Water Resources Planning - Strategic Options

Volume 1 - Main Report

Halcrow

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National Rivers Authority

Water Resource Planning - Strategic Options

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WATER RESOURCES PLANNING - STRATEGIC OPTIONS

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WATER RESOURCES PLANNING - STRATEGIC OPTIONS

VOLUME 1 - MAIN REPORT

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1 SUMMARY

1.1 Background

In March 1991, the National Rivers Authority (NRA) appointed Sir William Halcrow and Partners Limited to undertake a study of Strategic Options for the Development of Water Supplies in England and Wales. The study was intended to assist the NRA in undertaking their duties under Section 143(2)(a) of the Water Act 1989 (1). This section of the Act places a duty on the NRA to publish information from which assessments can be made of the actual and prospective demand for water, and of actual and prospective water resources in England and Wales. This Final Report presents the findings of Halcrow's study.

The report can be divided into three sections:

(i) Chapters 2, 3 and 4 investigate the need for more water resources.

(ii) Chapters 5, 6, 7 and 8 consider the full range of options available for increasing the water resources of the country, or of reducing the demand for water.

(iii) Chapter 9 examines how the various options can be used to meet the forecast need for water on a region-by-region basis.

The conclusions of the report are presented in Chapter 10.

The report gives an overview based largely on previous work done by the NRA, its predecessor authorities and various consultants.

1.2 The Need for More Water

There is a striking regional variation in the need for water. England and Wales can be divided by a line joining the Severn to the Humber. To the north-west of this line all NRA regions, including Severn Trent, are forecast to have a surplus of water resources (reliable yield over demand) by the year 2021. The five NRA regions to the south-east of this line are all forecast to be in deficit by the year 2021. The regions of largest forecast public supply surplus are North West (550 Ml/d) and Northumbrian (790 Ml/d). The regions of largest forecast deficit are Anglian (420 Ml/d) and Thames (950 Ml/d). Resources in these two regions and Southern Region are already heavily committed, leaving little scope for further local developments.

For the country as a whole, the forecast public water supply demands and reliable yields of existing schemes are estimated to be almost in balance in the year 2021 (approximately 20,000 Ml/d each). This suggests that the essence of water resource development strategy should be to meet those demand increases which cannot be overcome by improved husbandry and an appropriate level of demand management, by transfer of existing resources from the north-west to the south-east.

Water uptake via private abstractions has decreased significantly in recent years. This trend is unlikely to continue at the same pace, but it is difficult to predict with confidence how it may change. At worst, there may be a modest increase in private abstraction uptake. This would only be critical in areas such as Thames and Anglian, where resources are already heavily committed. Here new abstraction applications must be reviewed carefully, and, if necessary, conditions embodied in the consent which ensure that adverse impacts are minimised.

The forecast reductions in unaccounted-for water (UFW) have a major influence on the forecasts for surpluses and deficits. The water company demand forecasts assume an overall 5% drop in UFW by 2011 and a 6% drop by 2021.

1.3 Strategic Options

At a cost of about £0.12 million per Ml/d of saved water, leakage control is by far the cheapest means of reducing public water demand. The lower bound forecast for year 2021 demands assume that all regions achieve a 15% level of UFW by that date.

Pending the outcome of the national trials, the extent to which widespread domestic water metering could reduce overall demand is uncertain. If a figure of 5% is taken, the conclusion that the south-east of the country will have serious deficits in water resources by the year 2021 is not affected. Despite its relatively high cost (£2.7m - £11.2m per Ml/d of reduced demand, depending upon volume of water saved), it would be premature to rule out metering as an option for reducing supply deficits. Extensive benefits could accrue from volume related charging.

There remains some scope for local development of water resources in most regions, provided that it is carried forward in an environmentally sensitive manner. However, local development will be insufficient to meet all the regional deficits.

A National Water Grid, involving piped distribution of treated water from the regions of surplus to the regions of need has the potential for solving the resources deficit problem. However, its cost is very high, about £4.2 million per Ml/d, and it is not considered to be economically viable.

The desired effect of the National Water Grid, namely transferring water from the north and west of the country to the south and east, can be achieved by schemes involving inter-regional transfers of raw water. There are four major potential resources to be transferred:

(i) The 2021 forecast surplus of about 800 Ml/d in Northumbria Region (mainly from Kielder).

(ii) The forecast surplus of about 550 Ml/d in the North West Region.

(iii) The Craig Goch scheme in mid-Wales which could provide a new resource of about 1,000 Ml/d.

(iv) Utilisation and transfer of a further 360 Ml/d approximately from the River Trent.

In essence there are two ways in which the inter-regional transfers could be effected. Down the western side of the country, water from Wales can be transferred via the River Severn and a connection to the Thames to supply deficits in the Thames, Southern and Wessex Regions. Down the eastern side of the country, a series of transfers between the Rivers Swale, Trent, Witham, Ouse and finally to a new reservoir at Great Bradley, could be used to meet the deficits in Anglian, Thames and Southern Regions.

At present the water undertakings are investigating the effects of water metering and are carrying out studies into major local resource developments, such as the proposed new reservoir in the Upper Thames Region and Broad Oak Reservoir in Kent. However, there are no studies being undertaken of the major inter-regional transfer schemes which seem likely to be the ultimate answer to the deficit problems.

Although this report is not required to come to conclusions about the best means of meeting the forecast deficits, it seems likely that the optimum solution will be a combination of improved accounting for water, reduced leakage, demand management, local schemes and major inter-regional transfers. It is recommended that the inter-regional transfers are further investigated in terms of both cost and environmental/quality implications as a matter of urgency, so that rational decisions can be taken on the promotion of local schemes.

2 INTRODUCTION

2.1 Purpose of the Study

This document presents a review of present and future water use in England and Wales, and compares means of responding to growth in such demand. Its purpose is to provide a basis from which the National Rivers Authority (NRA) can formulate a Water Resources Planning and Development Strategy.

Inland surface waters fulfil a variety of functions. They are an important feature of the landscape, and provide habitat for a vast range of flora and fauna. They act as a focus for various forms of recreation, including angling. They, together with the underground waters from which their base flow is derived, are the source for all public and private water supplies in England and Wales; furthermore, they are widely used for the disposal of treated sewage effluent.

Some of these uses are potentially incompatible, and there is a clear need for development of a river system to be planned and managed in such a way that the water supply and sewage disposal demands placed upon it do not impact upon its environmental and recreational importance. This need was recognised in the Water Act 1989 (1), under which the NRA was established. Section 2.10 of the Act set out the duties and responsibilities of the NRA and others in respect of recreation and the environment, and sections 125 to 128 require the NRA to ensure that water resources are properly managed and used.

In addition, under Section 143 Clause 2(a), the NRA is required to

"collate and publish information from which assessments can be made of the actual and prospective demand for water, and of the actual and prospective water resources in England and Wales".

The study described in this report has been carried forward to enable the NRA to fulfil its duties as set out in Section 143.

2.2 Review of Previous Studies

Until the creation of the Water Resources Board (WRB) with the passage of the 1963 Water Resources Act (2), little regard was paid to strategic resource planning in the United Kingdom. Between the years 1965-71, the WRB produced three regional studies in the South East (3), the North (4) and the Midlands and Wales (5), which remain the basic works of reference for national water resource planning in this country, although they are now very out of date.

In 1973 the WRB produced a report on Water Resources in England and Wales (6), based upon the three regional reports and a large number of other studies and investigations.

Under the provisions of the 1963 Act, the River Authorities were instructed to provide surveys of their surface and groundwater resources, known respectively as the Section 14 and Section 24 reports. This work was undertaken in the late 1960s/early 1970s. The Section 14 and 24 reports are now some twenty years old and, except for information on reservoir capacities and estimated yields, have not been referred to in this study.

Besides those identified above, no other government sponsored national surveys of resources have been identified during this study. However, an EEC report has been produced on Ground Water Resources in the UK (7). Doubt has been raised on the findings of the EEC report, because of the simplistic methodology used for calculating groundwater recharge.

At the end of March 1991 the NRA produced a brief review of projected public sector water demand and available resources (8). This document provides a useful up-to-date first estimate of water availability on a regional basis.

Although the WRB regional studies remain a useful guide, the passage of time has shown the water demand forecasts contained in them to be gross overestimates. In selected areas of the North, the Midlands and Wales, the WRB forecasts for public water supply (pws) demand in the year 2001 are almost double current predictions (see Table 2.1). This is probably a reflection of the decline in manufacturing industry and related water use that occurred in the 1970s and 1980s.

Table 2.1 Comparison of Forecast and Actual Water Demand for 1991

	WRB (1974) 2001 PWS forecast (Ml/d)	Current (1991) 2001 PWS forecast (Ml/d)
Thames	4591	4353
North-West	4441	2283
Yorkshire	2140	1491
Severn-Trent	4961	2491

Details of current (1991) 2001 PWS forecasts are given in Annex B, Table B10.

Current forecasts for population in 2001 in these regions are some 13% (Thames) - 28% (North West) below those produced by WRB. It is suggested that the relatively close agreement of WRB and current pws forecasts for the Thames area in 2001 is due to a lesser dependance on manufacturing industry, and thus higher growth in both employment prospects and regional prosperity.

Stemming from their forecasts, the original WRB reports fostered a series of large feasibility studies into estuary storage on the Dee, the Wash, Morecombe Bay and Solway Firth as well as reservoir enlargements and river transfer schemes such as the Craig Goch Project. These have not been adopted. Some recommended schemes - especially in the South-East, such as the Ely Ouse-Essex transfer and Gatehampton groundwater - have been acted upon; other developments, such as Great Bradley Reservoir in Essex, are now under active consideration, having not been justified earlier.

2.3 Available Data

2.3.1 General

Data used in preparing this report have been assembled from

- reports of previous studies;
- discussion with the NRA;
- published material on salient topics.

The review of previous reports has already been described. Most data came from the NRA, either directly or indirectly through work for them by Halcrow on other projects, as described below. A comprehensive audit of all data collected was outside the scope of the study; however data were screened to identify any conflicting or extraordinary figures, which were then queried with the region concerned.

2.3.2 Demands

Present and forecast public water supply (pws) demand data, broken down into metered, unmetered and unaccounted for (UFW) components, has been provided by most companies via NRA regional offices for the years 1990, 2001 and 2011 (see Annex B). Where this information has not been supplied, estimates have been produced based on data from similar areas. In most cases, data on population up to 2011 were also provided, based on Office of Population Censuses & Surveys (OPCS) and local council forecasts. Further subdivision of pws data (into use categories such as domestic, industrial, commercial etc, for example) was not available from many regions.

Totals of public and private abstraction licences and licence uptake have been taken from the DoE Environmental Protection and Water Statistics document (9), and listings of abstractions above 10 Ml/d have been provided by the NRA regions. Where inland and tidal abstractions have not been differentiated, an educated estimate has been made.

Non-licensed abstractions have also been taken into account where appropriate. These include sources operated by British Waterways and the Crown, and dewatering of mineral workings. An effort has been made to identify all inter-regional, active and passive (via reticulation/sewage disposal systems) transfers of water. However, the list of transfers should not be regarded as exhaustive, as the company boundaries do not coincide with the NRA regions.

Details of existing demands and demand forecasting are given in Annex B.

2.3.3 Resources

Groundwater resource estimates have been obtained from all the NRA regions with a greater or lesser degree of accuracy, given that the method of calculation of groundwater recharge or yield varies greatly. Following discussions with the regions, an assessment has been made of the amount by which existing groundwater abstraction would need to be reduced in each region (if circumstances allowed) to limit significant adverse effects on streamflow.

NRA regions have provided data on the yields and storages of existing major reservoirs. Consistent data on the potential yield of direct abstractions from unregulated rivers is in general only available from consideration of estimated surface run-off and in-river flow requirements.

Assessments have been produced of the proportion of sewage effluent re-abstracted for indirect re-use, and that discharged to tidal waters. For most regions, this was done by apportioning the estimated total regional sewage flow between inland and tidal waters according to the ratios derived for those sewage treatment works (STW) with discharges greater than 10Ml/d; details of these larger works were provided by six of the ten regions. In the four remaining regions, the percentage of effluent discharging to sea has been extracted from Water Facts (10), while the quantity discharging to estuaries has been estimated.

Hydrometeorological data including rainfall, evaporation and river flows were obtained from the regions, from published data, from the DoE and from the Institute of Hydrology.

Data on water quality were taken from the DoE 1985 River Quality Survey (11).

Details of existing resources are given in Annex A.

2.3.4 Environmental Aspects

Information on the potential environmental impact of the options under consideration comes mainly from Environmental Impact Assessments (EIAs) of existing schemes and schemes under development. Until perhaps 20 years ago, consideration of the environmental impact of resource schemes was generally less thorough than is common nowadays, and detailed monitoring was very rare. Largely as a result of the heightened public awareness of environmental issues, all schemes being considered now are subject to vigorous and extensive impact assessments. These often include, implicitly or explicitly, analysis of the impact of existing operations.

In addition to numerous particular case studies representative of the environmental implications of various types of water resource development, more general information was gleaned from discussions with NRA regional officers and from published literature.

2.4 Approach

No new research has been carried out in the course of this study. The findings are based entirely upon the collection, collation and interpretation of existing available data contained in published reports or provided by the NRA.

Data collection was carried forward through a wide ranging literature survey and detailed discussions with NRA Headquarters and Regional staff. A number of relevant documents was assembled by reference to the WRc Aqualine key-word database and bibliographies of books and reports. The literature survey included published data on overseas, as well as UK, water industry experience. Consultation with the NRA was set in train through an initial meeting attended by Headquarters and Regional staff and the Consultants. At the meeting, the objectives of the study were explained and a questionnaire was circulated which set out the basic data requirements. These included details of existing and forecast public and private demand for water, available resources, and hydrometeorology. Following on from the initial meeting, the Consultants visited each region in turn, to collect and discuss the data provided in response to the questionnaire.

It was recognised from the outset that anomalies would exist in both the range of information from the NRA regions, and the manner in which it was presented. This is a reflection of historic practices, and the manner in which the water industry in England and Wales has grown and developed in the 20th century. In the event, good basic data were provided by most regions in most areas of interest; the main differences identified in the data collection exercise were found in the estimates in levels of unaccounted for water, and in the assessment of available yield from existing source systems. These issues are discussed further in Sections 3 and 4.

From the literature survey and data collection exercise, a perception was developed of existing gross and net demands for water in England and Wales, and how these are met. All regions also provided forecasts of public water demand up to at least 2011. In addition, various means of responding to future demand, including resource development options and demand management, were identified.

Data interpretation focused upon assessing the extent to which existing resources are committed in each region, taking into account environmental and water quality constraints. Probable areas of shortfall and surplus were then identifed, after allowing for projected changes in demand for water.

Examination of the areas of surplus and deficit in relation to existing river systems, infrastructure, topography and other features led to the identification of a range of potential solutions to the perceived deficits.

These included, but were not limited to, development opportunities already identified in the data collection and literature survey exercise.

These various options were formulated into strategies to overcome deficits on a region by region basis, and the relative advantages and disadvantages of each strategy were assessed in terms of approximate amortised cost and environmental impact.

2.5 Limitations of the Study

The investigations described in this report are focused upon providing a framework for the identification and broad comparison of alternative means of responding to changes in demand for water. Thus advantages and disadvantages of particular options are set out in relative rather than in absolute terms, and no detailed assessments of individual schemes have been made.

Whilst the work is intended to contribute towards a formulation of a National Water Resources Planning and Development Strategy, it must be seen as only a part of that process; further work is needed by the NRA - notably consultation with the water companies and other interested parties - before such a strategy can formally be put in place.

The approach adopted has intentionally been broad rather than detailed, and simplifications have been made, particularly in costing the various options. In addition, demands and resources have been assessed throughout in terms of average daily amounts. No allowances have been made for seasonal peaks, as it is assumed that these can be met from storage, provided sources are adequately integrated. Whilst such simplifications are entirely compatible with the terms of reference, results presented in the report should not be used out of context. Furthermore, the study has been based entirely on existing data, which in some cases are incomplete, incompatible or conflicting. In such cases, it has been necessary to make informed choices as to how gaps should be filled, and which specific data sets should be used.

The report has been assembled with a specific objective in view, and it is recommended that the findings are not used for other purposes.

2.6 Environmental Issues

A recurrent problem in considering the environmental impact of a scheme or proposal is to establish what level of effect is acceptable, or to put a value on environmental effects or quality so that impact can be compared to benefit in water resource terms.

To a large extent, the level of acceptable impact is arrived at by process of public pressure, consensus and planning controls. It is a truism that an impact is unacceptable because someone considers it so. New major water resource schemes generally have to pass through a Public Inquiry, during which the proposal and associated environmental safeguards are scrutinized and challenged by a wide range of interest groups. An authoritative EIA document is an essential pre-requisite for this process.

Dealing with the effects of existing schemes is rather different. On the one hand, the fact that the scheme may have been operating for a long period means that the impact can be reliably assessed. However, there may be a tremendous inertia to overcome in terms of status quo, Licences of Right, and established user interest. The approach generally adopted by the NRA is to identify, by consensus, the most extreme cases for initial attention. In the Thames Region, the six streams for the Alleviation of Low Flows (ALF) Study were selected mainly on the basis of strength of expressed public concern.

Throughout the discussion of environmental impact of resource development, the interest of game fisheries appears to predominate. This arises for several reasons, including of course the fact that such fisheries are valuable and are protected by vociferous guardians. The other reasons are that:-

- salmon and trout generally have stringent ecological requirements and are vulnerable to environmental changes, and may thus be considered as indicators;

- their requirements, population control mechanisms, actual levels of population etc are better known than for most other biota;

- salmonids generally occupy scenically attractive streams that are vulnerable to changes in flow regime;

- migratory salmonids (salmon and sea trout) generally make at least two migrations through much of the length of the river during their lives. They are therefore potentially sensitive to changes anywhere within the catchment;

- for the above reasons salmonids are generally considered to symbolize a healthy river environment so that their well-being is of interest far more widely than to anglers alone.

3 DEMAND FOR WATER IN ENGLAND AND WALES

3.1 How Demand is Assessed

For the purposes of this study, demand for water may be sub-divided into:

- public sector;
- private sector;
- in-river needs.

The public sector includes all water demand met by the 37 water companies, usually through provision of potable supplies. Private demand includes all water use where abstractions are made from inland surface or ground water, but the established water supply companies are not involved - usually because the abstractions are operated directly by the users. In-river needs reflect environmental and water quality considerations, such as amenity, recreation, fisheries and effluent dilution.

Historically, overall demand for water in England and Wales was assessed by extrapolation of past trends. Various events in the 1970's led to the blanket application of this approach becoming discredited, so that nowadays, demand is disaggregated into components. Best estimates are then made of prospects for change in demand for each component, according to the principal controlling factors; for example, for domestic demand, the controlling factors are population and per capita consumption.

For the purposes of this study, therefore, public sector demand has been further sub-divided into:

- non-measured;
- measured;
- unaccounted for water (UFW).

Non-measured demand comprises primarily domestic use, but also includes some commercial properties, small businesses and sundry other demands such as fire fighting and mains flushing. The measured component includes major individual consumers such as factories, together with others who have been put on meters through choice or as a result of local water company policy. For example, a significant minority of domestic properties supplied by Southern Water are now metered; this is not the case elsewhere, although many water companies have a policy of requiring all new domestic properties to be metered.

UFW is a balancing item between the volume of water put into supply and the sum of measured demand plus the best estimate of non measured demand. It thus includes such items as leakage, wastage and metering errors.

Private sector demands include a variety of industries, agriculture and irrigation. Abstraction for power generation is probably the most significant component. With the exception of Crown Properties and British Waterways, all private abstractions of greater than $20m^3$/day now generally require licences. Major private abstractors are required to submit annual returns of the amounts they have abstracted; where these data are not available, data have been taken from the DoE digest (1990) (9).

The foregoing discussion relates to gross abstractions; much of the water taken from inland waters is returned to them, either locally in the case of private abstractions, or elsewhere in the regional river systems in the case of public sector demand. Such returned water can often be reused, and therefore, in resource planning terms, net abstraction - that is, gross abstraction less returns to the river system - is of interest. In the case of public sector water demand, an assessment has been made of the proportion of population connected to inland sewage treatment works (STWs) on a regional basis, and gross abstractions have been multiplied by this amount and by another factor representing the proportion of water into supply which is normally returned to the river system via STWs in a totally inland distribution system.

