively undeveloped. Three are in the chalk, mainly unconfined and one in the Jurassic limestone mainly confined. It is envisaged that development could be undertaken in four stages corresponding to these four areas. Over these areas as a whole average annual recharge is estimated at approximately 610 x $10^6 m^3$ of which about 130 x $10^6 m^3$ must be allocated for existing abstractions.

A pilot scheme was carried out in the Lambourn catchment, an area of 234 km^2 within the Stage 1 development area and comprised 9 abstraction wells and a number of observation wells. The mean yield of each well is 3 300 m^3/d. The aquifer is in hydraulic continuity with the river, and wells close to the river bank drew only slightly upon aquifer storage; net gain to the river fell rapidly to a small fraction of the pumped output. Wells sited at a distance from the river bank made a substantial draft on the aquifer storage. With distances of approximately 1.5 km between river and well, a net gain of between 30% and 45% of the pumped output was obtained.

Based upon the experience gained from the pilot scheme the first stage operational development was designed and promoted and construction is now substantially completed. It comprises 34 abstraction boreholes, plus a comprehensive network of observation wells, and it is estimated that it will provide for additional demands on the Thames system of 75 000 m^3/d. The scheme was brought into operation in the unusually dry year of 1976. Pumping was continued from August to November and contributed 74 500 m^3/d to the flow of the Thames.

Further stages of the scheme are being investigated and it is now estimated that the full development should increase the net resources of the Thames system by 300 000 m^3/d.

The Great Ouse regulation scheme

It is proposed to develop the resources of the Chalk aquifer of the catchments of the rivers Great Ouse and Nar in order to regulate the flow of these rivers. The surface areas of the catchments is of the order of 3 800 km^2, of which approximately 2 500 km^2 is occupied by the Chalk outcrop.

The mean annual replenishment of the Chalk aquifer in these catchments is approximately 280 x 10^6 m^3. Assuming a maximum regional drawdown of 4 m, the scheme at full development could maintain the river flow to a level of 226 x 10^6 m^3/a. This figure includes an allowance for current licenced abstraction which in 1977 amounted to approximately 100 x 10^6 m^3.

A pilot area was selected in the catchment of the river Thet, a tributary of the Great Ouse, comprising 71 km^2. Eighteen abstraction wells were constructed, together with a number of observation wells. The mean yield of each abstraction well was proved to be 0.95 x 10^6 m^3/a. The pumped groundwater was discharged directly to the river Thet, and, after 240 days of continuous pumping, the net gain to river flow was of the order of 70%.

For the full development of the Great Ouse regulation scheme, approximately 315 new abstraction wells will be required. In 1977, the Anglian Water Authority received powers to undertake the first stage of this development. This stage comprises the construction of 52 new abstraction wells, which, together with 17 of the wells constructed for the pilot scheme, will develop approximately 24% of the estimated aquifer resources in these catchments.