Whilst an approximate overall estimate of pws returns to inland waters can be made in this way, there is no particular pattern to where returns are made within a catchment. Larger towns tend to have a local sewage works, but in many cases effluent from a number of smaller towns and villages, is conveyed to a common STW outside the catchment in which these communities live. Therefore, to assess how much water has been abstracted, and how much returned, at an arbitary point within any river system requires detailed investigation beyond the scope of this study.

Net private abstraction has also been derived, by applying an appropriate factor to the gross abstraction figures according to use type (Section 3.2.4).

An allowance ranging from $^1/_5$ to $^1/_{11}$ of average daily flow has been made for in-river needs, depending upon the region. The allowance adopted reflects the ratio of the Q_{95}/Q_{mean} of major rivers in the various regions, as deduced from published flow records.

3.2 Existing Demands

3.2.1 Public Sector

Estimates of existing and future public sector water demands to 2011 were obtained from water companies via regional offices of the NRA, and are presented in full in Annex B. In all cases, the demands were broken down at least into non-measured, measured and unaccounted for components; in some cases, the non-measured component was further sub-divided into domestic and non-domestic use. Estimates are based on records of water into supply, metered consumer billings and district meter readings.

The 1990 gross public sector water demand for England and Wales is estimated as:

Table 3.1 Current Public Sector Water Demand

Component	Demand (Ml/d)	Percentage of Total %
Metered	4,696	27
Unmetered	8,106	47
Unaccounted for	4,536	26
Total	17,338	100

The overall figures conceal considerable regional differences. Average demand is least in South West region, being 493 Ml/d. This is equivalent to an overall per capita consumption for all categories of pws use of 340 litres per day for the connected population of just under 1.5 million. Public sector water consumption in the South West is therefore some 3% of the total for England and Wales in 1990. Demand in all the water company areas which fall mainly within Thames Region is estimated at 4024 Ml/d, or 352 litres per capita per day overall for the connected population of 11.4 million. Demand in Thames Region thus represents 23% of the overall public sector total.

As illustrated below, per capita consumption for domestic use seems to vary almost as much within regions as it does between them:

Table 3.2 Per Capita Water Consumption

Region	Number of Water Companies within Region	Range of forecasts in per capita domestic consumption by different companies 1991 (l/c/d)
Anglian	5	136-150
Southern	7	155-174
Thames	6	144-151
Welsh	3	130-142
Yorkshire	2	126

See Annex B Table B6 for complete data set.

It is emphasised that these figures relate to domestic consumption only. Insofar as a trend is apparent, it would appear that the per capita consumption is greatest in Southern Region, and declines westwards and northwards from there. However, it should be borne in mind that Southern Region water companies probably have among the best estimates of per capita consumption, having been closely involved in the national metering trials.

Estimates of UFW in 1990 also show considerable local and regional variations (see Figure 1 and Table B7, Annex B). Discounting one exceptional figure, reported proportions of total water supplied vary from 11.1% for Hartlepools Water Company to 33.2% for North West Water. (The discarded result is a quoted 5.1% for West Hampshire Water Company; some 50% of their supply is in the form of a raw water bulk transfer to Fawley refinery, for which no assessment of leakage has been made).

Because of the difficulties of disaggregating UFW from legitimate unmetered demand, it may be that the wide range in reported UFW levels can be partially explained by variations in the methods by which such amounts are calculated. However, high reported UFW levels do not consistently correspond with relatively low levels of per capita consumption; Southern Region water companies have apparently among the highest current reported UFW rates as well as the relatively high rate of per capita demand noted above. Again, their close association with the National Metering Trials would suggest that these companies' estimates should be among the most reliable.

Regional differences in the way UFW is calculated are known to exist. However, it is not possible within the scope of this study to investigate the nature of these changes and to demonstrate their effect on reported figures. Although the relatively large UFW proportion quoted for the Southern Region companies on the basis of good information raises a question over figures for companies with less information, it is assumed that data for total water supplied are reasonably reliable. UFW should thus be seen more as a balancing item than as a true reflection of system losses as such. In this context meter accuracy is relevant; neither the water companies nor the NRA should overlook the importance of accurate metering in assessing UFW and leakage.

It is noteworthy that water company leakage assessments exclude losses from raw water aqueduct systems, for which no data are available. Such losses are a draw on resources like any other demand, and could be significant in areas like Yorkshire and North West; they should therefore be investigated.

3.2.2 Private Sector

Private sector demand data have been divided into industrial, agricultural, irrigation and other components. Current levels of demand were deduced either from uptake quantities as estimated by the NRA regions, or, where these were not available, from returns as published by the Department of the Environment. In some cases, such as Southern Region, uptake was expressed as a percentage of the licensed abstraction entitlement. In cases where the data conflict, the lower figure has been taken, on the basis that the higher represents licensed entitlement rather than uptake.

Gross private demand for water in England and Wales may be summarised:

Table 3.3 Gross Private Sector Water Demand

Component	Amount (Ml/d)	Proportion of Total (%)
Industry	* 9,627	69
Agriculture	355	3
Irrigation	315	2
Other	3,556	26
Total	13,853	100

Extracted from Annex B, Tables B18 to B21.

* Includes a high proportion of non consumptive use.

The estimated current 13,853 Ml/d average annual private demand is added to the 17,338 Ml/d estimated public sector demand to give a total current gross demand for water in England and Wales of 31,191 Ml/d average.

Private demand represents generally about 30-50% of total public and private demand on a regional basis; notable exceptions are Northumbria Region, where estimated private demand is only 4% of total public and private demand; Thames (12%); Anglian (20%) and Welsh, where estimated private demand represents 71% of total public and private demand.

The Welsh Region has an extremely high proportion of hydroelectric and cooling licences, which together account for 64% of the total licensed uptake.

On the basis of the foregoing figures, total irrigation demands are relatively modest. However, the problem with such demands is that, unless they are supported by storage, they have to be fully met by abstraction during the summer months, when the available resources can be most scarce.

3.2.3 Comparison of Present Demand with Previous Forecasts

Existing demands in 1990/91 are set in context with the forecasts produced for those years in the 1973 Water Resources Board Report "Water Resources in England and Wales"(6):

Table 3.4 Comparison of Demand Forecasts

Demand	Data Source	Public Sector (Ml/d)	Private Sector (Ml/d)	Total (Ml/d)
1971 actual	WRB Report	14140	28300	42440
1990/1991 actual	This Report	17338	13853	31191
1991 forecast (interpolated)	WRB Report	23550	Not stated	23550

It is clear from Table 3.4 not only that forecasts produced in 1973 were significantly higher than has proved to be the case for England and Wales, but also that private abstraction has declined significantly since they were prepared. Examination of the figures suggests that the forecasting discrepancies of the WRB Report are very unevenly distributed across the regions (see Section 2.2).

3.2.4 Net Use

Net use of water - the total volume of abstractions from inland and underground sources less the total volume of effluents returned to them - has been calculated on the following basis:

- public sector:
  - zero return of effluents disposed of in tidal waters;
  - 70% return of effluents returned to inland waters;
- private demand:
  - industrial : 70% return
  - agricultural : 80% return
  - irrigation : 10% return
  - other : 100% (non consumptive use)

On this basis, existing public water supply net use amounts to 9,320 Ml/d, or 54% of the gross pws abstracted. Private sector net use amounts 3,242 Ml/d or 23% of the gross abstraction (see Annex A, Table A1(A)). Overall net use of 12,562 Ml/d represents 40% of the current level of abstraction. The balance of nearly 19,000 Ml/d is returned to inland waters, and may thus in theory be re-abstracted further downstream and used again. In some large inland river systems such as the Thames and Trent, re-use already occurs. Elsewhere, the scope for re-use is probably much less than these figures suggest; this issue is discussed further in Section 7.5.

3.3 Future Public Sector Demand

Forecasts of public sector demands to the year 2011 were provided by the water companies via the NRA regions. These, and the assumptions they incorporate regarding leakage control and metering, have been taken as the "base case" public sector demand forecasts. Where data were not provided, estimates have been made on the basis of rates of growth in demand for similar water companies. Demands for 2021 were estimated by linear extrapolation of the 2001-2011 trends in demand.

The water company demand forecasts have been amalgamated as regional demands, and are presented in Table 3.5. Overall, public sector demand is forecast to increase from the present 17,338 Ml/d to 20,526 Ml/d in 2021. Forecast demand growth for England and Wales is shown on Figure 2.

Table 3.5 Public Water Supply Demand Forecasts (Ml/d)

NRA REGION	1990	2001	2011	2021		
				Base Case	Upper Limit	Lower Limit
Anglian	1820	2086	2346	2589	2884	2340
Northumbria	1082	1148	1218	1301	1502	1199
North West	2574	2283	2300	2317	2357	1902
Severn Trent	2421	2491	2569	2649	2757	2209
Southern	1408	1433	1576	1736	1963	1568
South West	493	516	598	687	783	635
Thames	4024	4353	4708	5076	5466	4515
Welsh	1182	1195	1236	1281	1373	1085
Wessex	904	1054	1172	1307	1494	1204
Yorkshire	1430	1491	1587	1583	1568	1242
Total	17338	18050	19310	20526	22147	17899

(Extracted from Annex B, Tables B10 and B16).

These figures include an average UFW component of 21% of total demand, compared to about 26% at present. In all cases, it has been assumed by the water companies that UFW as a percentage of total public demand will decline throughout the period to their forecasting horizon of 2011.

Only Southern Region forecasts incorporate any calculation of the effect on demand of universal metering. A nominal reduction in domestic per capita consumption of 10% has been assumed, with sensitivity checks on savings of 5% and 15% (see Section 6.5.2). Metering trials in the Isle of Wight suggest bigger savings; however, these trials are too incomplete to form the basis for any firm conclusions.

The largest rates of growth over the period 1990-2021 are forecast for Anglian, South West and Wessex regions; these generally reflect projected population changes, although South West, with the highest forecast population growth, does not have as high a proportional growth in public sector water demand as either Wessex or Anglian regions. A decline in demand is forecast only for North West region, although the population is also expected to fall slightly in Northumbria and Yorkshire regions.

Sensitivity of public sector water demand has been tested in relation to changes in:

- allowances for unaccounted for water;
- measured demand growth rate;
- per capita unmeasured demand growth rate.

Population growth forecasts are derived by local authorities from data produced by OPCS. Clearly they may be proved incorrect in future, and thus there is an argument for testing sensitivity of demand to this factor also. However, it is suggested that such a test would demonstrate little beyond what can be shown by the above-listed sensitivities - namely that forecasting is uncertain and a range of projections is needed.

Arising from the sensitivity tests, upper and lower bound estimates were produced as follows:

- upper bound:
    - UFW assumed to be 20% of total water supplied;
    - rate of growth in measured demand assumed to be 0.5% per annum higher than estimated by the water companies;
    - per capita growth rate in unmeasured demand assumed to be 0.2% per annum higher than assumed by the water companies;
- lower bound:
    - UFW allowance of 15% of total into supply;
    - rate of growth in measured demand 0.5% per annum lower than assumed by the water companies;
    - per capita growth rate in unmeasured demand 0.2% per annum lower than assumed by the water companies.

On this basis, the upper bound estimate for gross public water demand in 2021 is 22,147 Ml/d, whilst the lower bound estimate is 17,899 Ml/d. These figures compare with the water companies' estimate of 20,526 Ml/d.

The foregoing figures relate to gross public sector demand; net public sector demand has also been calculated, as described in Section 3.2.4 above.

Upper and lower bound forecasts of gross demand are presented graphically for England and Wales on Figure 2. Further data on demand forecasts are presented in Annex B.

3.4 Future Private Sector Demand

Only Anglian Region provided forecasts of private sector demand. It was therefore necessary for the Consultants to generate most of these data. This was done through discussion with representatives of the power generating industry, which is one of the most significant groups of the private abstractors, and a review of past trends in the various components of private sector water demand.

Discussion with the privatised power industry revealed that, whilst a steady growth in demand for electricity was anticipated, this would be met by introducing new plants using more water-efficient generating techniques or coastal stations, and phasing out the less efficient, older power stations. No further projections could be made beyond the next few years, other than that the trend towards more water-efficient generating plant is likely to continue.

A review of the demands for each private sector component under consideration for the period 1979-1990 did not reveal any clear trends. There has been a general decline in demand for both industry and agriculture, while irrigation demand has increased. The declines in demand for water by industry and agriculture are attributed partly to introduction of more water-efficient processes, as highlighted above for the power industry, and partly to the shift in the national economy away from production towards service industries. However, it is by no means certain that either trend will continue.

Accordingly, upper and lower bound forecasts for private sector industrial and agricultural demand were made using annual growth rates of plus or minus 1% applied to existing levels of demand. A similar procedure was adopted to forecast other private demands.

After scrutiny of past trends in demand for irrigation water, upper and lower bound growth rates of plus 3% and plus 1% per annum were adopted for all regions accept Anglian, where figures provided by the NRA were used instead.

Forecast private sector demand may thus be summarised:

Table 3.6 Forecast Private Sector Demand (Ml/d)

Component	Existing Demand (1990)	Lower Bound 2021 Forecast	Upper Bound 2021 Forecast
Industrial	9,627	7,333	13,007
Agriculture	355	272	478
Irrigation	315	551	735
Other	3,556	2,630	4,793
Total	13,853	10,786	19,013

Estimates of net future private demand have also been prepared, as described in Section 3.2.4.

Further information on private sector demand is presented in Annex B.

4 EXISTING RESOURCES AND FUTURE NEEDS

4.1 Existing Surface Water Supplies

Of the total public and private water demand in England and Wales, 70% is met from surface resources. By far the greatest proportion of the water is supplied to satisfy public demand, which is rising, the balance being supplied to the industrial and power generation sectors, where generally demand is falling.

Table 4.1 Surface Water Use by Demand Type

SUPPLY SECTOR	% OF CURRENT DEMAND MET FROM SURFACE WATER	PROPORTION OF TOTAL SURFACE WATER ABSTRACTION (%)
Public Supply	70	64
Private Supply		
Industry	74	14
Spray Irrigation	60	}
Agriculture	12	} 1
Power	100	17
Fish Farming	* >95	4

(From 'Waterfacts' and DoE Digest)

* Estimated value - no published data available on sw/gw breakdown for fish farming.

There is considerable regional variability in the magnitude and proportion of surface water supplied to the public and private sectors, as shown in Figure 3 and Table 4.2. From these data, the following points emerge in addition to the obvious relationship between regional population and public supply:

(a) With the exception of Anglian, Wessex and Southern Regions, surface water meets by far the greatest proportion of public demand.

(b) Although the quality and consistency of the data on private water consumption are variable, it is evident that public demand greatly exceeds demand satisfied by private abstraction. This is the case for all regions except Wales, where the pattern is reversed, due to the relatively high water demand for power generation and cooling purposes in that region.

TABLE 4.2 **Regional Utilisation of Surface Water Resources for Current Public Demands and Private Abstractions**

REGION	PUBLIC WATER SUPPLY		PRIVATE WATER SUPPLY	
	Total (Ml/d)	% From Surface Resources	Total (Ml/d)	% From Surface Resources
Anglian	1820	55	459	25
Northumbrian	1082	91	49	(90)
North West	2574	87	1167	90
Severn Trent	2421	59	2292	95
Southern	1408	27	1130	73
South West	493	90	355	87
Thames	4024	60	538	66
Welsh*	1182	96	3204	90
Wessex	904	49	376	95
Yorkshire	1430	87	1183	93

* Hydropower not included (3100 Ml/d)
( ) Estimated

Since 1960, the way in which surface water resources in England and Wales have been developed has changed substantially in order to meet demand growth. The emphasis has shifted from unsupported river abstractions and direct supply reservoirs towards the integration of large surface water storages for river regulation and downstream abstraction. The contemporary balance of surface water resources may be categorised as follows:-

- unsupported river abstractions
- direct supply reservoirs
- direct supply reservoirs in an integrated system
- pumped storage reservoirs
- river regulation reservoirs.

The drought reliable yield of unsupported abstractions is governed by the natural flow regime of the rivers from which they abstract, unless they are operated conjunctively with storage (see below).

Direct supply reservoirs are single independent sources and single function storages which have relatively constant output, where there has generally been little need for operational optimisation. Most were constructed in the 19th Century and many, particularly in Wales and the North of England, would be difficult to incorporate into an integrated multi-reservoir operational system.

Direct supply reservoirs in an integrated system are typically exemplified by conjunctive use of a reservoir and an unsupported river abstraction. In summer months, when river abstraction is constained by low flows, demand is met principally from the reservoir. At other times when flows are higher, an increased proportion of demand can be met from the river abstraction, allowing replenishment and conservation of reservoir storage for summer use. The combined yield of the sources is thus greater than would otherwise be the case since:

- more water can be taken from the reservoir through the summer months than if it had to meet steady demand throughout the year;

- the reservoir makes up yield from the river abstraction at times of low river flow.

A more complex example of direct supply reservoirs in an integrated system is provided by a group of, say, 3 or 4 reservoirs in series which are operated with other higher marginal cost sources. The principal advantage of the direct supply component is that reticulation largely operates by gravity, thus keeping pumping costs to a minimum. The operational objective is to permit these reservoirs to be overdrawn in the knowledge that, as a drought deficit develops, higher cost sources can be brought into fuller use - for example pumped river abstractions. An example of such a system is the Derbyshire Derwent-Dove system.

Pumped storage for water supply generally refers to an off-channel reservoir with a relatively insignificant natural inflow. In isolation, this form of storage has a high marginal cost. However, in the Thames Region there is little alternative because there are few, if any, natural reservoir sites. In all there are some 24 bunded pumped storage reservoirs in operational use. These provide a useful capacity of 220,000 Ml, mostly in the lower reaches of the Thames and Lee. The total capacity represents a little more than 3 months supply and acts as a buffer storage against persistent low river flows, reliant for replenishment upon almost continuous river abstractions (albeit at a reduced rate in summer). The storages form part of an optimised system wherein aquifers provide 42% of supply directly.

The storage in river regulation reservoirs is used to augment the dry weather flows in downstream catchments to support direct abstractions. An example is the Severn resource system with both Clywedog reservoir and the Shropshire groundwater scheme, whose function is similar to that of the regulating reservoir. Reservoirs such as Clywedog demonstrate the efficiency of river regulation as a means of surface water resource exploitation; the same storage supports abstractions from the Severn totalling some three times that obtainable by direct draw off from the impounded catchment alone.

Since 1960 a changing pattern has evolved, in which the theme has become multi-objective operation as part of an integrated resource system based upon total river catchment management. There has been a move away from direct supply towards river regulation, in order to use resources more efficiently. This changing balance of resource operation and the role of new schemes is indicated in Table 4.3.

Table 4.3 Reservoir Operation

Type	England and Wales: % of Gross Reservoir Storage by Type of Operation/Filling		
	1960	1975	1990
Direct Supply	80	61	36
River Regulation	<1	23	42*
Pumped Storage	19	16	22

* Includes Kielder

This pattern is being carried through to re-evaluation of existing schemes as well as to the assessment of future schemes. Pre-feasibility studies of possible schemes for reservoirs in Wales, based solely on hydrological and engineering criteria, show the following breakdown:

Table 4.4 Operation of Potential Storage Schemes in Wales

Wales: Possible new schemes by type. Expressed as a % of total sites examined	
Catchment-fed river regulation schemes	60
Pumped river regulation schemes	23
Conversion of existing direct supply to river regulation	6
Increased storage in existing direct supply reservoir	11
Total	100

Note: Table based on an interpretation of data on 102 existing and potential resource developments, summarised by Welsh Region NRA and sourced from Water Resources Board and River Authority Section 14 reports.

This change in reservoir operating principles is quite profound. The primary purpose of storage provision - to capture surplus winter resources for abstraction and use in summer when natural flows are lower - is still met; in addition, regulation releases enhance low flows in the river reaches between the reservoir and the point(s) of abstraction, with consequent potential for environmental gain which does not occur with direct supply reservoirs. Summer releases from the latter are confined to the prescribed compensation flow, which can be reduced by Drought Order in conditions of severe drought.