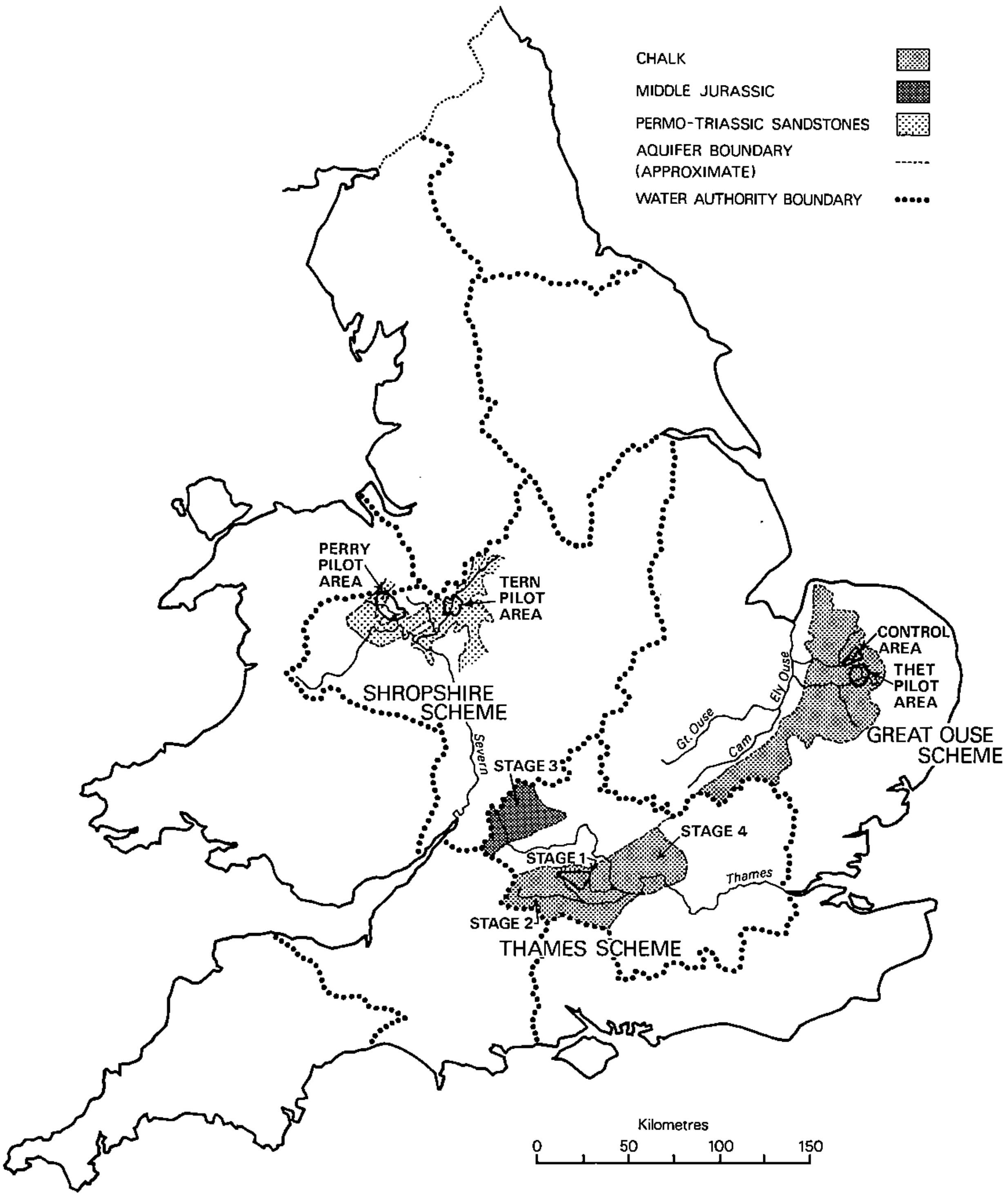

Fig. 7.1 Location of the three regulation schemes described in the text.

8. ARTIFICIAL RECHARGE

Artificial recharge is the process of replenishing groundwater storage within an aquifer, through wells or surface lagoons, with water other than that normally recharged by natural processes.

In the United Kingdom, experiments with artificial recharge through wells have been carried out into the Chalk of the London Basin, into the Permo-Triassic sandstones of Nottinghamshire, and into the Lower Greensand near to the south coast. The feasibility of artificially recharging these major aquifers has been shown to be possible and a first stage of development is in operation, utilising storage in the Chalk of part of the Lee Valley. Further proposals to construct and operate large schemes are being considered. Three such schemes are considered in this report, namely Hardham in the Southern Water Authority (Lower Greensand), the Lee Valley in the Thames Water Authority (Chalk), and the Stour Valley in the Severn-Trent Water Authority (Permo-Triassic sandstones). There are many local areas where techniques of artificial recharge could be used to increase total groundwater storage but their development will have to wait until such additional resources can be developed economically in preference to more traditional sources.

Hardham

In Unit 25 of the Southern Water Authority, in the vicinity of the village of Hardham, the Lower Greensand outcrop is partially overlain by clays of the Gault and by river alluvium in the valley of the river Rother. The structure over the area of investigation is a shallow syncline, elongated on an east-west axis. The Folkstone Beds of the Lower Greensand are here of the order of 55 m in thickness.

The synclinal structure forms a small basin measuring approximately 7 km in length and 4 km across. Its attraction from the viewpoint of artificial recharge is that the injected water is unlikely to overflow or discharge from the system.

The intention is to pump groundwater from the Lower Greensand during periods of high demand, generally through the summer months, and to recharge water during the winter when the river intakes have an adequate surplus. Tests have been carried out injecting water through lagoons and through a especially constructed well designed both for recharge and for abstraction.

When the scheme was considered in terms of the resource management of the area, it was found that the source, comprising the river intake and the Lower Greensand aquifer, would need to provide peak demands of 174 000 m^3/d when the scheme was fully operational between the years 1990 and 2000. Computer simulations showed that artificial recharge would become necessary only when the requirements reached a figure of 140 000 m^3/d, probably in or about the year 1985.

Preliminary experiments indicate that the capacity of the recharge well that has been constructed is approximately 2 500 m^3/d. Further experiments are now being carried out, and the design of further recharge wells and selection of suitable sites will be deferred for several years.

Lee Valley

The Lee Valley lies in Units 7 and 8 of the Thames Water Authority. The Chalk aquifer, which crops out on the north flank of the London Basin, is here confined by the Woolwich and Reading Beds and by the London Clay, both of Tertiary age. Abstraction of groundwater since 1800, in steadily increasing amounts, has resulted in the dewatering of a substantial volume of Chalk as well as the overlying Tertiary sands. The intention of the artificial recharge was to make use of the storage thus created by injecting surplus water when available through recharge wells.

As early as 1952, the Metropolitan Water Board (now the Metropolitan Division of the Thames Water Authority) had carried out experiments involving the recharge through wells of 2.5×10^6 m^3 of water. Further recharge took place in 1954 and 1955 and water was injected at two sites at a rate of 29 000 m^3/d. Pumping following the recharge period recovered the equivalent of approximately 29% of the recharged water. As a result of these experiments, a rise in groundwater levels was observed in some areas, and the general regional fall in levels was halted.

Experiments carried out by the Metropolitan Water Board and the Water Resources Board between 1970 and 1974 led to plans to inaugerate a large recharge scheme. Seven new boreholes were constructed and six existing wells were incorporated into the scheme. The maximum potential recharge rate is estimated to be of the order of 75 000 m^3/d, with a consequent gross yield from the complete scheme of 81 000 m^3/d. At the stage reached in 1979, the peak recharge rate was of the order of 20 000 m^3/d.

Stour Valley

The area of the Stour Valley lies in Unit 14 of the Severn-Trent Water Authority. In this area, there is concern that the demand for groundwater is exceeding the natural recharge and the nitrate content of the groundwater is rising. The intention of artificial recharge is to replenish the diminished volume in the groundwater storage and to dilute the nitrate concentration.

Across the area runs an aqueduct from which water for recharge can be taken. Two abstraction wells already exist, and will be modified and tested as recharge wells. In addition, an especially designed well for recharge will be constructed. The recharge rate is expected to be of the order of 4 000 to 6 000 m^3/d at this stage.

At the present time, negotiations for land have been completed, and borehole construction and the engineering work are expected to commence shortly. It is unlikely that the results from the pilot scheme will become available until 1985 at the earliest.

9. ACCURACY OF METHODS OF DATA COLLECTION

In estimating the groundwater resources available in a given catchment, and the hydrogeological properties of the aquifer concerned, a number of parameters must be evaluated, and the accuracy of the calculated results will depend upon the accuracy with which the basic data can be measured. This chapter considers the accuracy with which measurement of the following variables is made in the United Kingdom:

- Rainfall
- Evaporation
- Infiltration
- Groundwater level fluctuation
- Pumped discharge

Rainfall

There are two aspects to consider; the accuracy of point measurement of rainfall and the accuracy of assessment of total rainfall over an area. The former is a function of the accuracy of the raingauge installation; the latter, which is more important for the assessment of groundwater resources, is a function of the accuracy of the gauge and the density of the raingauge network.

In the United Kingdom there are over 6 300 manually read gauges whose general distribution is shown in Table 9.1. The vast majority of these gauges are of a standard type approved by the UK Meteorological Office and have collecting funnels with an aperture of 127 mm diameter set with their rims 305 mm above ground level. Rainfall is measured daily using a graduated glass cylinder except for isolated sites where, due to difficulty of access, readings are made weekly or monthly. There are in addition about 1 000 recording gauges, of the tipping bucket or syphon type, which produce continuous records on paper charts or magnetic tape.