Reservoir storage constructed since 1960 with the principal objective of river regulation has shown the following features (see Figure 4). These are:

(a) The rate of provision of surface water storage has increased dramatically since 1960. Schemes have been larger and more integrated into the total catchment and regional water resources. This reflects the development of the water industry itself, from small companies supplying a few local towns and controlling a family of independent direct supply reservoirs, to large bodies charged with the development and allocation of water resources over a large area to meet the needs and aspirations of communities often totalling millions of people.

(b) Since 1900, and particularly since 1960, the regional balance of surface water resources has altered radically. In the earlier part of the century the direct supply reservoirs in the Pennines and Derbyshire accounted for by far the greatest proportion of storage, with the southern regions of England largely dependent upon direct river abstraction and groundwater. The construction of large pumped storages in the Thames Valley in the 1920s and 30s, the post 1960 expansion of storage in East Anglia (Rutland, Grafham) and the recent completion of such schemes as Roadford in the South West has seen total storage in the south equal that in the North West, Yorkshire and Derbyshire. Finally, huge resource developments have taken place in Wales and Northumberland since 1960 with the objective of river regulation and the inter-regional transfer of water by river (Severn and Dee) and aqueduct. The balance of absolute resources development is now equal between the three broader regions in terms of water stored.

4.2 Existing Groundwater Supplies

Groundwater currently supplies just over 30% of licensed water supply in England and Wales, which is equivalent to 6500 Ml/d. 82% of this groundwater is abstracted for public supply, with the remainder taken by private industrial and agricultural abstractors. The degree of reliance on groundwater varies considerably between the NRA regions, as shown in Figure 3, and reflects the occurrence of the principal UK aquifers, as described below. However, even within those NRA regions which are relatively low groundwater users, there are large centres of population which are almost totally dependent on groundwater for supply.

Of the total groundwater supplied, over half (54.5%) comes from the chalk and a further 26% is from the permo-triassic sandstones. The remainder is derived from a whole series of minor aquifers, of which the Jurassic Oolitic limestones, the Lincolnshire Limestone, the Greensand, Carboniferous Limestone, and the Old Red Sandstone are the most significant. The chalk is present mainly in the East and South East of England while the Permo-Triassic Sandstones are mainly found in the Midlands and North West.

Operationally, groundwater sources may be compared with surface water reservoirs. In the long term, the average rate of outflow of water from aquifers via natural springs and artificial means should not exceed the rate of replenishment; however, as with surface reservoirs, this requirement still leaves scope for short-term variations in the abstraction rate to meet seasonal demand patterns. Groundwater schemes may also be used either for direct supply or river regulation. The former is more common, for historical reasons similar to those relating to surface storage; however, better yields can sometimes be obtained via river regulation, subject to suitable hydrogeological conditions.

In general, groundwater quality is good in terms of the drinking water standards which it is expected to meet after routine treatment. Although problems can occur which can only be overcome by special measures such as blending with water from elsewhere, there are few examples of sources having been lost through deterioration in quality. The main problems experienced are posed by nitrate, pesticides, waste disposal and various forms of organic pollution, but the scale of the problem and the degree to which it is understood varies considerably. For example, nitrate pollution is well researched and documented, whereas the occurrence of pesticides is still poorly understood. A national aquifer protection policy is currently being instigated by the NRA to include both whole-aquifer and discrete source protection.

4.3 Reliable Yield of Existing Supplies

Until recent years, the yield of the water resources of England and Wales was treated on a source by source basis as follows:

- the ascribed yield of river abstractions and of groundwater resources was related to the abstraction capacity alone without any reference to drought or possible long term effects;

- surface reservoirs were assessed in a more sophisticated manner in which the reliable yield equalled the draw-off that could be sustained during a drought event of some specified return interval.

The yield of river abstractions and groundwater schemes is still largely estimated without any meaningful assessment of risk. Throughout the history of public water supply in England and Wales, environmental implications have played a part in determining how sources are planned and operated; however, understanding of the breadth and depth of these implications has improved significantly in recent years. Thus environmental issues are becoming a major factor in determining the yield of new water resource developments. The bounds between which the operational optimisation of a source or group of sources can be realised are rapidly narrowing. This in itself provides an impetus to the move away from direct abstraction, towards river regulation use of surface and groundwater storage, with the consequent low flow enhancement opportunity noted earlier.

Yield for surface water storages is generally perceived as a single figure related to the emptying of the reservoir. This is conditional upon an average rate of abstraction over the critical drawdown period which permits target levels of service to be met. Such levels of service are defined upon a scale of increasingly remote probability from hosepipe bans to standpipes in the street. Thames Water Utilities Ltd, for example, have a target level of service which involves hosepipe bans once every ten years and pressure reduction/ leakage control measures once in 20 years. More remote probability is attached to economically damaging restrictions on so called 'non-essential supply' - such as automatic car wash facilities (12).

Given these levels of service, surface water resource yield is evaluated in terms of the 1:50 drought inflow and the average rate of supply that can be supported under such conditions. Although there is little statistical evidence to support it, the 1976 event is generally associated with conditions that might arise with a 2% probability in any given year. The inherent nominal conclusion is that the worst drought on record equates with the 1:50 year event. Within individual supply schemes there is a very wide variation in levels of service and critical drought period, such that measures of "drought reliable yield" are not comparable except at the broadest level.

If, however, surface water reservoirs are grouped regionally and total drought yield related to total available storage, then the relative performance of the regional storages emerges. Factors that control this performance are:

- the degree of integration of the surface storages and their conjunctive use with other sources such as groundwater - greater integration will lead to a higher yield per unit volume of storage;

- the regional balance between direct supply and river regulation reservoirs, since the latter have a higher reliable yield per unit of storage volume for a drought of given character.

For interest, data gathered from the regions on reservoir storage and drought reliable yield have been collated. The regional relationship is presented in Figure 5. It appears from the Figure that:

- the expected higher unit yields in the wetter regions of England and Wales do not emerge from the exercise, probably because they are masked by other factors such as source integration, conjunctive use and variants in the precise definition of drought yield;

- on the basis of the data provided, Thames and North West regions exhibit a more favourable than average relationship between storage and yield.

Although Thames and North West Regions have highly integrated surface water resource systems by virtue of the River Thames and the North West regional aqueduct, it is unlikely that this fact alone explains the degree of apparent improvement in unit storage yield. The Thames reservoirs are filled by pumping from river intakes, whose operation is governed by a relatively modest low flow constraint. Thus the storages can be replenished almost continuously throughout the year. This situation may be compared with an impounding reservoir, from which continuous compensation releases have to be made, which usually approximate to the dry weather flow of the impounded stream. It is suggested, therefore, that the specific replenishment characteristics of the Thames pumped storage reservoirs may be significantly better than those of conventional storages. In the North West it is suggested that the high degree of resource integration, the relatively sophisticated operational strategies that are applied and the favourable hydrology of most of the storages combine to improve overall system yield.

The degree to which the advantages of source integration can be achieved in other regions is constrained by physiography and the geographical relationships between resources and demand. Other considerations are also relevant. For example, Roadford reservoir would be expected to improve the integration of resources in the South West, since it is operated in conjunction with the Taw/Torridge and Dart systems. However, the expected regional yield gains are not apparent; this is because commissioning of Roadford has enabled changes to be made in the operation and management of pre-existing sources in the same integrated system. Thus their adverse environmental impact has been reduced, thereby curtailing the net gain arising from the introduction of the new reservoir.

This assessment of regional surface storage yield cannot be complimented by a similar evaluation of unregulated river abstraction and groundwater. These account for 16% and 30% respectively of the total declared yield of all sources in England and Wales. The reliable yield of total regional resources must therefore be based upon those in the NRA Section 143 Report (8), in the absence of any other estimates.

The availability of developed resources for public water supply is shown in Table 4.5, by NRA Region. The data are expressed in terms of reliable average source output in a drought year, and have been taken from the NRA Section 143 Report of March 1991.

Table 4.5 Average Annual Yields of Existing Public Water Supply Resources Sustainable Through Drought

Region	Drought Reliable Yield (Ml/d)				
	From Reservoirs		Other Sources$		Total
Anglian	763	(35)	1405	(65)	2168
Northumbrian	1607	(76)	487	(24)	2094
North West	965	(34)	1902	(66)	2867
Severn Trent	798	(29)	1981	(71)	2779
Southern	183	(13)	1272	(87)	1455
South West	524	(88)	73	(12)	597*
Thames	1812*	(44)	2313	(56)	4125
Welsh	1359+	(91)	136	(9)	1495
Wessex	162	(16)	880	(84)	1042
Yorkshire	789	(49)	807	(51)	1596
Totals	8962	(44)	11256	(56)	20218

() % of total drought yield
* Updated regional figure
\+ Estimate
$ Direct abstraction, groundwater, natural lakes

All figures in Table 4.5 are sourced from the NRA Section 143 Report, except those relating to South West Region, for which additional information was available.

4.4 Possible Climatic Change

Any significant climatic change will directly affect river flow. This in turn will affect not only direct abstraction and reservoir storage but also the other uses of rivers, such as effluent dilution, cooling, navigation and fisheries. Such uses would not only be sensitive to changes in the volume and pattern of flow, but also to associated changes in water quality and temperature.

Broadly, one or other of the following climate change scenarios is likely to dominate:

- a significant change in the mean annual amount of rainfall, with little change in the seasonal pattern.

- a shift in the seasonal pattern of rainfall with wetter but shorter winters and longer, drier summers.

Either scenario could be associated with an increase in the interannual variability of both amount and pattern.

Hot and very dry periods of three or four months such as those of 1984 and 1989 can affect the yield from upland resources and severely reduce flows in 'flashy' rivers in impermeable catchments. A dry winter can severely reduce seasonal replenishment of groundwater storage, upon which the southern and eastern regions of England are particularly dependent, so that further depletion during the following summer becomes inevitable. Any increase in the incidence of such events would clearly be of concern.

Quantitative evaluation of the impact of climate change is difficult, because of the complex relationships between rainfall and streamflow. Studies have therefore only been able to point to the wider implications. These include:

- locally, warmer and drier summers could lead to a strain on smaller "short term" resources. This applies particularly to upland sources in the north and west. Principally, these are direct supply reservoirs with quite short critical periods. If the following breakdown for North West Region reservoirs is representative, then current levels of service and operational strategies would see up to 55% of storages severely drawn down by drought episodes such as 1989, when rainfall was generally in deficit to a critical degree well into December;

Table 4.6 North West Region: % Distribution of Critical Periods for Surface Water Reservoir Systems

Critical Period:	< 3 months	3-6	6-9	9-12	> 12 months
% of Reservoirs	4	19	32	10	35

- although increased winter rainfall may make up for drier summers, serious concerns remain. The water resources of the south east in particular are highly sensitive to even small changes in rainfall and evaporation. The increase in demand during a warm summer month relative to a winter month can often be as much as 25% in the south, compared with only 5% in the north;

- the changes in agricultural practice that may be brought about by climate change are likely to affect irrigation demand, especially in the south and in East Anglia. Temperature increases coupled with decreased rainfall in summer may dictate the cultivation of a different range of crops and pattern of irrigation. The Advisory Council for Agriculture and Horticulture estimated that the demand for water for agricultural purposes would double by the year 2000 (13). At the time this was generally considered to be an over-estimate, but if significant climate warming occurs, demand for water, especially for spray irrigation, could rise substantially. Such an increase would be very difficult to accommodate, unless it could be so managed that it did not coincide with seasonal peaks in public sector demand;

- prolonged hot dry summers that are followed by heavy rainfall can lead to poor surface water quality. This occurred extensively in the peat moorlands of northern England after the 1984 drought. First flush pollution loads after long dry spells can seriously impair river water quality, particularly when storm runoff from urban areas is a substantial component of the flow (14);

- Underground mains and sewers are greatly stressed when there is soil movement. This is most likely to occur under conditions of frost and drought. In general, more rapid and extreme changes in either temperature or rainfall will increase the stress on the underground infrastructure. For example, ground movement due to the shrinkage of clay soil in dry summers could increase mains bursts and therefore leakage loss (14).

4.5 Future Environmental Constraints on Existing Sources

4.5.1 General

The growing awareness of the environmental impact of existing water resource management, and the rapidly developing perception that many such impacts are unacceptable, mean that the yield of existing sources cannot be considered immutable. Some of the impacts, involving drying-out of reaches of streams of rivers, are blatant but others are much more subtle and their significance is only now becoming apparent.

4.5.2 Surface Water Abstraction

Several NRA regions have developed, or are developing, guidelines for the management of surface-water abstractions which take account of environmental concerns. However, many existing abstractions fall well short of the levels of environmental protection which are considered acceptable for new schemes. For example, many (mainly private) surface abstractions operate without a prescribed flow rule, even to the extent of complete drying-out of stretches of river. The NRA has recently been put in the difficult position of having to issue licences of entitlement for abstractions which they know are causing significant environmental damage. In the past, efforts to limit the environmental impact of surface water abstractions have concentrated, understandably, on protection of low flows. However, there is now a growing understanding of the subtle relationship between variations in medium to low flows and stream ecology. For example, migratory fish utilize minor spates and elevated flows for upstream migration, and periodic wetting of river margins can be most important in ecological terms. Most water undertakings take a responsible attitude to incorporating environmental safeguards where possible; however many sources, particularly those allowing considerable abstraction in dry weather, are too valuable to relinquish voluntarily without compensation or allocation of other resources. Nevertheless, the widespread and growing view that the environmental harm being done by many abstractions is unacceptable means that revocation or modification of many licences is likely, by whatever mechanism.

Some of the most extreme cases of environmental impact are being caused by private abstractions operating by Licence of Right (Water Resources Act 1963). Loss of drought-reliable yield by revocation or modification of such licences would have to be replaced with an alternative source, or be absorbed into a more efficient integration of sources (see Section 4.3).

A recent study undertaken by Halcrow for the South West Region (15) identified 109 cases of low flows caused by abstraction that were perceived to have adverse environmental impact. Most of these are surface water takes, reflecting the limited groundwater resources of the region. Seventy two are local abstractions for fish farms, hydro-electric power or other industrial uses. Of the remaining 37, twenty four are abstractions for public water supply. In a number of cases, the compensation flow below reservoirs was considered to be inadequate.

4.5.3 Groundwater Abstraction

Groundwater abstractions perhaps represent the greatest problem. Most abstractions of groundwater have some effect upon stream flow, even if only, as in the best planned schemes, in causing a reduction in winter flows while aquifer recharge takes place. Even here, however, it is now becoming apparent that the chalkstream environment is in delicate balance with the whole range of variations of the hydrological regime, including winter flows. Problems caused by groundwater abstractions include:-

- complete drying up of streams at times, often headwaters but sometimes middle reaches. This is of devastating impact on local ecology, fisheries and amenity;

- delayed break-through of springs and winterbournes. Headwaters are often important spawning grounds for trout, and delay in the increased flows in autumn/winter can make them valueless in this respect;

- generally lowered stream flow. Renders the stream too small for its channel, causing shallow flow and loss of wetted perimeter and established margins. This can cause long-term ecological damage;

- change in the hydrological regime. As already discussed, even the relatively high winter flows are considered important, for example in removing fine silt and detritus and cleaning gravel;

- stream-flow decrease represented by the abstractions either until the water is returned downstream, or throughout the river system to the estuary.

- impossibility of managing groundwater abstraction on a short-term basis to take account of fluctuations in stream-flow. Thus it is not realistic to impose a prescribed flow rule to protect low flows;

- possible drying-out of ecologically important wetland habitats on the valley floor due to lowered groundwater levels.

Abstraction may not be the only, or even major, cause of the above problems. However, combined with other changes in management of the catchment, it may cause, or be perceived to cause, an impact. For example, the River Test, which is by no means heavily affected by groundwater abstraction in hydrological terms compared to other rivers in the South, appears at present to be experiencing serious environmental damage. There seems to be a large-scale failure of natural spawning by salmon and trout, possibly due to subtle changes in the dynamics of sediment balance and transport in the system. In many other cases, eg Hampshire Avon and Kennet, perceived environmental degradation is associated with (though not necessarily solely or even mainly caused by) only moderate groundwater abstraction.

It is of interest to note that 17 of the NRA "top 20" low flow problems are associated with groundwater abstraction. These of course represent only the most extreme cases. Regional Resource and Environmental Managers in the main groundwater areas concede that there are many more affected streams where the problem is less obvious or the level of public perception is lower. While local palliative measures such as bed-lining and flow augmentation from boreholes, as proposed on the River Slea, have a role to play, in the long term reduction in abstraction from present levels is seen as inevitable and desirable.

As already mentioned, groundwater abstraction may deprive the stream of water throughout much of its length.. As groundwater-fed rivers represent a most valuable water resource, especially in the form of relatively high base (summer) flows, abstraction of surface flows well downstream would appear to be a more benign option. Abstraction at the tidal limit leaves the great majority of the river unaffected, and with appropriate operating rules a high degree of protection of the tidal reaches, estuary and the needs of migratory fish can be achieved.

4.5.4 Impact of Environmental Concerns on Yield

It is not possible to make a reliable assessment of the likely impact of environmental concerns on yield of existing sources, for two reasons. First, the level of acceptability of various degrees of the environmental impact is changing, as is our understanding of some of the more subtle impacts of abstraction. This clearly has an influence of the potential loss of yield from individual sources. Second, there appears to have been no integrated survey of environmental impacts of sources, though NRA Regions are rapidly gathering such information.

However, the rapidly changing perception of permissible levels of environmental impact in relation to water resources means that some estimate of the likely associated derogation of reliable yield is essential for planning purposes. This is discussed further in Section 9.

4.6 The Need For Increased Water Supplies

Chapter 3 of this report gives details of the forecast demands for water up to the year 2021, and in Sections 4.1 to 4.4 estimates are presented of the reliable yields of the existing water supplies in England and Wales. By combining these data, predictions can be made of the likely deficits or surpluses up to the year 2021.

Table 4.7 illustrate the forecast deficits and surpluses for public water supplies up to 2021 on a regional basis. The forecasts assume the best estimates for demands (as opposed to upper or lower bounds), which make appropriate allowance for leakage control but do not reflect the possible effects of water metering. The deficits do not take into account planned resource developments.

It can be seen that regionally there are very great discrepancies in the forecast balance between reliable yield and demand. The south eastern parts of the country - Anglian, Thames, Southern and Wessex Regions - are forecast to have substantial deficits. The northern and western parts of the country - North West, Northumbria and Welsh Regions - will still have a large surplus of water resources in 2021. The Severn Trent, Yorkshire and South West Regions are forecast to have slight surpluses or deficits in 2021.

Detailed estimates by water company of current and forecast balances between demand and yield are given in Annex A, whilst means of responding to forecast deficits are discussed in the following chapters.

Table 4.7 Forecast PWS Deficits and Surpluses by Region

	Demand (Ml/d) (Base case)				Reliable Yield	Surplus/Deficit Forecast (Ml/d)			
	1990	2001	2011	2021	(Ml/d)	1990	2001	2011	2021
Anglian	1820	2086	2346	2589	2168	348	82	-178	-421
Northumbria	1082	1148	1218	1301	2094	1012	946	876	793
North West	2574	2283	2300	2317	2867	293	584	567	550
Severn Trent	2421	2491	2649	2649	2779	358	288	210	130
Southern	1408	1433	1576	1736	1455	47	22	-121	-281
South West	493	516	598	687	597	104	81	-1	-90
Thames	4024	4353	4708	5076	4125	101	-28	-583	-951
Welsh	1182	1195	1236	1281	1495	313	300	259	214
Wessex	904	1054	1172	1307	1042	138	-12	-130	-265
Yorkshire	1430	1491	1587	1583	1596	166	105	9	13
Total	17338	18050	19310	20526	20218	2880	2168	907	-308

Demand data are detailed in Annex B and reliable average yield data in Table 4.5.

The relationships between currently available resources for public water supply and forecast demand on a water company basis are shown in Figures 6-10. The effect of leakage reduction targets is apparent for the North West water supply area, where the resource surplus will grow by about 200Ml/d between 1990-2001 if these targets are met.