The true rainfall is not measured by any of these gauges due to wind effects and to splashing as the raindrops strike either the gauge or the ground alongside, indeed no method of measuring the true rainfall has yet been devised. However upon level ground it is considered that a properly installed and maintained standard gauge is likely to provide a measure of rainfall within 3% of the true rainfall. On hillsides exposed to strong winds, errors as much as 20%, or in extreme cases 30%, may be incurred.

Quality control of rainfall data is carried out by the Meteorological Office in collaboration with the water authorities and similar bodies. Control is achieved by a mix of manual and computer methods based on comparison with 'near neighbour' data. Initial quality control, especially the elimination of obvious errors in individual records, is, to an increasing extent, carried out by water authorities and similar bodies. Final quality control provides a best estimate data set.

Precipitation in the form of snow and ice is even more difficult to measure accurately. The normal procedure is to measure light falls using the raingauge funnel as a coring tool and heavy falls with graduated poles or boards and to convert this to a water equivalent. Unfortunately, due to its propensity for drifting before the wind, the mean of a large number of measuring points is necessary to produce useful figures which must also take into account the degree of compaction of the snow. More sophisticated techniques for snow measurement are becoming available such as snow pillows and various forms of remote sensing but these are not generally applied in the UK and little is known of the degree of accuracy of the conventional measurement of snow cover.

An evaluation of the accuracy of areal assessments of rainfall was made as part of an 8 year research programme which had as one of its main objectives investigation of the accuracy with which areal precipitation can be measured by radar in a hilly (mountainous) area. In the catchment selected for the research a dense network (80 gauge to 1 000 km^2) was established to provide a basis for comparison with the radar measurements. In addition to minimising the gauge error by careful siting and maintenance the concept of an 'optimum field' of rainfall was adopted to determine the areal rainfall. This assumed the point readings of the raingauges to be accurate and used the rainfall pattern displayed by the radar to establish the isohyets joining the point readings. This not only provided the best assessment of areal rainfall (subject to the errors of the gauges themselves) but also provided information on the accuracy with which networks of various densities could measure areal rainfall in different types of rain.

Based on the results of that research and further advice from the Meteorological Office Table 9.1 shows the probable errors of areal estimates of rainfall derived from the current network of manually read gauges assuming uniform distribution.

Table 9.1. Daily, Weekly and Monthly Read Raingauges

	No of gauges	Area km^2	Gauges per 1000 km^2	% error in areal estimates
England	4077	130 447	31.25	8-12
Scotland	1387	78 775	17.60	9-15
Wales	616	20 766	29.66	8-12
N Ireland	278	14 120	19.69	8-15
	6358	244 108	26.05	

This of course does not take into account the 1 000 recording raingauges which are also available, nor the relatively lower density of gauges in inaccessible mountainous areas and the corresponding higher density elsewhere. Allowing for these factors it would be reasonable to assume a probable density of 40-50 gauges per 1 000 km^2 over areas of aquifer outcrop which should provide an areal assessment with an error of 5-10% in addition to the error in the gauge itself. These errors in areal assessment apply to assessments over relatively short periods of time; the errors will tend to decrease with longer periods.

Evaporation

Evaporation can take place from a water surface, from a wet soil surface, from snow and ice surfaces, and from vegetation wetted by rain. In addition, soil water is conveyed by vegetation to the atmosphere by transpiration. Since the readiness with which the soil will yield water to plants depends upon the degree to which it is saturated, the transpiration will vary. Thus there is a potential evaporation rate and an actual evaporation rate.

Direct measurement of evaporation has only limited possibilities. Evaporation from open water surfaces may be measured from suitable pans and tanks. Lysimeters are theoretically useful in determining both potential and actual evaporation but, unless they are of large size, the true evaporation figures tend to be masked by the drainage of water down the inside of the containing walls. Weighing lysimeters are very costly. The most serious problem with direct measurement of evaporation is the degree of reliability with which the various devices accurately simulate natural conditions.

The alternative approach is to use indirect methods. The first of these is the energy budget approach. An equation is solved for the heat balance between the income and expenditure of energy which includes the energy used in evaporation. The difficulty with this method is that some energy is used simply in heating the air adjacent to the ground surface and this is extremely difficult to measure, and assumptions have to be made for this parameter.

Other approaches include aerodynamic methods and eddy flux measurement. Similar difficulties arise in that certain parameters are almost impossible to evaluate.

The approach generally in use at present is the Penman method (Penman, 1948) sometimes with slight modifications. This is essentially a two-stage approach, calculating first the evaporation from a hypothetical water surface and converting this to the potential evaporation from turf, forest, various crops, and so forth. With modifications to the original method, the Penman approach, applied over a reasonable area and over a period of months, and assuming that the rainfall has been accurately measured, appears to be accurate to within 5%.

To convert potential to actual evaporation, the usual method is to apply a root constant which varies according to the vegetation type. This method is naturally dependent upon the accuracy of the root constant chosen for a particular situation. The most favoured approach is to employ a number of root constants and select that which produces the results comparing best with observed conditions.

Recently the Meteorological Office enhanced its method of calculating actual evaporation by using a system described as the Meteorological Office Rainfall and Evaporation Calculation System (MORECS). This attempts a more realistic treatment of rainfall interception, evaporation and soil water extraction. The soil moisture in soil under vegetation is considered to occupy two distinct layers which correspond to a relatively dense system of shallow roots and a sparse system of deep roots. It is assumed that vegetation is able to extract soil moisture freely from the upper layer but that water is removed from the lower layer with increasing difficulty. The MORECS system is used currently, with rainfall data, to estimate potential and actual evaporation and soil moisture deficiencies for each 40 x 40 km square in the United Kingdom excluding Northern Ireland. This information is forwarded weekly to the water authorities and other users.

Infiltration

By definition, this is that part of the precipitation that actually reaches the water table. Direct measurement is theoretically possible by the use of lysimeters, but it is difficult to establish how reliably these reflect natural conditions. In particular, it is important that the contents of the lysimeter represent the undisturbed natural state of the aquifer and the overlying soil, and this is not easy to achieve.

The classical approach is an indirect derivation from a catchment water balance estimation. The parameters of rainfall, actual evaporation, surface run-off and base flow are measured or calculated. Infiltration can then be assessed as:

Infiltration = Rainfall - Evaporation - Surface Run-off

The accuracy of such an estimate is difficult to establish. Hopefully, the results should be within 10% assuming that the necessary parameters have been properly determined.

Another method, which has proved useful, is the use of neutron probes to measure soil moisture at successive horizons. This permits the observer to follow the downward path of the percolate and so allows an estimate of the velocity.

Groundwater level fluctuation

The piezometric surface as represented by the water level in wells is measured in a large number of observation wells in England and Wales. These wells form a groundwater observation well network which was instigated by the Water Resources Board in the period 1966 to 1974. In the latter year, 1392 observation wells were in use, and more wells have since been added to the network. Levels are measured by the Water

Authorities and their agents.

The majority of observation wells are measured manually either weekly, or, in some cases, monthly. The usual instrument is an electronic probe suspended on a graduated cable or tape, contact being made by the water to complete a circuit which gives either an audial or a visual signal at the surface. Measurements are normally made to the nearest centimetre.

20% to 25% of the observation wells are equipped with continuous water level recorders. These are of various types, driven by clockwork or by electric battery power, and recording either on paper charts or punched paper tapes. Levels are recorded to the nearest centimetre, although some instruments are capable of measuring to the nearest millimetre.

Groundwater levels are also measured upon a continuous basis in most of the large wells pumped for public supply. The usual instrument is a pneumatic gauge, which is capable of measuring to within two centimetres when in good working order. Care must be taken to avoid any leakage in the air-line.

Pressure transducers have also been considered for level measurement. The problem is that either a transducer is available that will measure to within one centimetre over a small range of fluctuation (up to 2 or 3 m), or will measure much less accurately over a wide range of fluctuation. This limits their use at the present time.

Even after making allowance for the inevitable faults in mechanical and electrical equipment and possible observer errors, groundwater level fluctuations are without doubt the most accurately measured of all the parameters and errors are, in general, so small that they can be ignored.