5 THE RANGE OF OPTIONS FOR FUTURE SUPPLIES

5.1 Regional Water Balances

Details of the methods used to estimate the regional water balances in terms of gross resources (rainfall minus evaporation) are presented in Annex A, Table A1. The data are summarised in Table 5.1 below and represented geographically on Figure 11.

Table 5.1 Regional Public and Private Demands in Relation to Gross Resources

Regional Water Demands expressed as a % of Total Gross Resources under Average and Drought Conditions						
	Average Conditions			Drought Conditions		
Year	1991	2021	2021	1991	2021	2021
		Lower bound	Upper bound		Lower bound	Upper bound
Anglian	24	33	38	71	98	115
Northumbria	14	15	19	30	32	41
North West	14	11	15	23	17	25
Severn Trent	28	23	34	54	46	67
Southern	37	36	51	89	85	121
South West	5	5	7	9	10	14
Thames	50	54	68	119	128	162
Welsh	21	17	27	34	27	44
Wessex	14	17	23	31	36	49
Yorkshire	22	18	26	51	41	62

Note: Estimates include current net gains and losses from the existing inter-regional transfer of water.

Great caution is needed in interpreting the apparent resource utilisations shown in Table 5.1. Particularly it should be borne in mind that:

- gross demand, rather than net consumption, has been taken into account. Thus regions with a high proportion of non-consumptive use, such as Welsh, or with extensive re-use opportunities, such as Thames and Severn Trent, will show a higher level of utilisation than others. The effect on figures quoted in Table 5.1 of re-use of potable resources is addressed in Annex A, Table A.1;

- regions underlain by extensive aquifers (Southern, Wessex, Anglian, Severn-Trent and Thames) are better able to capture effective rainfall than those which are not, due to the storage capacity afforded by these natural underground reservoirs. Thus they may be able to utilise a larger proportion of gross resources, provided the aquifers can be significantly exploited without adverse environmental impact;

- it follows that there is no clear cut-off between acceptable and unacceptable levels of utilisation. A utilisation of 20% in an environmentally sensitive location may be far more damaging than a much higher level elsewhere.

A predominantly coastal region without substantial aquifers, such as South West, may thus be expected to have a relatively low level of utilisation.

An upper and lower bound quoted for each estimate indicates the associated measure of uncertainty. The importance and utility of the figures lies in their relative and not their absolute values, since the objective is to portray the comparative degrees of supply security and of potential resources available for future development.

There are important conclusions to be drawn from this type of analysis:

- in the South East quarter of England (Anglian, Thames and Southern Regions) the resource demand balance indicates serious levels of shortfall. Although figures presented in Table 5.1 relate to gross abstractions, consideration of varying levels of effluent re-use shows that resources in these regions are still very heavily committed (see Annex A, Table A1, rows 27a-27c). If it is acknowledged that only a fraction of the total available resource can be developed, then to a very large degree this proportion has already been exploited. Levels of service of supply are likely to be increasingly under pressure from even modest drought episodes. Projected levels of deficit are such that it is clear that significantly improved demand management, increased re-use and/or the strategic inter-regional transfer of very substantial quantities of water are the only feasible long-term solutions;

- sources for transfer schemes clearly lie with the substantial resources surpluses in the North and Wales.

5.2 Shortcomings of the Existing System

5.2.1 Political Aspects

Public water supply remains the responsibility of a relatively large number of undertakings, whose areas often relate more to particular groups of towns than to whole river basins. These organisations have an understandable preference to use water resources from within their own supply areas, for reasons of operational independence. Although there are many instances of shared resources, there is some inertia among the water companies towards extending such arrangements. Heightened commercial sensitivity among them in the immediate aftermath of privatisation of the 10 largest companies may exacerbate this preference for local rather than strategic planning.

The traditional water industry philosophy is that water is a cheap commodity which is expensive to move. Thus high leakage losses and wastage have been deemed acceptable, and local resource development options have been preferred to strategic ones. Pressure on resources and environmental concerns are leading to the revaluing of the commodity, and must therefore call such attitudes into question.

5.2.2 Hydrological Aspects

The existing water resources system has evolved over 200 years and contains many elements that are out-dated. Substantial parts of the distribution network, particularly in the north and the metropolitan areas of the south are in need of replacement. A major benefit from this will be a reduction of leakage. The evolution from a great number of local water companies is reflected in the numbers of small upland direct supply reservoirs which are difficult to integrate into and operate as a part of the total regional resource system.

Other deficiencies in the system include:-

- environmentally damaging rates of groundwater abstraction, particularly the south of England, which are permissible by virtue of the fact that the sources were in operation before 1963. These have led to the progressive drying-up of a number of spring-fed streams; even larger rivers such as the Kennet cease to flow in upstream reaches in moderately dry summers. Such unsound rates of withdrawal are difficult to reduce, as alternative sources of supply would need to be found. These would be costly to develop, and water companies would expect recompense from the NRA as licensing authority;

- difficulties in source integration and/or conversion to more efficient operation as a preference to a new source of supply. One of the options considered during the Public Inquiries of 1973, 1976 and 1977 as an alternative to the new Carsington Reservoir in Severn Trent Region was the conversion or partial conversion of the Derwent Valley reservoirs from direct supply to river regulation with the additional option of pumped refill to augment their yield further;

- a lack of inter-regional transfers. Although transfers from Wales to the North West and Midlands by means of the Vyrnwy and the Elan aqueducts are almost 100 years old, it was not until the construction of Clywedog Reservoir and the regulation of the Severn from 1968 that any substantial increase in the degree of strategic transfer of water took place. These three schemes, along with the Trent-Witham scheme, the Dee transfer to Liverpool, and the Gloucester-Sharpness Canal transfer, remain the only long distance inter-regional bulk water transfers in excess of 100 Ml/d. The shortcoming of the existing system implied by this is that water is still perceived as a regional rather than a national strategic resource, in which the emphasis lies with the local option for resource development;

- insufficient use of treated effluent as a resource. As effluent standards improve, the potential for their use for low flow alleviation increases. Traditionally, however, sewage treatment works have seldom been viewed as an integral part of the available resource system, and they are generally sited in a way that precludes their optimal development as a resource component. (Thames Region is a partial exception to this generalisation). The problem goes deeper, in that past failure to recognise that effluent can be re-used has led to insufficient emphasis being placed upon achieving and maintaining adequate quality standards for discharges of used water. Thus significant stretches of inland waters are of such poor quality that their use for potable supplies cannot be contemplated for many years. The River Mersey system exemplifies this;

- insufficient use of and provision of storage for winter flows. This resource could be further exploited in three ways:

  (i) the provision of small off channel reservoirs that store excess winter flow for summer spray irrigators. There is considerable scope for such developments in regions other than Anglian, where it is already well established;

  (ii) the conversion of direct supply to river regulation reservoirs. The latter are not drawn upon during winter when rivers are generally unregulated and abstractions can be fully supported by the river system alone. Winter storage is then held over to the summer;

  (iii) pumped storage, making use of high winter flows to fill new or existing reservoirs.

5.2.3 Water Quality Aspects

Significant inland water resources are currently unexploited due to water quality problems which render them very difficult to treat to potable standards. In the 1985 River Quality Survey (11), some 9% of rivers (3,500km) were found to be of poor quality and 2% (800km) of bad quality. Conversely, some 89% (34,700km) were of good or fair quality, and, by inference, suitable for potable use. However, these results should be treated with some caution, since the Lower Trent, for example, is shown as suitable for potable supply after advanced treatment; past doubts on this issue are highlighted below.

Many of the localised problems in 1985 related to sewage works discharges and, with the planned expenditure on improving effluent discharge quality, many class 3 rivers should achieve class 2 in the medium term. Conversely, the implications for major rivers of increasing salinity loadings due to such factors as flue gas desulphurisation and denitrification plants at waterworks in the future are not known.

As with groundwater, the long term implications of exotic pollutants such as heavy metals and pesticide residues are not fully understood.

It is an obvious fact, but worthy of re-statement, that all waters may be rendered drinkable. It all comes down to cost. Accordingly, rivers with water below average quality have to be compared with other rivers which are currently being used for potable water abstraction. One then has to form a view on whether the difference is sufficiently great to require an order of magnitude increase in the likely cost of treatment.

The lower reaches of the Trent will provide a source of water which is potable after advanced treatment, and they are already used as such with varying degrees of blending with waters from other sources. However, there is a degree of operational risk attaching to the use of the Trent water. Occasional pollution from the urban catchments upstream may be detectable by telemetry, or not, depending upon the nature of the pollution. Therefore, given the present state of automatic water quality monitoring technology, there will remain some risk that polluted water could be abstracted unknowingly.

The River Trent is the largest source of water in England which may be regarded as verging on treatable for potable water supply, at a cost which is not obviously unrealistic in today's terms. The Trent has been the subject of much study, but its development as a potable supply source has probably been held back for longer than it need have been due to the very research programme which sought to demonstrate its potential for such use. Since this is a potentially contentious issue, it is worth reviewing the recent history of catchment quality planning in order to provide background. The WRB research programme in 1973 (16) was well intended and executed, but the methodology (involving the use of the Trent water quality model) was not well suited to addressing the question which formed the objective of that programme: "Can one drink the Trent?" - to which the study concluded "No". Consequently, the WRB could not recommend that the Trent should be used for potable supply. Since 1973 there have been significant advances in the water industry's understanding of the principles of catchment quality planning. Were the WRB study to have been conducted post-1982, it would have started by asking the question "Is it possible to devise a regional strategy for sewerage and sewage treatment which might render the Trent potable after appropriate treatment?" With today's improved understanding of probabilistic water quality modelling, combined with the application of operational research techniques, the answer would almost certainly now be "Yes".

Apart from the short reach in Stoke-on-Trent, and the longer reach between the Tame and the Dove confluences, the Trent is of a comparable quality to the upper reaches of the Severn, or the Avon between Bath and Bristol. The determining influence on the Trent's quality over much of its length is the River Tame, which drains the West Midlands catchment, including the Birmingham conurbation. It is unlikely that the Tame itself will become significantly better in quality over the coming twenty years, and therefore its influence on the Trent is equally unlikely to moderate. Consequently, the quality of the Trent downstream of the Tame confluence falls short of the quality of the Great Ouse at Grafham, despite receiving the same general water quality classification (NWC Class 2).

The River Mersey is a long way from being treatable economically, despite some improvements which have been noted over the past five years. The fact that no major study to date has sought to address the issue of using the Mersey as a supply source demonstrates that this view is almost universally held. The rivers which rise on the Pennine foothills and run immediately into urban, industrialised catchments (the Rivers Mersey, Don and Rother) are the most polluted in England. The Mersey itself becomes polluted at its head by the city of Manchester. Consequently the river has no natural buffering capacity (by way of dilution) to cope with any pollution which arises from the city. Furthermore, it forms the centre line of an almost continuous industrial corridor which runs all the way to its tidal limit at Warrington. It should further be recognised that any reduction in diluting flow (as a result of abstraction) at any location in the Mersey catchment could act to nullify the efforts of North-West Water to improve the quality of the river.

Unlocking the Mersey would require a major change in the way industrialists in that part of the country view their environmental and social responsibilities. They may be forced into this by pending legislation, but it will take many years yet.

5.3 The Range of Strategic Options

5.3.1 Definition of Strategic Options

For the purposes of this study, a strategic option is defined as:

"a scheme or combination of schemes which individually provides a partial but effective response to projected changes in demand for water in England and Wales, and collectively overcomes the problems which may arise by 2021 if no action were taken".

It is emphasised that steps to reduce the rate of growth in demand are as admissible as new schemes to accommodate it in full.

Options are divided into three broad categories, being those which:

- reduce the need for water;
- increase the availability of water locally;
- transfer water across NRA regional or national boundaries.

These are described in general terms below, and in more detail in Sections 6-8.

5.3.2 Reducing The Need For Water

Options to reduce the need for water include:

- reduced wastage;
- metering;
- modifying standards of service.

At present, some 26% of water put into public supply in England and Wales is unaccounted for (UFW). This is due to a combination of factors, chief among them being leakage, wastage and reading discrepancies between different meters within the system. Where local UFW rates may be shown to be relatively high, it is unlikely that a new resource scheme could be successfully promoted without effort being made to reduce them.

Water supplies to most of the 20 million homes in England and Wales are not metered. Charging is based upon the rateable value of the property, irrespective of how much water is used. The introduction of metering would enable consumption-related charging to be introduced, and would allow the implementation of tariff schemes which discourage excessive water use, particularly at times of resource shortage. This in turn will help to bring about suitable market conditions for the development of more efficient water using domestic appliances.

The standard of service which has most impact on water demand is mains system pressure. By reducing it, both leakage and consumption are also brought down. At present, most water companies' target levels of service allow for periodic pressure reduction, during droughts of about 1 in 20 year return frequency.

5.3.3 Increasing the Availability of Water Locally

Local options to increase water supplies include:

- further development of ground and surface water systems;

- more efficient use of existing sources;

- mobilisation of poor-quality sources such as treated effluent and seawater.

The scope for further development of surface and groundwater is, perhaps unsurprisingly, relatively limited in the main regions of projected shortfall. However, this category is taken to include provision of more surface water storage, in order to capture a higher proportion of winter flows for release in dry weather.

Options to use existing sources more efficiently are a function of how they are used at present. Guiding principles are that:

- the yield of a given reservoir is greater when it is used for regulation to support river abstractions downstream, rather than for direct supply;

- the overall yield of a collection of individual schemes can be improved if they are operated conjunctively;

- demand peaks tend to be localised, and do not necessarily coincide across wide regions.

It is clear from the foregoing that it may be possible to improve source yields in some cases, notably where there is scope for further integration.

No direct effluent re-use schemes were identified in England and Wales. However indirect re-use is commonplace, particularly in the major inland regions such as Thames and Severn-Trent. Nevertheless some 34% of water supplied by the public system is discharged as effluent to tidal waters after use. Accounting for 30% "process loss", this amounts to some 4100 Ml/d. The scope for redeployment of this water via the inland river system is clearly of interest. Similarly, the economics of desalination of seawater merit review.

5.3.4 Major Transfers

The demand/resources balance exercise (Section 4.6) has demonstrated the projected shortfall in the south and east, and surplus in the north and west. Transfer schemes include various options to mobilise this surplus to overcome the shortfall. Such schemes could use purely pipelines and tunnels, or pipelines and tunnels coupled with conveyance in existing rivers and canals.

There may also be opportunities to move water by sea - from Kielder reservoir, for example - or to import it from Europe via an undersea pipeline or tunnel.

5.4 Costings

The basis for costing of the strategic options is given in Annex C. The values provide a means of comparing the differing options, and to allocate them between the three broad bands of "relatively cheap", "moderate" and "relatively expensive" as required in the Brief. Thus a fairly straightforward approach has been adopted; quoted costs are not intended to be taken as an accurate reflection of a particular scheme's price in absolute terms. For example the costing of reservoirs, which may represent a major scheme component, can vary enormously according to particular site characteristics. The same can equally be said of re-use schemes, where the level of treatment will depend on the effluent quality.

5.5 Environmental Impacts

Greatly increased awareness and understanding of the environmental impact of water resource development means that future developments are likely to incorporate operating rules to ensure that they remain "environmentally acceptable" for the foreseeable future. However, the yield of new schemes is likely to be partly taken-up by reducing the yield of existing schemes where the environmental impact is at present unacceptable. This is likely to be a condition of granting a licence for the new scheme. The NRA have already publicly stated that the solutions for over-abstraction of groundwater in the Kentish Stour catchment are linked to the proposed Broadoak Reservoir.

Further, recent experience has shown that the potential yield of proposed schemes may be highly sensitive to the operating rules that are applied. Thus proposed operating rules are likely to be a highly contentious issue during scheme promotion, particularly where environmental concerns make desirable more stringent rules than might have been applied to similar schemes in the past. This is likely to have fundamental repercussions on the choice of appropriate future developments, and upon the cost of securing future water supplies. It also means that the economic viability of approaches to reducing demand, eg leakage control and metering, may be transformed.

6 OPTIONS TO REDUCE THE NEED FOR WATER

6.1 Leakage Control

Leakage control and waste detection have not always been given the priority of attention by the water industry that they deserve. The publication of the technical paper by the Water Research Association (17) and the DoE/WRc standing Technical Committee Report 26 (18) have done much to assist water undertakings standardise the methods and procedures necessary to deal with leakage detection.

Most of the published unaccounted for water (UFW) figures are seen by the public to be unacceptably large. They have, probably rightly, become a focus in the debate on water supply which privatisation, the recent series of hosepipe bans and publicity surrounding groundwater overabstraction have stimulated.

Present levels of wastage, expressed in terms of UFW as a percentage of total public water supply, are shown on Figure 1. The present values of UFW for the larger companies range from 33.2% in North West to 16.2% in Wessex Water's supply area. All the larger water companies have stated their intention, with varying degrees of ambition, to reduce the levels of leakage within the next ten to twenty years. By 2011 most companies forecast a UFW level of 18- 25%, with the lowest forecast of 15.7% in South West and the highest 27.9% in Yorkshire. This variation reflects not only the degree of leakage control envisaged by the companies, but also regional conditions such as the density of service connections, the age and working pressures of distribution mains and the topography and geology of the regions.

Several of the smaller water supply undertakings have predicted levels of UFW below 15%. These figures must be treated with caution, since many relate to small urban distribution systems. In addition, the methodology for calculation of UFW is not consistent in the water industry, and since it represents a balancing item its value is highly dependent upon the quality of estimates for unmeasured per capita demand.

To evaluate satisfactorily the volume of water that can be saved by implementation of leakage control, UFW should be related to a measurement of minimum night flow. In urban areas, the most useful measure is net night flow per separately charged property, while in rural areas an expression of night flow in terms of kilometre of main is more appropriate.

Translation of a percentage UFW into a minimum night flow is a treacherous exercise. However, a crude calculation based upon an occupancy rate of 2.5, a per capita consumption of 150 l/h/d and an assumption that public demand represents 50% of total supply, shows that a leakage rate of 8 l/prop/hr is equivalent to 21% UFW. This calculation assumes that all UFW occurs in the measured night line, whereas in practice much also relates to reservoirs, service mains, industrial connections and metering errors.

A review of the literature (19) indicates that, with an active leakage control programme, combining district and waste metering, leakage can be reduced to 6 l/prop/hr, an equivalent 16% UFW. Wastage may further be reduced by installation of pressure reducing valves and conversion to variable speed pumps for lower night-time mains pressure. Other measures such as relaying mains with welded instead of traditional flexible joints will allow further reductions, but with an ever increasing cost.

For the purposes of this study, the following UFW values have been assumed for 2021, as a proportion of total public water supply:

(a) lower bound: 15% overall

(b) upper bound: 20% overall.

The lower bound figure reflects the arguments presented above about the progressively higher unit cost of successive reductions in UFW. The upper bound figure of 20% is in fact slightly below the overall assumed UFW achievement enshrined in the 2011 "base case" public sector demand forecasts produced by the water companies (see Section 3.3); its adoption here reflects the Consultants view that, as the public debate on the environmental implications of water resources development intensifies, the pressure on companies to improve their performance in relation to UFW will also increase. It is submitted that an overall UFW figure of more than 20% of total water supplied will become politically unacceptable.

6.2 Metering

The public have historically regarded water as an inexhaustible and cheap resource, paying a fixed amount relative to the rateable value of the house, for unlimited usage. Despite this, the United Kingdom has one of the lowest per capita consumptions in Europe while remaining one of only three countries not to meter domestic supplies.

The 1983 per capita consumption (pcc) of water in various European countries is shown in Figure 12. All of the countries identified, except for the UK and Ireland, have metered supplies. Only Belgium reports a lower consumption than UK. Switzerland had the highest use (285 l/hd/d), and in Italy, where water has a 'comfort' value, the use was 215 l/hd/d. The per capita consumption may be related to climate, prosperity and relative cost of water of a country; it is generally recognised in all of these countries that, without metering, consumption would be higher.

It is worth noting that pcc in Germany is now said to have stabilised, having remained at about 145 l/c/d for the last six years (20). In UK, pcc is apparently still rising. The German view is that consumption has reached a saturation level; two other factors are relevant:

- a higher proportion of the population in Germany lives in flats (and therefore have no gardens);

- the cost of water in Germany is twice as high as in UK when expressed as a percentage of household income.