Pumped discharge

Measurements of pumped discharge are made during pumping tests, to determine borehole yields and aquifer properties, and routinely from production boreholes to provide the assessments of total abstractions from an aquifer given in Chapter 5.

In pumping tests it is customary to measure the discharge from the well by passing the flow through a baffled weir tank containing either a 90° V-notch, for small discharges, or a rectangular notch for large discharges.

In both cases, the accuracy is at worst within 2% of the true value providing that the rules for calculating flows over weirs with such contractions are followed. Similar accuracy is obtainable with orifice plates which are sometimes used.

When considering the accuracy of measurement of total abstractions we are concerned with the possible error of measurement in many thousands of individual abstractions.

In Chapter 6 it was shown that in England and Wales 75% of groundwater abstractions were made by the public water supply authorities. Equivalent data is not readily available for Scotland and Northern Ireland but it is thought that the proportions will be roughly the same. In public water supply installations abstractions are in general measured continuously by well maintained meters of appropriate rating. It may be assumed therefore that this major part of the total abstraction will have been measured within the range of accuracy of the meter itself. Most manufacturers claim an accuracy of 2% over the rated flow range. Allowing for possible deterioration with age before renewal or recalibration an error of 5% seems likely.

The remaining 25% of industrial, agricultural and other uses comprise of the order of 2 000 individual abstractions. Of these about half of the total quantity is accounted for by a much smaller number of individual abstractions each exceeding 2 000 m^3/day. It would be reasonable to assume that these significant abstractions would be metered with something approaching the same degree of accuracy as the public water supply abstractions. For the remaining the record provided by the abstractor is likely to be no more than a best estimate of the quantity of water abstracted based upon the number of hours a pump has been running and its nominal rated capacity. Possible errors here are unknown but could be very large. They could be significant for individual groundwater units but their effect on the total abstraction will be small.

Overall it is considered that the error in measurement of the total abstraction is likely to be of the order of 10%.

10. SELECTED GLOSSARY

Abstraction well:-
well constructed for the purpose of pumping groundwater from an aquifer

Aquifer:-
a rock formation containing groundwater that can be abstracted economically in usable quantities

Artesian well:-
a well, within which, when the aquifer is penetrated, water rises within the well to a level above the top of the aquifer ie above the base of the confining layer. Hence artesian conditions, artesian aquifer (see Confined aquifer)

Artificial recharge:-
the replenishment of groundwater storage in an aquifer other than by natural means

Basalt:-
dark-coloured rock formed from volcanic flows onto the surface of the earth; contains a relatively low proportion of silica

Base flow:-
the groundwater contribution to stream flow; the sustained dry-period run-off

Bed rock:-
solid rock underlying unconsolidated material

Boulder clay:-
unassorted mixture of glacial drift; usually comprises material of gravel size embedded in a fine silt or clay matrix

Breccia:-
rock composed of angular material of gravel size embedded in a matrix of finer grain size

Calcareous:-
formed of, or containing a large proportion of, calcium carbonate

Casing:-
see "Lining tubes"

Clay:-
soft, plastic, impervious rock composed largely of clay minerals (mainly hydrous aluminium or magnesium silicates with a layer type crystal structure)

Coefficient of storage:-
a dimensionless measure of the volume of groundwater held in storage in a confined aquifer. Defined as the volume of water released from a unit area of aquifer for a unit decrease in piezometric had in response to a pumping well.

Confined aquifer:-
an aquifer containing water under pressure. If the confining formation is penetrated by a well, the groundwater will rise to a level above the top of the aquifer

Conglomerate:-
rock composed of rounded material of gravel size embedded in a matrix of finer grain size

Development:-
1) of a well: using chemicals, explosives or physical means to induce a well to provide its optimum yield

2) of an aquifer: the controlled exploitation of the groundwater resource

Dolomite:-
rock formed largely or wholly of magnesian carbonate; the balance is generally of calcium carbonate

Drawdown:-
difference between the elevation of the initial piezometric surface and its position after or during pumping

Effective saturated thickness:-
the thickness of the saturated aquifer within which groundwater movement may take place in response to pumping in wells

Fault:-
a fracture in the strata along which rocks on the one side have moved relative to the other

Filter pack:-
a sand or gravel material filling the annular space in a well between the sand screen and the aquifer

Fissile:-
a lithological term indicating a tendency to split into thin sheets

Fissure:-
open joint or crack in rocks

Fluvial deposits:-
deposits laid down by streams (alluvial) or in lakes (lacustrine)

Formation:-
a distinct geological stratum or series of strata

Gravel:-
arenaceous material with grain size greater than 2.00 mm

Greensand:-
sand containing the green silicate mineral glauconite

Groundwater:-
that part of underground water that is contained in the zone of saturation; its lower limits are the zone of rock flowage or the lower confining bed; the upper limits are the water table or the upper confining bed

Groundwater divide:-
a line drawn upon a map dividing one groundwater unit from another; groundwater does not flow across a groundwater divide

Hydraulic conductivity:-
a measure of the ability of an aquifer to transmit groundwater. Defined as the volume per second flowing through an aquifer face one unit square under a gradient of 1:1 ($m^3/m^2\ s = m/s$)

Hydraulic continuity:-
when water can pass freely between two aquifers, the latter are said to be in hydraulic continuity one with the other. A river may also be in hydraulic continuity with an underlying aquifer

Hydrogeology:-
the study of groundwater in its geological context

Impervious:-
not permitting the passage of water

Infiltration:-
the flow of water through the soil surface downwards to the water table. Usually expressed as millimetre per year (mm/a)

Intermontane basin:-
basin lying between two mountain ranges

Karst:-
limestone terrace marked by very large solution openings

Limestone:-
rock formed dominantly of calcium carbonate

Lining tube:-
solid-walled tubes inserted in a well (a) to provide support, (b) to prevent ingress of unwanted water

Marl:-
calcareous clay

Massive:-
a lithological term meaning of large, solidly cemented and homogeneous appearance

Mudstone:-
indurated clay

Observation well:-
well constructed or utilised for the purpose of measuring groundwater levels, pressure heads, or groundwater quality

Oolitic limestone:-
limestone comprising a deposit of ovoid or spherical grains

Percolation:-
the movement of groundwater through saturated pore space

Potable water:-
water of adequate quality for drinking purposes

Pumping test:-
well-test to determine aquifer transmissivity and specific yield, and to measure well efficiency

Recharge lagoon:-
lagoon or pond with a pervious floor constructed for the purpose of inducing infiltration to an underlying aquifer

Recharge well:-
well constructed for the purpose of injecting water into an aquifer

Run-off:-
discharge of water through surface streams of a drainage basin: sum of surface run-off and groundwater flow reaching the streams

Sand:-
arenaceous material with grain size between 0.06 mm and 2.00 mm

Sand screen:-
lining tube with slots or perforations; set opposite water-bearing horizon or horizons in a well to permit entry of water but excluding sand

Sandstone:-
indurated sand; sand with intergranular cement

Shale:-
partially indurated clay with preferred direction of fissuring

Silt:-
arenaceous material with a grain size less than 0.06 mm

Specific capacity:-
the ratio of pumping rate to drawdown; usually expressed as cubic metres per day per metre drawdown (m^2/d)

Specific yield:-
a dimensionless measure of the volume of groundwater held in storage in an unconfined aquifer. Defined as the fraction of a unit volume of aquifer that consists of water that is readily released, for example, to a pumping well, resulting in the dewatering of the aquifer.

Submersible pump:-
pump capable of operating under water. Usually refers to an electrically powered submersible pump commonly used in water wells

Surface water:-
water found on the ground surface; includes rivers, lakes, ponds, etc

Topographic divide:-
crest line dividing one drainage basin from another

Transmissivity:-
a measure of the ability of an aquifer to permit lateral groundwater flow. It is measured as the volume in cubic metres that can pass through an aquifer face one metre in width and the full thickness of the aquifer in depth in one second under a gradient of 1:1 (m^2/s)

Unconfined aquifer:-
an aquifer in which there is an unsaturated zone underlying the water table

Volcanics:-
rocks formed of igneous materials ejected onto the surface of the earth, for example, from volcanoes

Water table:-
the junction of the saturated and unsaturated zones in an aquifer. It is taken to intersect a well at the free water surface in that well. A water table can exist only in an unconfined aquifer

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