Predicting the water savings which universal metering in the UK might bring about, and therefore its economic viability, is an imprecise operation. Reductions of between 5% or 45% have been recorded overseas, but the very high figures are unlikely to be reproduced in the UK. They were recorded in Philadelphia (45%) and Colorado (36%), USA, and were reductions from very high consumptions of up to 400 l/hd/d. In Belgium, a study in Ghent estimated metering saves 20-35%. In the Netherlands, which has a similar climate and social conditions to the UK, the recent introduction of metering has achieved and maintained a 15% reduction in demand.

The reductions in water supply associated with customer metering may not be solely attributable to a decrease in demand by consumers. Some are likely to stem from the improved understanding of flows in the system which metering will bring about; this will enable further refinement of leakage control policies.

Through imaginative tariff structures, metering allows interaction and feed-back between the customer and the water company. A tariff structure must be easily understood by the customer and be practical to administer. Within these constraints, tariffs can be used to control consumption and reduce seasonal and daily peak demands. This is a very important consideration in the UK, where the size of such peaks relative to average demand, and the need to meet them if some customers are not to suffer loss of supply, governs the planning and operation of the potable water system.

However, the water industry is essentially a monopoly; it would be inappropriate to allow water to be treated as a market commodity such as oil or metal, with prices rising and falling according to demand and supply. Nevertheless, in severe drought conditions, a facility could be designed to allow water prices to rise by a fixed proportion, if linked to a similar increase in NRA abstraction charges. In this way the water companies would not benefit from shortage of water resources, but monies would be available to cover costs of environmental damage, public relation campaigns and research.

The Watt Report, published in 1985 (21), reviewed the social, economic and engineering aspects of introducing general metering in this country; among the identified advantages were:

- metering would be a more equitable system of charging for water than the present rateable value principle;

- there would be an estimated 12 % reduction in water usage, leading to costs savings due to reduced operating and treatment costs and deferment of capital expenditure for resource developments;

- metering would provide a more direct measure of per capita demand and might reduce customer leakage.

The 1988 passage of the Public Utilities and Water Charging Act (22) gave powers to the water industry to carry out compulsory water metering and charging by volume. This allowed the water industry, in association with the Department of the Environment, to set up ten regional metering trials in accordance with recommendations of the Watt Report.

Early results from the largest trial site, on the Isle of Wight, showed a reduction in water consumption in both unmetered and metered properties before installation of the meters was complete. The 12% reduction in consumption reported by WRC in July 1990 (23) at the latter is seen as probably unsustainable in the longer term, as the novelty of the new water charging arrangements wears off. Southern Region demand forecasts assume a 5% drop in consumption as metering is introduced; however, it was suggested in discussion that 10% might be more appropriate. The issue of water savings related to metering is discussed further in Section 6.5.2.

The UK water industry is prohibited from charging for water upon the basis of the rateable value of a property after March 2000. Of the available alternatives, including licence fees, property banding and charging by numbers of bedrooms or appliance types, only metering allows charges to be directly related to customer consumption. As part of the assessment of the costs and implications of metering, the national trials are considering various alternative volume-related charging systems or tariff structures.

A number of water companies in the Southern Region are seriously considering general metering; the remaining large companies, except for Dŵr Cymru who have rejected the idea, are awaiting the final results of the metering trials. If a significant proportion of the companies select the metering option, the meter manufacturers and civil contractors will be under great pressure to meet the Government's year 2000 deadline. In view of the number of properties involved, this could well cause installation prices to inflate. On the other hand, large manufacturing production runs will lead to economies of scale which may manifest themselves in the purchase price of metre units.

It may be that, as an alternative to general metering within a water company area, the company could elect to meter only the potentially high water users living in larger properties with extensive gardens. The danger of this strategy is that increased charges may not deter the more affluent individuals, with the reduction in usage being minimal. Furthermore, whilst the metering trials now in progress result in a section of the community being charged in a different way for their water, that section is intended to be representative of the country as a whole in socio-economic terms. The legal implications of deliberately adopting a different charging policy for a particular socio-economic group are less clear. Some compromise is needed, whereby perhaps effort is focused on the larger properties initially. This would give further time to assess the benefit both to the water undertakings and to the country as a whole, with installation of meters at other properties coming later in the programme.

6.3 Improving Efficiency of Water Use

6.3.1 Domestic Demand

Total domestic demand represents approximately 50% of the public water supply in England and Wales, although the proportion will vary according to the levels of industrial demand and unaccounted for water in the regions. Domestic premises contain a variety of water using appliances, all fed from a pressurised plumbing system. A breakdown of the average household water use is shown in Figure 13.

More efficient use of water in the home may be achieved by:

- public education
- redesign of appliances
- alterations to the plumbing system.

The effects of public education initiatives are generally seen as useful in controlling water use during periods of temporary supply shortfall (see Section 6.4) but ineffective in the longer terms unless coupled with another initiative such as metering.

Examples of appliance design changes which could be made include:

- positive closure taps, which are held shut by the system pressure, and opened against it;

- smaller capacity lavatory cisterns

- dishwashers/clothes washing machines which store water for re-use in different cycles.

Modern wc's can work satisfactorily with a 7.5 litre cistern capacity, compared with the traditional 9 litres. This 16% reduction in water use would translate to a 5% reduction in use in the home (see Figure 13) or 2½% reduction in overall demand, if fully utilised in all wc's in all new and existing homes. Similarly, if washing machines used 25% less water, the reduction in overall demand at full implementation would be 1½%. Reductions which could be achieved by more efficient "miscellaneous" water use (Figure 13) are less easy to quantify.

Of equal interest with potential reduction in demand through appliance redesign is the speed with which such changes can be implemented. This will be driven by:

- appliance life
- consumer will for design changes

Washing machines last 5-10 years, while taps and wc cisterns may last much longer. Consumer will for design changes may be partially driven by social conscience about excessive water use, but is more effectively mobilised by volume related charging ie, metering. Such a policy, if embraced in the near future, could take up to 20 years to implement fully throughout the country, but could be brought in more quickly (say 5-10 years) in the areas where demand levels are more critical. Replacement of the majority of appliances with more efficient ones could take a further 5 years to complete.

On this basis, a significant proportion of the full water savings arising from redesign of appliances could be realised within the 2021 planning horizon. However, some spur such as the introduction of volume related charging is needed to achieve this.

Alterations to the plumbing system could lead to significantly improved home water efficiency, principally by re-use. For example, bath and washing machine effluent ('grey water') could be re-used for wc flushing or garden watering. Full re-use of such water would lead to a 30% reduction in domestic demand, although practical difficulties (eg relative levels of bath outlet/wc cisterns) render achieving this level of reduction unlikely. However, it is clear that potential savings here are greater than with improved appliance design, and some further study is warranted.

Replumbing of existing houses would be very costly and is unlikely to be undertaken purely for water economy. The changes could only be introduced in new homes or as existing ones are refurbished, and would thus take perhaps 50 years to implement fully, although the benefit stream of moderating domestic demand should begin to manifest itself much earlier. Again, there needs to be an incentive such as volume related charging.

At a more basic level, the introduction of household rainwater tanks fed from roof gutters could help reduce garden watering demand. However, it must be appreciated that garden sprnklers would still be supplied from the mains system, because of the pressure requirements.

6.3.2 Non-domestic demand

The larger industrial and commercial users already pay for water by metering, and are further encouraged to use water efficiently by stringent sewerage charges. The mechanisms to encourage efficient water use are thus already in place, although it is likely that greater savings in water use would be made if more onerous tariffs were to be introduced.

6.4 Restricting Supplies During Droughts

Under the 1945, 1948, 1958 and 1989 Water Acts and the Drought Act of 1976, the water undertakings have a range of restrictions which they can impose during drought conditions in order to reduce demand and conserve and supplement resources. Companies have the right to impose bans on hose pipe use, but for more stringent measures such as standpipes and water rationing they must apply to the Secretary of State of the Environment for a Drought Order. Similarly, Orders are required to suspend or modify any licensed abstraction from a water source or to relax water quality obligations.

To assess the potential impact of restrictions of use and publicity campaigns on consumption, it is useful to review the events of a recent drought. Thames Region was severely affected by the prolonged dry period from the summer of 1975 through to the summer of 1976, during which a maximum demand for water coincided with a minimum availability (24). The potential threat of a drought was recognised as early as October 1975, and steps were taken to control demand and conserve resources. Water pressures were reduced in the mains to the minimum required by statute, and an overall regional operational resource conservation strategy was introduced. A ban on hosepipes came into force in July 1976, together with further pressure control measures. Standpipes were installed in limited areas, but rationing and cutting off supplies was averted by the onset of rains in September.

Although they were not practicably enforceable, evidence showed that hosepipe bans were effective in the short term in reducing demand; North Surrey Water Company reported an approximate 7% reduction in demand compared with the week prior to the introduction of the ban. Any such semi-voluntary reductions need to be supported by extensive publicity campaigns including TV, radio, newspapers, posters and even loudspeaker appeals. The effectiveness of this last option in Sutton Water Company was shown by a 14% reduction in 7 day peak demand following repeated appeals.

The total demand reduction in the Thames region at the end of the drought was approximately 25% (Fig 14). The cost of this saving is not available and would anyway be difficult to assess. General metering, if introduced, may result in the balance between water savings and costs becoming more tangible in the future.

6.5 Overall Potential for Reduction

6.5.1 Leakage

In attempting to calculate the overall potential for reduction, it has been assumed that the first step will be for the water companies to achieve their leakage reduction targets. Other measures, such as metering, would come later. Weighted averages of the water company UFW targets for each region are shown in Table 6.1.

Table 6.1 Regional Forecasts of UFW

Region	Unaccounted for Water %			
	1990	2001	2011	2021
Anglian	22.0	18.3	17.3	17.2
Northumbria	16.2	15.9	15.5	14.8
North West	33.2	25.0	24.8	24.6
Severn-Trent	23.5	22.3	21.8	21.8
Southern	27.1	19.2	17.8	16.6
South-West	30.0	15.3	15.2	15.3
Thames	27.3	22.4	20.6	19.2
Welsh	28.2	22.3	21.8	21.3
Wessex	16.2	16.8	16.0	15.3
Yorkshire	30.1	27.9	27.2	27.2
TOTAL	26.2	21.5	20.5	19.7

Of the regions Northumbria, South West and Wessex have the most ambitious final 2021 targets of 14.8%, 15.3% and 15.3% respectively. In the Yorkshire Region and in North West Region, very cautious targets of 27.2% and 24.6% have been set. Further savings are possible in these regions with greater investment in leakage control.

Using the above figures and the base case estimates for public water supply demand in 1990,it is possible to estimate future demand in the regions if no leakage control improvement above 1990 levels is attained. Thus, by subtracting the base case demand from the 'no improvement' demand forecast, the saving due to leakage control is calculated (see Table 6.2 & Annex C, Table C32).

Table 6.2 Water Savings by Leakage Control

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Company target	1115	1437	1701
15% target	2744	2913	3067
20% target	1520	1605	1679

A full regional breakdown of leakage savings is given in Annex C, Table C32

If the water companies are able to reach their leakage target levels, UFW will be reduced to a national average of approximately 20% and a saving of 1701 Ml/d will be achieved.

There are physical constraints to the volume of water which can be economically recovered. The optimum sustainable level to which leakage can be reduced will vary between regions and supply zones within region. With application of active leakage control measures, UFW levels of 20% in rural areas and 15% in urban area are believed to be attainable.

6.5.2 Metering

As stated in Section 6.2, it has been assumed that, with the adoption of general metering, there will be a 10% reduction in demand at formerly unmetered properties, which would translate to a reduction of approximately 5% in total demand. The water savings in England and Wales with metering would rise from 975 Ml/d in 2001 to 1108 Ml/d in 2021.

Additionally the effect of general metering on demand in 2021 on the three driest regions and on England and Wales as a whole has been investigated with assumed reductions in domestic demand of 5, 10 and 15%.

Table 6.3 Water Savings by Metering

Region	2021 Demand (Ml/d)	Unmeasured demand (% of total)	Reduction in Demand by 2021 with Metering (Ml/d)		
			5%	10%	15%
Anglian	2589	57	74	148	221
Southern	1736	48	42	83	125
Thames	5076	65	165	330	495
England & Wales	20526	54	554	1108	1663

The upper bound savings by metering of 1663 Ml/d would meet the overall deficit in England and Wales, but it would not meet demands regionally. There would remain a total regional deficit of 999 Ml/d, principally in Thames, Anglian and Southern Regions.

The introduction of a drought metering tarriff would help in reducing demand at times of resource shortage, but its effect would depend upon the allowable increase in cost of water services. For present purposes a saving of 7% has been estimated, arising from hosepipe restrictions and publicity campaigns. This is not seen as a maximum; in practice the saving achieved will depend upon the tarriff structure in place, and is thus not possible to forecast at this stage. The 7% saving via such a tariff corresponds to reductions achieved by South West Water during the 1989 drought.

Long term savings are foreseen with the introduction of water economy appliances and fittings as discussed in Section 6.3, but they are not estimated to be above 2% to 3% excluding 'grey water' re-use. The total water savings potential in England and Wales, with fulfilment of the water companies leakage control targets, adaption of general metering a 7% reduction during drought conditions, and a 2% reduction due to more efficient water use are shown in Table 6.4.

Table 6.4 Overall Potential for Water Saving (Ml/d)

	2001	2011	2021
Leakage Control†	1094	1360	1691
Metering	975	1043	1108
Drought restrictions	1200	1283	1365
Water Economy	319	341	363
Total	3588	4027	4527

† Savings due to leakage control taken into account in base case forecast.

If a further 5% reduction is allowed in 2021 due to re-use of 'grey water' in the home, the overall saving increases from 4527 Ml/d to about 5330 Ml/d. These figures may be compared with the estimated upper limit growth in pws demand of 4809 Ml/d over the period 1990-2021 (see Table 3.5).

6.6 Costs of Reducing the Need

6.6.1 Leakage Control

Determination of a unit cost for leakage control is difficult, since distribution systems will have inherently differing levels of leakage. In addition, cost savings in terms of reduced demand and deferment of capital costs required for resource development will depend on the location of the control area within the distribution system. In Table 1 part 2 of Report 26 (18) the level of right flows in an urban area is related to the leakage control method. For an area where a medium level of leakage is inherent, control with district metering corresponds to 8l/prop/hr and control with combined district and waste metering to 6l/prop/hr. Using the calculation given in Section 6.1, these leakage levels convert to UFW figures of 21% and 16% of total demand.

As a compromise, district metering has been assumed to correspond to 20% UFW and combined metering to 15% UFW. Leakage costs have been based upon the 1979 updated prices given in Table D4 of Report 26. It is emphasised that these targets have been taken for comparative purposes;

It is accepted that they are somewhat hypothetical insofar as they may not be practically applicable in all NRA regions.

The initial capital costs are based upon the increased expenditure over and above the cost for passive leakage control. No attempt has been made in this study to estimate cost savings due to reducing volumes of water into supply and capital expenditure deferment.

Costs of leakage control for capital expenditure and 30 years operation using this approach are given in Table 6.5.

Table 6.5 Leakage Control Unit Costs

	15% UFW	20% UFW
Capital Cost £/property	3.02	2.04
Annual Operating Cost £/property	0.96	0.33

(Based on Table D4 Report 26)

The total cost of leakage in England and Wales based upon a total of 19 million domestic dwellings is set out in Table 6.6.

Table 6.6 Total Costs of Leakage Control

	Capital Cost £m	Operating Cost £m	Total £m
(1) 15% UFW	3.02 x 19 = 57.4	0.96 x 11.26* x 19 = 205.4	262.8
(2) 20% UFW	2.04 x 19 = 38.8	0.33 x 11.26* x 19 = 70.6	109.4
(3) 5% improvement	57.4-38.8 = 18.6	205.4 - 70.6 = 134.8	153.4

* Discounting factor for 8% rate over 30 years. See Annex C.

The unit costs of leakage (Table 6.7) expressed in terms of Ml/d have been calculated by the division of the total costs in Table 6.6 by the average water savings as shown in Table 6.2.

Table 6.7 Unit Cost of Leakage Savings

	Water Savings ml/d	Cost £m	Unit Cost £m/Ml/d
15% UFW	2913	262.8	0.09
20% UFW	1605	109.4	0.07
5% improvement	1308	153.4	0.12

Table 6.8 Unit Costs of Water Metering

Region	Estimated unmetered population (millions)	1990 Forecast No of unmetered properties +(millions)	Metering installation £200/prop (£m)	Metering operating costs (£m)	Total (£m)	5%		10%		15%	
						Volume saved (Ml/d)	Unit cost (£m/Ml/d)	Volume saved (Ml/d)	Unit Cost* (£m/Ml/d)	Vol. Saved (Ml/d)	Unit cost* (£m/Ml/d)
Anglian	5.8	2.2	440	248	688	74	9.3	148	4.6	221	3.1
South West	1.5	0.57	114	64	178	20	8.9	40	4.5	60	3.0
Southern	3.9	1.5	300	169	469	42	11.2	83	5.6	125	3.8
Thames	11.4	4.3	860	484	1344	165	8.1	330	4.1	495	2.7
Wessex	2.5	0.95	190	107	297	36	8.3	72	4.1	108	2.8
England & Wales	47.5	19.2	3846	2162	6008	554	10.8	1108	5.4	1663	3.6

+ Based on occupancy rate of 2.5 person/property and 95% installation potential.

* Using water company forecasts of the proportion of total demand unmetered in 2021

Note the cost of installation of meters into new houses has been omitted in these calculations

6.6.2 Metering

The capital cost of installation of external meters is estimated to be £200 per property including costs of administration. Costs associated with meter reading and billing are estimated to be £10/property/year higher than those of the present system. Thus implementation of general metering throughout the country, entailing installation and regular reading of 19.2 million meters at existing properties, will cost an estimated £3,850 million in capital terms, and an extra £190m/year to operate.

The unit costs of metering in regions where 2021 deficits are forecast are shown in Table 6.8. The unit costs range from £2.7m/Ml/d saved to £11.2m/Ml/d saved.

If the cost of meter installation is reduced to £150 per property, the above cost range reduces to £2.2m/Ml/d to £9.3m/Ml/d.

6.6.3 Drought Measures

Costing of drought measures is very difficult, and has not been attempted in this study. The application of water use restrictions such as hosepipe bans in itself costs little, but the publicity campaigns necessary to gain the public's awareness are expensive. The long term introduction of water economic appliances and fittings will have no direct cost, since new appliances will only be purchased by the public once their existing units have become unusable or obsolete, or for perceived economic advantage in the form of reduced water charges.

6.7 Environmental Aspects of Reducing The Need

Clearly, any effective control of demand or demand growth could be used to reduce the environmental impact of existing abstractions; equally it could be used to delay the need for new sources, with no additional environmental impact or gain. Demand control does present the scope for reduction of impact if the overall policy embraces it.

The perceived practicable savings through improved leakage control of the order of 2000 Ml/d (Table 6.2) represent a potentially significant redistribution of groundwater and groundwater recharge. It is possible that this greater control of leakage could result in reduced stream flows in some areas, but it is felt that this is unlikely to represent a significant environmental impact.

The potential reduction in environmental impact by control of demand during periods of drought is considerable. It is suggested that this is a benefit that is not so far costed in the calculations of the economic viability of metering.

7 LOCAL OPTIONS FOR INCREASED SUPPLIES

7.1 Increased use of Groundwater

7.1.1 Conventional Development

As part of this study, an attempt was made to collate data on groundwater availability, including identification of specific schemes for additional exploitation of groundwater resources. In general, the task proved to be difficult and unproductive, and the validity of available information is questionable. Considering the importance of groundwater, this situation is surprising and disappointing.

Each of the NRA regions was asked to supply data on groundwater availability in the aquifers under their jurisdiction. The quality of the data varied considerably and it is clear that different techniques of assessment are being applied; it is understood that the NRA are commissioning a study on techniques of assessment in order to achieve some consistency. However, in terms of usable data, some current resource estimates were clearly unrealistic - for example, where large quantities of water were implied as being available from minor aquifers.

In addition, the problem of low streamflows has in recent years made a considerable difference to attitudes towards groundwater abstractions. This has two bearings on the existing and future use of groundwater. Firstly, it is possible that, in some areas of currently high groundwater abstraction, pumping will be reduced at some time in the future. Secondly, it probably means that potential groundwater schemes, many of which were conceived more than 10-15 years ago, will not be licensed to an extent anywhere near to the quantities originally envisaged.

The question of groundwater availability has been discussed with several senior representatives of the NRA; the current view is that the potential for additional groundwater abstraction is very limited. Although there may be scope for increased abstraction in some areas, it is generally likely to be offset by reduction in others. Therefore, in calculation of additional available groundwater, any schemes which are unlicensed have been treated with caution.

7.1.2 Artificial Recharge

Artificial recharge is taken to include any system devised by man for the replenishment or injection of aquifers with water. Its purpose may be to:

- increase the sustainable summer output of the aquifer by recharging at other times of year when available resources are more plentiful;
- filter partially treated river water through the ground;
- treat settled effluent.

Recharge as usually effected via infiltration lagoons or by injection via boreholes.

In Europe, USA and Israel, there are a number of long-running artificial recharge schemes. For example in Germany about 10% of the total public water supply comes from such schemes, mainly utilising the Ruhr River. Similarly in the Netherlands, the Rhine waters have been used to recharge alluvial aquifers for water supply since 1940. In Sweden, about 15% of the total water supply comes from river-charged glacial sand/gravel aquifers.

In comparison, artificial recharge schemes in the UK are relatively new. During the 1970s the Water Research Centre promoted field experiments in the Lee Valley in North London, at Hardham in West Sussex and in Nottinghamshire.

In the last century through to 1940-50, the chalk aquifer beneath London was heavily pumped for water supply, and consequently groundwater levels declined by up to 60-70m in some areas. Since then, due to a reduction in groundwater abstraction, levels have gradually risen, but there is still a significant storage deficit in the chalk aquifer and overlying Tertiary sands.

The Lee Valley borehole recharge scheme was completed in the early 1980s to utilise part of this storage. Encouraged by the success of this project, Thames Water Utilities Ltd are currently implementing a similar scheme in the Enfield-Haringay area. Mains water is used for recharge, during off-peak demand periods, and is injected into the aquifer via boreholes constructed for the purpose.

The total extra yield which can be sustained over a six-month drought as a result of these schemes is expected to be 180Ml/d. Investigations are currently under way to examine the potential for recharge elsewhere in London.

For a recharge scheme to be effective, certain hydrogeological conditions are required. In particular, the aquifer to be recharged need to:

(i) have a utilisable storage deficit;

(ii) be hydraulically distinct from the river system;

(iii) possess groundwater flow characteristics which retain a significant proportion of winter recharge sufficiently long to allow summer abstraction, rather than losing it to riverflow earlier in the year.

There must also be a suitable source of water of appropriate quality to be used for recharge when needed.

The storage deficit could be developed by pumping during the summer. Condition (ii) is relatively seldom met in England and Wales.

A possible constraint to such schemes is groundwater quality protection; a national aquifer protection policy is currently in preparation, and proposals for artificial recharge will be subject to review under the policy. On the positive side, a possible benefit of artificial recharge schemes is an improvement in flows in rivers that have suffered from the effects of groundwater abstraction.

From experience gained in this country and overseas, the advantages and disadvantages of an artificial recharge scheme may be summarised as follows:

Advantages

1 Better use of a catchment's resources can be made by aquifer storage of high winter riverflows;

2 probably easier to promote on environmental grounds (particularly where borehole recharge is concerned) than an equivalent surface water storage scheme;

3 generally improves the chemical quality of a recharged water by natural filtration and dilution processes;

4 can create a barrier to saline intrusion in coastal aquifers, thus allowing greater development of groundwater resources inland;

5 can raise groundwater levels and reduce pumping costs in an over-abstracted aquifer;

6 lower pollution risk than surface storage, less evaporative losses and, in some cases, utilisation of river flows for recharge may help to reduce incidence of downstream flooding.

Disadvantages

1 Comprehensive field trials programmes are generally required to prove the technical feasibility of artificial recharge schemes;

2 substantial pre-treatment of recharge water is required to minimise clogging of lagoon beds or boreholes (typically caused by silt, microbial growth and chemical precipation) and therefore maximise recharge rates;

3 even with pre-treatment, a regular maintenance programme is necessary, as low silt concentrations can eventually cause problems for operation;

4 of the total recharge, only a percentage will be recovered by abstraction, according to hydrogeological conditions.

Similar large scale schemes in urban areas to those being currently implemented in North London are unlikely to be feasible. There the chalk aquifer is overlain by London Clay, and the groundwater is of good quality, except for a saline zone adjacent to the Thames. In other cities such as Birmingham and Bristol groundwater quality in the Sherwood Sandstone aquifer (second in importance to the chalk in this country) has been significantly impaired by leakage of contaminants from numerous industrial sources. At present, therefore, such aquifers do not represent a potable resource, and thus artificial recharge is not a realistic development option. Furthermore, the availability of mains water for recharge is far less in those cities than in the London area.

In view of quality constraints and potential clogging problems, re-cycled effluent is not seen as suitable for aquifer recharge.

There is perhaps scope for large scale schemes involving piped transfer of river flows for recharge at major aquifer outcrops, such as the chalk in southern/eastern England and the Sherwood Sandstone in the Midlands. If such transfers were made, however, the water would more probably be used directly for river regulation in summer or for replenishment of surface reservoirs. These latter purposes are simpler to control, in that the water is delivered where and when it is needed, without the disadvantages outlined above.

In summary, therefore, the scope for significant further resource development via aquifer recharge is believed to be limited.

7.2 Increasing Use of River Water

The more intensive use of river flows, including sequential abstraction and effluent return, is constrained by the fact that this has to be considered in conjunction with some form of storage if the yield is to be reliable during droughts. Rates of abstraction are limited by prescribed flow criteria, whilst low water quality can severely reduce the economic viability of a scheme because of treatment costs.

The options for the increased utilisation of rivers include:

(a) the repeal of any outdated legislation which sets residual flows for the control of pollution. Where river quality has improved significantly, new standards can be set that are not detrimental to navigation, fisheries or amenity;

(b) abstraction from rivers which are suitable for public supply, but not yet used for this purpose;

(c) improvement in quality of certain rivers which cannot be used for public supply at present (eg Mersey);

(d) the conversion of upland direct supply reservoirs to river regulation. Potentially, yields can be increased by up to 50%;

(e) the support of river abstraction by groundwater regulation. An example is the development of the regulation of the River Clwyd in North Wales from the artesian boreholes. The yield of this single scheme is 13.6 Ml/d;

(f) the re-evaluation of prescribed flows that are set at instantaneous rates of discharge. In some cases, these may be inappropriately high and could be reduced by considering a mean flow over a number of days. This is particularly appropriate for the operation of regulation reservoirs on large rivers, where the travel time to the control point is a matter of days;

(g) the use of winter flows by storage in small cut-off channel dams, particularly for summer spray irrigation and general agricultural demand. In the Anglian Region, several hundred such schemes already exist, generally with a storage of 20Ml or less (25);

(h) the redirection of treated effluent discharges, possibly in conjunction with storage to avoid excessive inputs. It has been estimated that the Chelmsford and Witham effluents could yield up to 45 Ml/d at minimal cost to the Essex-Ely Ouse system (25).

7.3 Provision of More Storage

The options for reservoir expansion to increase the available resource are:

(a) the expansion of existing strategic resources such as the Elan Valley system, in order to make available the required water volume for inter-regional transfer involving levels of capital expenditure upon tunnels, pipelines and channel improvements;

(b) the identification and development of new regional reservoirs. However, natural sites are very limited within those regions of greatest resource deficit. In the Thames, Anglian, Wessex and Southern regions there are few sites where storage could be developed. While economic considerations are obviously important, promotion of the scheme may be made easier by selecting locations which are already environmentally disadvantaged, such as derelict areas and areas already intruded upon by reservoirs. With this approach, it may be possible not only to provide new storage but improve amenity and recreation in disadvantaged areas (12);

(c) the expansion of existing reservoirs. Most of the reservoirs in England and Wales are between 50 and 100 years old, but are not amenable to the expansion of storage by the raising of dams. The best option for the existing catchment fed direct supply reservoirs is integration into the larger resource system, resulting in improved operational control and yield; this has largely been achieved in the North West region;

(d) increased pumped supply from rivers to existing storage. Here the principal constraint is the need to preserve residual river flows for fisheries, effluent dilution and other environmental factors. These issues are currently under investigation for Grafham Water in Anglian Region, and there is known to be scope in other regions such as Wessex and South West;

(e) the use of head of tide storage, where the greatest flow is available for storage. The Wash scheme may be viewed as falling into this category. These schemes, in addition to being expensive, are often constrained further by water quality problems.

7.4 Integration of Resources

Historically, the water supply infrastructure of England and Wales has moved from a great number of direct supply reservoirs, independently owned and operated by municipal water companies, towards the present integration of resources on the regional scale. This itself reflects the evolution of the industry to fewer, larger management authorities. A recent characteristic of this integration is that it has changed in its emphasis upon the linking of potable supply networks to linking up the primary raw water resources. This has allowed higher efficiencies in resource utilisation. The options for resource enhancement that have been followed include:

(a) the extension and development of regional aqueducts, which has allowed the linkage of formerly independent direct supply reservoirs. An excellent example was the Yorkshire regional strategy to integrate the separate supply systems of the 22 former water undertakings. The basis of a grid system existed in 1974 and, following the 1976 drought, the grid strategy was accelerated. The main spinal aqueduct from the Derwent to Sheffield and Leeds was linked to the Wharfe and Yorkshire Ouse abstractions and the system extended to connect Wakefield and Hull. The success of the policy was demonstrated in 1984 and 1989 when the droughts were managed with a minimum of supply disruption (26).

(b) the conjunctive use of different resources, such as groundwater to support river abstraction intermittently, eg the Shropshire groundwater scheme;

(c) the fuller system integration of ground and surface water resources such that overall yields can be optimised. This policy has been emphasized with Southern Region.

These trends in river basin management and resource integration have stemmed from the opportunity to plan and manage water resource schemes over a much wider area and over a larger range of options. Logically this leads to the next step which is the integration and utilisation of resources throughout England and Wales.

7.5 Re-use of Effluents

Effluent re-use can be either:

- direct, whereby treated effluent is put straight back into the supply system via a pipe-to-pipe connection to a water treatment works, or discharge to a direct supply raw water reservoir;
- indirect, whereby effluent discharged to a river system is subsequently re-abstracted and treated for water supply.

There are no direct re-use schemes at present in operation in the United Kingdom, but there are examples overseas. Most notable is the "pipe-to-pipe" scheme in Windheok, Namibia (27). Since 1969, a 4.5 Ml/d scheme has been operating in which effluent is reclaimed in a physio-chemical plant and used as potable water. The city's water supply may consist of 22-27% of treated effluent, after blending and dilution with water from conventional sources.

Pipe-to-pipe connections, although technologically feasible, leave little room for human error and are rare. Direct re-use schemes involving discharge of effluent to either surface or ground reservoirs are more common. The reservoir provides effluent dilution, time for natural purification of the water, and a temporal buffer against treatment failure; this last point is important, since even with constant quality monitoring, tests have not yet been developed which give instant results for certain key contaminants.

Indirect re-use of effluent is widely practised in some regions of England. It is most prevalent in the Thames basin, where analytical studies have shown that treated effluents represent 13% of river abstractions used for public water supply on average.

Schemes are now being looked at to extend indirect re-use in Anglian, Thames and South West regions, by pumping highly treated effluent upstream of public water supply abstractions, thereby increasing the resource. Future plans by Anglian Water include increasing river abstractions to take advantage of large effluent flows caused by greater water consumption.

Thames Water have been considering re-use of Deephams STW effluent, by pumping a proportion of its discharge water to the Lee Valley system, instead of allowing it to flow by gravity into the tidal River Thames. The effluent would be highly treated and would be discharged into either the storage reservoirs or the River Lee, or used for groundwater recharge. It is estimated that 100 Ml/d could be reclaimed from the Deephams works; similar quantities are available from Becton and Mogden STWs. However, the promotion of the Deephams scheme has been temporarily shelved because it is felt that the proposal would be unacceptable, given current public awareness of both environmental and drinking water quality issues.

The long term health implications of effluent re-use are not well known. The complete removal of viruses and synthetic organic compounds cannot be guaranteed with existing effluent treatment technology; until better technology is available at an economic price, indirect re-use is to be preferred over direct re-use for public water supplies, since the former affords greater opportunity for dilution and self-purification for the effluent.

Notwithstanding the degree to which indirect effluent re-use is already practised in, for example, the Thames basin, the risks associated with it need to be taken into account. Careful monitoring of water quality is needed, so that public supply abstractions can be suspended in the event of failure of an effluent treatment process at a sewage works upstream, or some other pollution incident in the catchment. Some indirect re-use schemes may require modification to the sewerage system upstream to reduce the frequency of storm overflow. All schemes will require carefully formulated operating rules which avoid abstraction at times when water quality is likely to be significantly poorer than average (eg first flush off a catchment).

For the purposes of this study, re-use of effluent for public water supplies has been costed on the following basis:

- any scheme would be indirect, rather than direct;
- the effluent would be treated to a high standard prior to discharge upstream of the water abstraction point.

Effluent treatment processes have been taken to include filtration, ultra-violet disinfection and activated carbon absorption; prices have been obtained from a Halcrow study of a 37 Ml/d STW scheme. For costing purposes, it is assumed that demineralisation by reverse osmosis would not be necessary, and that nutrient removal would be undertaken as part of the conventional sewage treatment process. Strict control and constant monitoring are required to ensure that the effluent discharge quality is maintained.

There is undoubtedly scope for industries which use water for a number of processes to recycle the effluent from one process for use in another. Several examples exist in UK of this and similar practices, such as direct re-use of sewage for cooling and quenching processes in the power generation, oil, chemical and steel manufacturing sectors. The scope for water economies of this nature has not been investigated during the study, since it is considered that the very modest demand growth rates assumed for industry already encompass a move towards greater efficiency of water use, and that such a process is already well underway; with large water users paying by volume both for water abstraction and subsequently for its disposal, moves to reduce consumption at a particular site lead to a double saving for the user.

Constraints on effluent re-use by industry include:

- storage requirements;
- increased metallic corrosion with high water conductivity;
- scaling problems with precipitation of organic salts;
- increased biological growth;
- fouling.

In general, effluent re-use will cause a lower equipment efficiency and increased downtime; in the final analysis, this may discourage more widespread following of the practice.

The agricultural re-use of effluent in the United Kingdom for irrigation during drought years is probably impractical, since the large sums of capital investment required for permanent distribution systems and storage would not be economic. In addition, public health restrictions and adverse effects - such as crop sensitivity to toxins - make re-use an unlikely alternative to winter abstraction and storage to meet irrigation needs.

7.6 Desalination

There is at present only one public water supply desalination plant in the United Kingdom, located on Jersey in the Channel Islands (28). It is used to meet peak demands caused by the influx of visitors during the summer. A smaller facility was in existence until recently at the Channel Tunnel, and was used to supplement water supplies provided by the Folkestone Water Company. This plant has now been decommissioned and sold.

In the early 1970's, there was a distinct prospect of desalination plant producing large quantities of cheap fresh water. Although the size of plants has increased, with facilities in Saudi Arabia capable of producing up to 800 Ml/d, the unit cost of water production has not fallen. Membranes for the reverse osmosis (RO) process have been developed to allow sea water to be demineralised at a lower energy cost than the established multi-stage flash (MSF) plant. Unfortunately, the semi-permeable membranes used in the RO process are expensive and, although reducing, this cost at present cancels out any energy savings made over the MSF process.

Energy is the main production cost component in MSF plant. Savings can be made by locating plants close to power generation facilities in order to take advantage of off-peak generation capacity and exhausted turbine steam. The heat generated from incinerating domestic waste can also be used to reduce fuel costs, and any income can be off-set against costs.

The capital and operation costs are not the only limitations on desalination. The plant must be able to receive a reliable supply of sea water at all times, while still maintaining good road access. In this country where large tidal ranges are experienced, this may require the construction of extensive intake works. Desalinated water has a very low concentration of dissolved salts and as such has an insipid and unpalatable taste. The water has to be mixed with water from conventional sources, and this entails pumping to existing storage facilities. In addition, disposal of the more concentrated brine effluent from desalination plants with minimal impact on the coastal environment can pose problems which are costly to overcome.

Costs for desalination have been extracted from a feasibility study undertaken on both a 50 Ml/d plant based upon desalination only, and on a combined power generation and desalination plant.

At present desalination does not appear to be a realistic alternative to conventional water resource strategies, except in special circumstances. Neither can it be described as an environmentally friendly solution to water shortages.

7.7 Costs of Local Options

Costs for groundwater and river abstraction schemes vary according to the location of the demand centre with respect to the source. Detailed estimates of Anglian groundwater developments listed in the NRA Section 143 Report (8) show unit costs of between £0.285m/Ml/d and £0.45 m/Ml/d for combined capital and amortised 30 year operation costs. The longer the life of the scheme, the more economic the water supply becomes. Costs were based upon 25m deep boreholes, each borehole yielding 3 Ml/d from chalk/limestone or 2 Ml/d from Sandstone. It has been assumed that in general treatment only by chlorination is adequate for groundwater, although it is acknowledged that some schemes now require additional processes. The length of the collection mains was assumed to be in proportion to the size of the scheme's yield. Further information is given in Annex C.

River abstraction costs depend greatly upon the level of water treatment required. All river abstractions are assumed to be lowland sources requiring sophisticated treatment including ozone disinfection and nutrient removal. The average unit cost for river abstractions is estimated to be £0.5m/Ml/d (12p/m^3).

Unit costs including distribution for strategically important surface water schemes vary between £0.55 million/Ml/d and £1.75 million/Ml/d (13-43p/m^3). The most expensive schemes are given as the Dee and Barrage, followed by the proposed bunded reservoir in the upper Thames Valley (£1.65m/Ml/d or 40p/m^3). Great Bradley reservoir unit cost has been assumed to be £1.5 million/Ml/d (36p/m^3) while that for Craig Goch is estimated to be £0.55 million/Ml/d (see Annex C, Table C1).

The updated value for the cost given in the Craig Goch feasibility study for a scheme with a yield of 1000 Ml/d is £150 million. The original estimate was made in 1971 during a period of high inflation, and therefore it was treated with caution. A more conservative estimate of £550m (£0.55m/Ml/d or 13p/m^3) was made, based upon more recent reservoir schemes; this is still low compared with other schemes, and reflects economies in scale.

Several planned re-use schemes, including Deephams STW in London and the Witham and Chelmsford developments in Essex, have been costed in detail. The average unit cost was approximately £0.7m to £0.8 m/Ml/d (20p/m^3). The unit costs varied only slightly due to the assumptions made regarding the water treatment required. The processes included:

	Treatment	Cost £m/Ml/d
•	ENECCO Sand Filter	0.04
•	UV Treatment	0.032
•	Activated Carbon	0.08

The type of treatment process required will depend upon the quality of the incoming water and the effluent dilution requirements of the watercourse. Since the treatment outlined is the minimum required, higher unit costs are to be expected.

Costing information for desalination is limited. The only plant currently in existence in the UK, on Jersey, is being used solely to meet peak demands during the summer months and therefore unit costs are not directly applicable. Data are available from the large desalination plants in Saudi Arabia, but unfortunately the cost of fuel, a major cost component of desalination, is not comparable with that in the UK.

Costs were eventually abstracted from a recent feasibility study of a 35Ml/d multi-stage flash plant. The unit cost, including capital and operation costs for the plant, has been estimated to be £3.65 m/Ml/d (89p/m^3) or, if the plant is combined with a power generation plant, £3.50m/Ml/d (85p/m^3). These costs include distribution of the water, but not the facilities required for blending.

The unit costs for local schemes are summarised in Table 7.1.

Table 7.1 Average Unit Costs for Local Options

Option	Unit Cost £m/Ml/d
Groundwater	0.35
River Abstraction	0.5
Reservoirs	0.55 - 1.75
Re-use	0.85
Desalination	3.50

Groundwater and river abstraction schemes are the cheapest source of supply, as expected. Reservoirs and re-use are sensitive to site location and therefore no conclusion should be drawn from the relative difference in cost.

7.8 Environmental Aspects of Local Options

7.8.1 Increasing Use Of River Water

There is doubtless considerable scope for further abstraction of river water to help satisfy increased demands as part of an intergrated resource programme. However, there is little scope for development of drought reliable sources without storage or alternative sources during times of low flow.

The most obvious environmental requirement in developing new resources is the protection of flows, for protection of downstream biota and water quality, maintenance of wetland habitats and protection of brackish water habitats in the estuary. Generally the most valid approach is that of a prescribed flow, below which abstraction must not reduce residual flows. Generally the prescribed flow will be higher than minimum natural flows; typically the Q95 flow is considered as a starting point. Several NRA regions have been developing guidelines for abstraction rules. South West has a system based upon Q95 plus a range of environmental weighting factors according to local conditions.

Generally, a prescribed minimum flow is a more meaningful and realistic concept than a minimum maintained flow or minimum acceptable flow (MAF). However, there are situations where a minimum maintained flow is a useful concept, eg where;

- the prescribed flow is lower than the naturally occurring minimum flow;
- river flows are highly unnatural, due perhaps to land drainage or mine pumping (eg Wear) or to regulation by very large main-stream reservoirs (eg Welsh Dee);
- other upstream abstractions have caused a reduction of low flows to below the natural minimum.

The implications of, say, a Q95 prescribed minimum flow in terms of storage or alternative sources vary with the type of river. Clearly no river would reliably experience flows of Q95 or less on the 18 days a year that the percentile suggests. Some years would produce no such low flows at all, while in drought years longer periods of such conditions may prevail. Perhaps the greatest extremes are shown by groundwater fed streams. For example, in the period 1975 to 1990, flows as low as the Q95 occured in only six of the 16 years on the Hampshire Avon. These were 1975 (16 days), 1976 (238 days), 1984 (38 days), 1987 (1 day), 1989 (80 days) and 1990 (95 days). The imposition of a Q95 prescribed minimum flow in such a situation would render the source of limited value during a drought, unless used conjunctively with another, storage-based, resource. This highlights the need for each situation to be judged upon local conditions and constraints.

While protection of low flows is clearly important in ecological terms, it is likely that it has dominated consideration of environmental impacts to the neglect of some other aspects. Flow and levels variation can be important in the maintenance of certain marginal habitats, and for the stimulation of movements of migratory fish. Rules limiting takes to 50% of the flow above a pmf, and temporary cessation of abstraction during minor spates, are concepts currently being examined to try and maintain some environmental variation.

Head of tide abstractions clearly offer considerable attraction in that any impact is limited to the tidal reaches of estuary. In many situations this can effectively reduce the impact to zero, as long as estuarial water quality can be protected. The needs of migratory fish entering the river may need careful protection in this situation, but there is likely to be scope for modulation of abstraction (eg 12 hours on, 12 hours off) to reduce impact. Further, it may be that a "window" of higher flows, when migratory activity is greatest, justifies protection to an even greater extent than very low flows. Modulated head of tide abstractions could thus be very valuable in providing water at very low flows as part of an intergrated resource scheme.

The greatest scope for further development of surface water resources, however lies with increased use of higher winter flows, which involves storage.

7.8.2 Increased Use Of Groundwater

The environmental problems associated with abstraction of groundwater are discussed in Section 4.5.3 Due to:

- an increased public awareness of the problems;
- increasing understanding of some of the more subtle impact;
- lowering thresholds of public acceptance of environmental changes;
- the likely requirement to reduce the impact of many existing groundwater sources,

it is concluded that little net increase in groundwater derived supplies can be foreseen. This is particularly the case in those areas where groundwater abstraction currently comprises a major part of supply, and where the greatest resource deficits are foreseen eg Southern, Thames, Wessex.

Although fraught with practical difficulties (see Section 7.1.2), artificial recharge of aquifers has considerable theoretical appeal, as there are likely to be general environmental benefits accruing from raised groundwater levels. The potential for discharge of partially treated sewage effluent to groundwater, such as takes place at Winchester and Whitchurch in

Hampshire, has considerable environmental merit. This is particularly so in "headwater" areas, where the alternative to local treatment by conventional means or by groundwater recharge is for the effluent to be taken by sewer out of the area for full treatment at a large works. The loss of up to 16 Ml/d of sewage effluent from the Misbourne valley once local treatment at Amersham stopped represented a major loss of flow in the river.

The conjunctive use of groundwater sources, especially if used to regulate stream flow for abstraction downstream, represents a more environmentally positive use of the resource than does direct abstraction. The Candover Scheme in Hampshire is of this type; abstraction near the tidal limit means that a considerable length of river benefits from enhanced flows at the times of lowest natural flows. Such schemes are not totally without adverse impact however, with flows being reduced during the period of natural recharge .

7.8.3 Provision Of More Storage

This represents a most attractive option in environmental terms, as it allows a whole range of measures to protect low river flows or other aspects of hydrology that are considered sensitive. River regulation, carefully controlled by appropriate operating rules, can represent a positive environmental enhancement - especially at times of very low natural flow. The streams below reservoirs, if properly managed, can become fascinating and productive habitats in their own right. In most situations, reservoirs represent a considerable bonus in terms of wetland habitat, habitat diversity, fishing and other recreation activities. Although there are often strong objections in reservoir developments from a vociferous few who perceive personal disadvantage, once established they are highly popular and greatly cherished locally. The general environmental bonus represented by such reservoirs and Chew, Blagdon, Burrator, Wimbleball, Grafham and Rutland is such that any proposal to revert them to farmland would be met with storms of protest. Chew and Blagdon, for example, are Sites of Special Scientific Interest and are considered of national importance in ornithological terms, with over 200 species of birds recorded. They afford excellent dinghy sailing, and the trout fishing is of international reputation.

Pumped storage to increase the reliable yield of reservoirs is also considered as an environmentally desirable development. Abstraction of winter flows is of minimal impact compared to the derived benefit of low flows being alleviated by adequate storage. Construction of pipelines from intakes to reservoirs can have an environmental impact, but careful routing and modern techniques of habitat restoration reduce this to a minimum. Pumped augmentation of existing reservoirs is being considered at various places at present, for example Chew Valley Lake and Wimblehall Reservoir.

7.8.4 Integration Of Sources

This logical development is to be welcomed in environmental terms, as it increases the scope for adjustment of abstraction from various sources to protect sensitive flows.

7.8.5 Re-Use Of Effluents

Again, generally this development represents a positive environmental benefit. It reduces the need for new resources, and the discharge of potentially polluting discharges. One of the most appealing developments is that of root-zone STW, producing very high quality effluents which can be discharged to small streams without significant impact. As an alternative to exporting the sewage downstream to large works, it means that more water is available to support the sensitive upper reaches of rivers.

7.8.6 Desalination

There are significant environmental disadvantages associated with desalination. Water is produced by the direct or indirect burning of fossil fuels, thus contributing to possible climatic change problems. The brine waste has a salinity of between 50 to 70 parts per thousand. Increased salinity and higher pH, due to high carbonate/bicarbonate concentrations in the brine cause internal plant corrosion and may lead to high metal (Aluminium, copper, zinc, iron) concentrations. Brine from distillation plant in addition will be about 15°C above the ambient sea-water temperature.

These factors can reduce the ability of organisms to survive and/or grow or reproduce in localised brine disposal areas. The impact of brine varies from species to species, but is likely to cause most serious problems to benthic organisms. Being denser than normal sea-waters, the brine has a tendency to sink to the bottom, forming a blanket from which sessile or slow moving organisms are unable to escape.

In planning a desalination plant, early consultation with the fishing industry is required to determine the least damaging brine discharge point. If the brine is released into an estuary, shell fisheries may be damaged; in addition high salinity and metal concentration could form a barrier to migrating fish.

8 OPTIONS INVOLVING TRANSFER OF WATER

8.1 Inter-Regional Transfers

8.1.1 General

Demand in the southern and eastern regions continues to rise, and local resources are already highly developed. Further such development will be constrained by the need to minimise adverse environmental impact. Thus, unless the upward trend in demand can be halted in the very near future, it will have to be met by importing water from outside these regions.

The schemes developed by the Water Resource Board (WRB) in the early Seventies to transfer quantities of water from the north east, north-west and Welsh regions should be re-evaluated in the light of present forecast shortages. In this section, five inter-regional transfer schemes are evaluated, and examples of how the water could be distributed are given. The schemes do not necessarily reflect the 2021 demand needs of the individual regions or the precise demand centres (see Section 9), but allow discussion of the potential for inter-regional transfer in England and Wales. The schemes discussed have been chosen as representative from a wider range of possibilities.

The mixing of waters from two different sources has an obvious consequence in terms of the mass-balancing of individual dissolved substances. If such transfers result in water being transferred into a river channel prior to its abstraction elsewhere, then the following points should be noted:

- changes in flow regime can lead to changes in re-aeration characteristics. Generalised quantitative statements cannot be made, because much depends upon the channel morphology relative to the typical range of flows conveyed, and the contributing effects of control structures, pool/riffle sequences and received discharges;

- the maximum concentrations of metals which are allowed by the EC Directive on the Quality of Freshwaters needing Protection or Improvement in order to Support Fish Life (78/659/EEc)(29) are dependant upon the associated total hardness. Care is required when considering transfer of a soft water into a naturally hard water, particularly if the latter is a designated fishery; the resulting decrease in hardness has the effect of making dissolved metals such as Nickel, Copper and Chromium more toxic to fish.

8.1.2 Severn-Thames Transfer

First proposed by the WRB 1966 Report(3), this shceme was the subject of a five year feasibility study published in 1980(30). It has fallen from favour due to its predicted high cost, the likely complexity of the scheme's management structure and the uncertainty of long term water demand forecasts made at the time. There were also concerns about water quality and impact on receiving waters, which persist despite being deemed surmountable following the feasibility study.

When first proposed, the project was an element of a larger scheme. The construction of a large new dam at the site of the existing Craig Goch reservoir was planned to provide regulation water for the Rivers Severn and Wye to meet demand growth in the river basins. The yield of the scheme was sufficient to allow transfer of regulation water from the Severn to the Thames via a new pipeline and associated intake and treatment works.

The Craig Goch scheme was investigated in 1974 by Sir William Halcrow and Partners (31) and it was calculated that the maximum yield was 1200 Ml/d if water was pumped from the Wye and Severn. The high forecast demand in the Severn and Wye basins did not materialise and the Craig Goch scheme was shelved.

An alternative source of water for the Severn-Thames transfer could be pumping of water to the Severn from the River Dee, supported by regulation releases from existing reservoirs in its catchment. The transfer could be made in the region of Oswestry. Such a scheme could be feasible if the forecast reductions in demand in North West region materialise. However, there have been no known studies into the feasibility of such a scheme.

The Severn-Thames transfer feasibility study (30) states that a total transfer of 690 Ml/d was available to the River Thames to be abstracted from the Severn above or below Tewkesbury. It was recommended that the scheme be split into three stages of development of 225, 225 and 240 Ml/d each, and that on economic grounds, water be transferred by pipeline instead of either canal or aqueduct.

The water could be discharged into the river Thames at Lechlade, the River Cherwell below Banbury or the River Evenlode.

Without the need to meet demands in the Severn and Wye basins, a significantly larger yield from Craig Goch would be available for transfer to the Thames basin and beyond. Figure 15 is a schematic representation of a possible transfer system using 1000 Ml/d to be yielded from Craig Goch or a similar mid Cambrian scheme. Water is transferred from the Elan Valley to regulate the River Severn for abstraction as follows:

Table 8.1 Illustrative Allocation of Craig Goch Yield

Location	Amount (Ml/d)	For Transfer To
Tewkesbury	500	R Thames at Lechlade
	100	R Cherwell
	100	R Gt Ouse
	50	R Nene
	150	R Welland
	900	
Gloucester	100	Sharpness Canal/Bristol

On the Thames, water would be abstracted at Oxford and London. Of the 500 Ml/d abstracted at London, 100 Ml/d would be passed by pipeline to the Upper Medway area of Southern Region. Water would be abstracted from the Great Ouse and Welland to enhance the yields of the Grafham and Rutland reservoirs, and would be distributed from these via the existing systems. Water would be abstracted on the Gloucester-Sharpness canal at Purton to meet the demand growth in the Bristol and north west Wessex areas.

The scheme's problems were identified by the 1980 feasibility study. They include:

- environmental impact of increased flows in rivers;
- water quality aspects;
- operation and management complexity of the system.

The pumping of water to the river Evenlode was thought to be unacceptable due to possible ecological damage caused by increased flows in the small river. In the Cherwell, flows would be limited and, to protect operation of existing land drainage schemes, there would be a requirement to widen and deepen the existing river channel. The ecology of both the Thames and the Cherwell would be changed directly downstream of the discharge points, but this effect would be limited.

Water quality problems may occur, particularly for abstractions from the Severn basin below the River Avon tributary at Tewkesbury. There may be a requirement to harden the Severn water artificially, especially if abstracted above the Avon confluence. Higher concentrations of persistent hazardous chemicals found in the Severn water, due to a higher level of industrial development than in the upper Thames, were not thought to be a risk to the public, since lower Severn water is regularly consumed in Bristol without reported problems.

Comments made in Section 8.1.1 regarding dissolved metals have given rise to the perceived need to harden artificially water from the River Severn before it can be transferred to the Thames catchment. The freshwater River Thames is designated under EC Directive 78/659/EEC(29) over its entire length, as are many of its tributaries, notably those which drain the Cotswolds including the Rivers Windrush and Evenlode. The proposed Severn-Thames transfer would also need to take account of the fact that the Thames is subject to a much higher degree of re-use than the Severn; this will have a direct bearing upon the pathways of any pollutants which may be "imported" into the Thames catchment as a result of the transfer.

The option of transfer into the River Cherwell below Banbury deserves special attention. The Cherwell suffers from the impact of the effluent from Banbury sewage treatment works, whose effects are exacerbated by

- the unusually shallow gradient (<0.0001) of the Cherwell valley, and

- the high degree of aquatic macrophyte growth in the summer, which increases the "roughness" of the channel, and leads to retention times of the order of 3 days in the reach between the effluent discharge and the cross-over point of the River Cherwell itself and the Oxford Canal.

Clearly any proposal to increase the flow in the Cherwell would need to be studied in the light of the possibility of flooding, and it may be necessary to cut back much of the vegetation in the summer, in order to increase the water velocity and lower the water surface elevation. Besides significant adverse general environmental impact, this would reduce the amount of photosynthetic oxygen production, which in turn would reduce the Cherwell's ability to absorb the impact of the sewage effluent, notwithstanding the additional dilution which this would receive. Essentially, the option to transfer into the Cherwell is, of those proposed, the one most fraught with potential water quality problems, and would require very sophisticated analysis.

The operation and management of the transfer system would be complex and would involve the NRA, Dŵr Cymru, Severn Trent Water and Thames Water, but the problems are not unique and should not be insurmountable. If any new scheme went ahead, Thames Water Utilities Ltd as principal beneficiaries, would probably have to fund most of the costs associated with both the transfer pipeline and the enlargement of Craig Goch. There may be some reluctance on their part to invest in such a large capital cost scheme whose operational control would probably be vested in the NRA.

The capital cost of a Craig Goch reservoir capable of yielding 1000 Ml/d has been assumed to be £500 million. This compares with a cost of £150 million derived by updating the estimate presented in the Halcrow feasibility report. The difference between these two figures reflects the uncertainty of estimates made during the 1970's, and the additional operating costs. The reservoir cost has been apportioned pro-rata to each transfer. A full breakdown of costs is given in Annex C and the unit cost of water delivered to different locations is shown in Table 8.2.

Table 8.2 Craig Goch Transfers and Costs

River Location	Volume Transfer Ml/d	Unit Cost £m/Ml/d
Thames	500	1.3
Cherwell	100	1.5
Ouse	100	1.9
Nene	50	2.3
Welland	150	2.3
Southern Transfer	100	2.4

N.B. These costs include for Craig Goch (£0.55m/Ml/d)

8.1.3 Trent-Witham Transfer and Ely Ouse-Essex Scheme

The River Trent represents a significant resource in the centre of England. At present, only limited abstraction for public water supply occurs in the upper Trent, although the power industry abstracts large quantities for cooling water, most of which is returned to the river locally. Water is transferred to north Lincolnshire via the Trent-Wicham-Ancholme scheme, mainly for industrial use in Scunthorpe and Grimsby. The demand of the north and east Midlands is met from abstractions and storage on the Rivers Dove and Derwent, which drain the Peak District.

As discussed in Section 5.2.3, the water quality in the Trent was subject of a WRB research programme in 1973 (16), which could not recommend it be used for public water supply. Although there have been improvements in the river's condition, and the water is now used for potable supply in the Scunthorpe area, it requires dilution and blending before public use.

The new scheme proposed is to link two existing schemes - the Trent-Witham Link and the Ely Ouse-Essex scheme - and transfer up to 500 Ml/d from the Trent to the Anglian and Thames regions. Some water could also be transferred on into Kent (see Section 8.1.4).

Provision has already been made in Stage I of the Trent-Witham scheme to transfer 136 Ml/d to the Foss Dyke Canal and River Witham from the River Trent via Torksey Pumping Works. Water is pumped from the Witham to the Toft Newton Reservoir and released into the River Ancholme, Lincolnshire. The Ancholme is regulated up to a flow of 118 Ml/d to feed abstractions for industrial and public water supply use in Scunthorpe and Grimsby. The works have been planned and constructed to allow for expansion to Stage II with regulated flows of up to 182 Ml/d in the River Ancholme.

The existing NRA Ely Ouse-Essex scheme transfers a maximum of 360 Ml/d from the Cut-Off Channel at Blackdyke via a 2.5m diameter tunnel and a 1.8m diameter pipeline to the River Stour and, by regulation and pipeline, to the Rivers Colne and Blackwater. Abstractions from these rivers already feed Abberton and Hanningfield reservoirs and could also feed Ardleigh. Transfer of flow is at present constrained by the availability of water in the Ely Ouse system.

A groundwater augmentation scheme has recently been developed in the upper reaches of the River Thet, which helps boost the Ely Ouse-Essex transfer yield to approximately 350Ml/d.

The potential yield of the Trent at Torksey is not known, although it is believed to be substantial. Based upon the Q95 flow on the lower Trent (2560 Ml/d at North Muskham) and indirect transfer of Welsh Water (approximately 360Ml/d from the Elan Valley), a yield of 500Ml/d was chosen as an acceptable level of abstraction which should not cause an adverse environmental impact. Of this, 180 Ml/d would be used to regulate the River Ancholme and 320 Ml/d to regulate the River Witham (see Figure 16).

As shown on the figure, at King's Lynn 50 Ml/d would be transferred to the River Wensum at Fakenham and then be abstracted at Costessey for use at Norwich. A flow of approximately 20 Ml/d regulates the River Witham at present, and it is assumed that this flow is abstracted at Boston. The remaining 250 Ml/d would be pumped via a new aqueduct to the Ely Ouse, to connect with the Ely Ouse-Essex transfer.

To transfer the combined flow of 250 Ml/d and the existing 350 Ml/d from the Ely Ouse to the River Stour, extra pumping facilities and a new tunnel and pipeline would be required in order to maintain velocities below 1.5 m/s.

A new storage facility would be required in the headwaters of the Stour, to allow for blending of waters, regulation of the rivers Stour, Colne and Blackwater and a transfer to the Lee Valley. The Essex River Authority in the 1960s commissioned a feasibility study of Great Bradley reservoir on the Stour, and estimated that, in combination with the existing Ely Ouse-Essex system, the reservoir yield would be 200 Ml/d. This scheme is at present being reconsidered as an option to meet the demands of Suffolk and Essex. The yield of the reservoir combined with flows of 600 Ml/d from the Ely-Ouse system has been calculated to be 800 Ml/d.

The example scheme (Figure 16) shows transfer of 350 Ml/d split between the rivers Stour, Colne and Blackwater plus an additional 100Ml/d transferred to the Blackwater to feed a proposed Essex-Kent transfer (see section 8.1.4). The remaining 350Ml/d is transferred to the River Stort and the water would flow into the River Lee, where it would be abstracted and stored in the existing reservoir system.

The unit cost for the various transfers is shown below in Table 8.3.

Table 8.3 Trent-Witham Transfers and Costs

River/Location	(Additional) Volume Transferred Ml/d	Unit Cost £m/Ml/d
Ancholme	62	0.9
Wensum	50	1.3
Stour	250	1.3
*Stort	350	3.0
Essex-Kent transfer: *Blackwater-Broad Oak	100	4.0

* These costs include for Great Bradley reservoir

This scheme would provide water to meet the growth in demand anticipated in North Lincolnshire, supply the rapid growth areas in Essex, thereby reducing Essex's reliance on the Thames Region for supplies, and provide additional resources for London.

8.1.4 Essex-Kent Transfer

Figure 16 shows the 800 Ml/d yield from the proposed Great Bradley/Ely Ouse-Essex System. A surplus of say 100 Ml/d could be available for transfer across the Thames Estuary to Kent.

The shortfall in resources in the Southern region for public water supply is forecast to reach 281 Ml/d by the year 2021. One proposal to meet part of this shortfall is for a new reservoir to be built at Broad Oak in Kent, which would have an estimated yield of 70 Ml/d. The proposed transfer scheme would release water into this new reservoir, increasing its yield to 170 Ml/d. This scheme is illustrated diagrammatically in Figure 17.

The proposed transfer initially utilises the existing 1.68m diameter pipeline which at present regulates the River Colne and River Blackwater from a pumping station at Wixoe on the River Stour. The regulated River Blackwater has an existing abstraction point above its tidal limit at Maldon, from which water is pumped into Hanningfield Reservoir. This intake and pumping station could be extended to provide transfer facilities for a new pipeline, approximately 60km long, which would outlet into Broad Oak Reservoir or one of the streams above it.

The proposed route of the pipeline runs from Maldon to the coast east of Southend-on-Sea before crossing the Thames Estuary to the Isle of Sheppey. Following the crossing of the Swale Estuary, the pipeline would outlet into Broad Oak Reservoir after crossing the higher ground to the north-west of Canterbury.

The governing factor for choosing an economic pipeline route is the cost of the off-shore section of pipeline. Transferring water from the River Blackwater gives a reasonably direct pipeline route to the Broad Oak Reservoir with an estuary crossing of approximately 14km. This estuary crossing distance could be reduced still further by increasing the length of pipeline across land dramatically. This warrants further cost benefit analysis for the different envisaged routes.

Estimated costs associated with the Essex-Kent transfer are given in Table 8.3 above.

8.1.5 Vyrnwy Supply Redistribution Scheme

It is estimated that the North-West Region has at present a resource surplus, including imports, of 293 Ml/d. This is likely to grow in the future to an estimated 540 Ml/d (Table 4.7). The trend can be explained by a falling regional population and proposed implementation of active leakage control measures.

The region has historically received water from the Severn catchment, with 210 Ml/d being transferred from the Vyrnwy reservoir to Merseyside. The North-West redistribution scheme proposes that allocation of this water reverts back to the Severn system and either present resources in the North-West are redistributed or new resources are developed.

The available new sources of water in the Merseyside area include the possible full development of the Dee estuary barrage, which according to the WRB reports would yield 200 Ml/d (4), or the utilisation of the River Mersey. The water quality of the Mersey in the 1985 DoE Water Quality Survey (11) is classed as poor. However following the efforts of North-West Water to clean up the river, abstractions close to Davy Hulme sewage treatment works in Manchester may be possible in the future (see also Section 5.2.3).

The Vyrnwy water could be used to regulate increased abstractions from the Severn, either to meet the demand in the West Midlands or to be transported to the Thames via the Severn-Thames transfer scheme (see 8.1.2 above). Water could also be transferred to the upper Trent to improve quality standards and allow abstractions for public supply use. The scheme shown in Figure 18 indicates how the water could be transferred via the canal system to the Rivers Thames, Nene and Ouse as an alternative to pumping water from the Severn in the Severn-Thames transfer scheme.

In the proposed scheme shown, the 210 Ml/d from Vyrnwy would be abstracted at Telford, from where the water would be piped to the Trent and

Mersey Canal near Stafford. The canal would act as an open conduit transporting water to Fazeley Junction, where it would be overpumped to join the Grand Union Canal at Solihull. The water would be abstracted again at Leamington and transferred to the Oxford Canal. From this point, 100 Ml/d would progress down the canal to Oxford, with 55 Ml/d being transferred to regulate the Nene and 55 Ml/d being pumped to the Great Ouse at Bedford.

The route bypasses any sections of canal with a reverse flow or large flights of locks. The problems involved in water transfer by canal include:

- additional freeboard to accommodate hydraulic gradient;
- restriction of flows into canal balancing system;
- overpumping large flows around locks;
- pollution;
- leakage.

It has been calculated that to allow passage of 210 Ml/d down a level, 1.5m deep and 3.0m wide canal an additional freeboard of 0.09m/km would be required in order to accommodate the hydraulic gradient needed to provide the necessary flows.

The unit costs are given in Table 8.4.

Table 8.4 Vyrnwy Transfers and Costs

River/Location	Volume Transferred Ml/d	Unit Cost £m/Ml/d
Cherwell	100	3.7
Ouse	55	4.35
Nene	55	5.25

N.B. Costs include for a Dee Barrage (£1.75M/Ml/d).

8.1.6 Kielder - Anglian Region

The Kielder reservoir was completed in 1982. It was originally planned to meet the estimated industrial and public water supply deficiencies in the conurbations of Newcastle and Teeside in the North-East region. These shortages did not materialise and the potential yield of 900 Ml/d of Kielder represents a massive undercommitted resource.

At present the reservoir is used mainly to meet the compensation requirements of the rivers North Tyne, Derwent, Wear and Tees, although in 1989/90 public water supply needs dominated the release pattern.

Regulation water released into the Tyne from the reservoir is abstracted at Riding Mill and pumped to a balancing pond, from which there is a tunnelled gravity feed to the rivers Derwent, Wear and Tees. The present capacity of the Riding Mill pumping station is 546 Ml/d and the 2.9m tunnel allows transfer of up to 1180 Ml/d. The 1970 WRB studies considered a further connection between the river Tees and Swale with regulation of the river Ouse in order to meet forecast demands in Yorkshire. The predicted water deficits were again inaccurate and up to the present time such a scheme has not been warranted.

Figure 19 shows a possible development of the Kielder transfer scheme which would meet all the demands in Northumbria and supply water to North Lincolnshire and Essex and Suffolk via the Ely Ouse-Essex system.

The plan presupposes that at present 100 Ml/d of Kielder water is required in Northumbria Region to meet public water supply demands in the event of a drought. Demand growth of approximately 210 Ml/d in Northumbria by 2021 is also met from Kielder, being equally split between the three main catchments. As shown on Figure 19, the remaining 590 Ml/d is passed to the Swale and the Yorkshire Ouse, and then pumped via North Lincolnshire to the River Witham, supplying Grimsby and Scunthorpe en route. Eventually 410 Ml/d would be transferred via the Witham to Essex and London via the Ely Ouse-Essex system (see Section 8.1.3).

The Kielder-Anglian Region transfer scheme presents a possible problem arising from the differing pH of the Kielder and Swale waters. The acidity of a water, measured in terms of pH, is significant on two counts:

- both upper and lower limits are prescribed for pH in the so-called EC Fish Directive 78/659/EEC(29);
- pH is a major factor in determining the toxicity of fish of ammonia, which is a component of sewage effluents and agricultural runoff. The precise relationship is defined as a function of pH, temperature and total ammonia concentration.

A lowering of pH results in a decrease in the proportion of ammonia which is present in the non-ionised (as opposed to the ionised) form; since it is the non-ionised component which is toxic to fish, this toxicity is thereby reduced. However, if the water has a natural pH of about 6, any further lowering can lead to a contravention of the relevant limit in the EC Fish Directive. pH balance is a delicate issue, which, if significant in the case of the various Kielder transfers, would require detailed scrutiny.

The capital and operational cost of the Kielder-Anglian Region scheme is estimated at £1147M. The unit transfer costs are given below in Table 8.5.

Table 8.5 Kielder Transfers and Costs

River/Location	Volume Transferred Ml/d	Unit Cost
Swale	590	1.0
North Lincolnshire	180	1.5
Witham	410	1.8

The costs of the scheme depend greatly on the price charged by the NRA for water from Kielder reservoir, since there will be a need to recognise a proportion of the capital investment tied up in the reservoir. In the immediate future a River Tees - Swale link is unlikely, since demands in Yorkshire can at present be met by local resources.

8.2 A National Water Grid

The idea of a National Water Grid as a method of transporting water from areas of surplus to the deficit regions dates from the 1940s. In 1942, inspired no doubt by the great Roman aqueducts of southern Europe, John Frederick Powell developed the idea of an elevated canal system linking the major population centres and ports of England (32). Known as the Grand Contour Canal, it was a system of level canals at 310 feet above Ordnance Datum which would be used principally for commercial transport but could act as a reservoir with a capacity of approximately 168,000 Ml. The scheme was not taken up, due to the scale of investment required.

People's perception of a water grid differs. To some it is a combination of aqueducts, pipelines and regulated rivers, similar to the system proposed by WRB in the seventies, while to others it is a widespread network of large pipelines linking every part of the country distributing either treated or untreated water. For this study, since river transfers have been addressed elsewhere (Section 8.1), the piped system definition has been chosen.

As a starting point, only the skeleton of the grid has been suggested (see Figure 20). Further branches could be attached to this initial building block when the need arises.

The main ring of the grid is defined by the cities of Birmingham to the west, Cambridge to the east and Bristol and London in the south. Connected into the ring are an east coast main transferring water from the Kielder reservoir and a west coast main bringing surplus water from the North West region. In the west a new aqueduct connects an enlarged Craig Goch reservoir with Birmingham. Spur mains from the cities of Cambridge, London and Bristol would feed Suffolk and Essex, Southern Region and Wessex Region respectively. Norwich is fed from a spur off the east coast main at Peterborough.

The grid is composed of mainly new aqueducts and pipelines, and its path has been chosen so as to minimise the variation in pipeline elevation. It is appreciated that in selecting a route, there is an optimum balance between the capital cost of the pipeline and the revenue costs of pumping to overcome static and friction head. However, it has not been possible within the limitations of this study to carry out detailed investigations.

The grid has been designed to meet the forecasted base case deficits in 2021.

Anglian	-421 Ml/d
Thames	-951 Ml/d
Southern	-281 Ml/d
Wessex	-265 Ml/d
TOTAL	1918 Ml/d

The deficit in the South West Region of 90 Ml/d has not been included, since it is assumed that it will be met by local resource development.

The main sources of water for the grid to meet these deficits are:

Kielder Reservoir	793 Ml/d
North-West regional surplus	550 Ml/d
Enlarged Craig Goch scheme	575 Ml/d
TOTAL	1918 Ml/d

The small resource surplus in Yorkshire has been discounted and the surplus in Wales is believed to be too fragmented to be easily utilisable.

Treated water would be distributed, although this would entail water being disinfected more than once and leakage costs would be higher. However, it would minimise the problems caused by biological growth and the production of noxious gases, and thereby improve the operational efficiency of the system. In addition, in distributing treated water the grid can be integrated into present distribution systems, alleviating the need for construction of a large number of treatment works.

Birmingham would be the natural hub of the grid receiving water from the North West and Craig Goch. At 140m AOD it is the highest city on the grid. Water would be distributed from Birmingham to the south and east.

To the south, 450 Ml/d would be transferred to Bristol with 265 Ml/d passing on to Bournemouth and the remaining 185 Ml/d being transferred to the upper Thames Valley.

In the east, 675 Ml/d would be transferred to the east coast main at Cambridge.

The 793 Ml/d from Kielder would travel down the east coast main, supplying Norwich with 150 Ml/d and Ipswich and Essex with 271 Ml/d. The remaining 372 Ml/d would join the 675 Ml/d from Birmingham to supply Greater London with 766 Ml/d and Southern region with 281 Ml/d.

The capital cost of the grid has been estimated at £7594 million and the amortised 30 year operational costs at £509 million totalling £8295 million. The unit cost for the national grid is estimated to be £4.3 m/Ml/d (£1.04/m^3).

8.3 Water From Europe

The French already export electricity to the UK's National Grid and, with French investment in the UK water industry, importing water in bulk has been considered. Enquiries on the French side in the Pas de Calais region suggest that there is at present a small surplus of developed resources; however, with the area being declared an economic zone, this water will be required to supply new industrial and commercial developments associated with the Channel Tunnel.

Therefore, if any transfer scheme is to be feasible, further water resource development in the Pas de Calais region of France will be needed. Generally, the water industry in France has a similar resource distribution problem to the UK, with a relatively water-rich north and water poor south. It has therefore been assumed for the purposes of this study that, if water were available for export from France, it would be obtained by means of a new groundwater abstraction scheme from chalk in the Artois Region. A nominal source output of 100 Ml/d has been assumed.

This development would have to be guaranteed by the French authorities for transfer to Kent even in times of drought, which could be politically sensitive; France suffered a major drought in 1989-90 with consequences exceeding the two previous droughts in 1947 and 1976. Severe environmental damage was caused in the southern region, with up to 3,000km of river bed drying up, and extensive fish mortalities (33).

The major cost of the transfer scheme would be the laying of a 42km long, 1.2m diameter pipeline, across the English Channel. A price of £126 million has been estimated for this. The estimate is based on information from a major offshore pipe laying contractor.

Extensive land pipelines will also be required to transport water from the borehole sites in France and to distribute the water to suitable receiving points in Kent. It has been assumed that 50 Ml/d of the new resource will directly supply developments in the Ashford area following opening of the Channel Tunnel, with the remaining 50 Ml/d being used to regulate the Great Stour below Ashford. The proposed new Broad Oak pumped storage reservoir could be used either conjunctively with the new resource or could be augmented by it.

The combined capital and operating cost of the above scheme to bring water from France, calculated in accordance with the cost function in Annex C, is £245m, or £2.45m/Ml/d. However, it should be noted that this figure excludes abstraction charges which the French authorities may levy. A charge of £10/Ml would increase the overall cost to £249m present value (£2.49m/Ml/d or 60p/m^3).

The corresponding figure for an abstraction charge of £100/Ml is £286m (£2.86/Ml/d or 69p/m^3).

8.4 Transfer by Ship

The two options included under this title are the shipping of treated water and the towing of icebergs from Arctic waters. The destination of water obtained by either option would be the south-east and southern ports of England, between Harwich and Southampton.

Northumbrian Water Group plc have developed the capability to ship either untreated or treated water from a dedicated loading facility at Teeside. The company have the capacity to supply up to 45 Ml/d treated and above 70 Ml/d untreated water using vessels of up to 80,000 tonnes. Although they have not undertaken shipment within the United Kingdom, during the Eighties they successfully shipped water to Gibraltar while the colony's border with Spain was closed.

The feasibility of water shipment depends upon the size and frequency of the vessels being operated, and the handling facilities at the destination port. In general, the larger the vessels used, the more economic the option becomes, but there will be a limitation on the ultimate size due to the docking capacity available. In Saudi Arabia a feasibility study was undertaken in 1987 (34) to compare the cost of shipping water from Sudan with the cost of water from existing desalination plant. Based upon the purchase of seventeen supertankers and the construction of a pipeline from Lake Victoria to Port Sudan, the cost of supply of 910 Ml/d, equivalent to the Jubail desalination plant, was \$0.29/m^3 (1985), which was eight times cheaper than desalination. The shipping option was not taken up, due probably to the sensitive political situation in the area and the possibility of supplies being cut off in the event of war; however, the example demonstrates the possibility of economic schemes being designed for large deficits if facilities in the supply and destination ports are able to receive these very large vessels.

To transfer the water from the docks, pipelines would need to be laid, linking handling facilities to storage reservoirs. In the south-east this may not be a problem, since reservoirs exist close to the coast, but in the south and south west pumping to inland storages may be impractical and reservoirs may have to be constructed.

Northumbrian Water have produced a rough budget cost of supplying treated water to the port of Harwich. Using a 40,000 tonne vessel with a round trip time of five days, the unit price would be approximately £5.00/m^3 (£5,000/Ml) This estimate could vary according to the season, the availability and basis of hire of ships, and insurance costs.

The harvesting of the fresh water contained within icebergs by towing them from Arctic waters is an option which has a certain media notoriety. Although theoretically feasible, any scheme would be fraught with difficulties and does not make economic sense when compared with using tankers. The problems and limitations include:

(a) return journey distances and times;

(b) multiple vessels requirements to manoeuvre the iceberg;

(c) need for secure towing anchorages;

(d) limitations on size of iceberg that can be received into UK ports due to the large drafts, and thus the necessity for offshore handling;

(e) the physical dismantling of the iceberg.

The iceberg option is thus considered not viable and has not been costed.

8.5 Costs of Transfer Options

The total estimated costs, including capital and amortised 30 year operational costs for the five transfer options described in Section 8.1 are shown in Table 8.6. Detailed costs given in Annex C.

Table 8.6 Estimated Costs for Transfer Schemes

Transfer Scheme	Total Cost £m	Capital Cost £m	Operational Cost £m
Severn-Thames	1630	1193	437
Trent-Witham/Ely-Ouse-Essex	918	665	253
Essex-Kent	116	94	22
Vyrnwy-reallocation	889	661	228
Kielder-Anglian Region	1150	557	593

Unit prices for all the transfer options are summarised in Table 8.7.

Table 8.7 Unit Cost Prices for Transfer Options

Option	Yield	Unit Cost	
	Ml/d	£ m/Ml/d	p/m³ +
Inter-regional transfer schemes (all)	2164	2.1	51
National Grid	1918	4.3	104
Transfer from Europe*	100	2.9	70
Water Shipment	40	20.5	500

* subject to availability + £m/Ml/d x 0.243 (see Annex C)

The unit costs of the individual transfer schemes vary according to the location of the demand centre with respect to the source. Unit costs are detailed in Section 8.1 and range from £1.0m to £5.0/Ml/d. The cost of the transfer from France to Kent, including an abstraction charge of £100/Ml, is comparable with water transfer within the country.

All transfer schemes and the National Grid option have been costed based upon continual operation. If the transfer options were used to meet peak demands only, by operating for, say, 25% of the time, then the unit cost as shown in Table 8.7 would increase by more than threefold.

8.6 Environmental Aspects Of Transfer Options

8.6.1 Inter-Regional Transfers

Detailed consideration of the impacts of individual transfer proposals is beyond the scope of this report. However, a number of general principles can be considered.

Transfers do of course have the potential for considerable environmental impact. These include water quality effects of mixing waters from quite different catchments, and the potential for transfer of flora and fauna, as well as the impact normally associated with river regulation eg sudden changes in flows, maintained very high flows in small watercourses, and temperature effects. However, with careful planning and operation there is no reason why any of these is inherently insuperable.

In respect of alleviation of local over-abstraction, the balance may well be in favour of the transfers in environmental terms. Further, as the yield of some of the major transfers is very large, it could be considered that concentrating impact in a few areas, where it may be throughly evaluated and, with good planning, ameliorated, may be preferable to a large number of smaller schemes with more diffuse, but possibly greater, overall impact.

In conclusion, it is suggested that there is no over-riding environmental problem inherent in transfer schemes, but that very thorough analysis of potential impact is essential at the earliest planning stages.

8.6.2 Other Transfer Options

The other transfer options - national water grid, water from Europe and transfer by ship - all have scope for environmental impact depending upon how they are executed. However, none poses any insuperable problems and a decision on their viability is likely to be based upon factors other than environmental impact.

9 REGIONAL REVIEW OF STRATEGIC OPTIONS

9.1 The Country as a Whole

Chapters 3 and 4 of this report describe the forecast demands for water and the reliable yields of existing supplies. Chapter 4 concludes with an estimate of forecast surpluses and deficits. Chapters 5 to 8 of the report consider a wide range of schemes for increasing the drought reliable yields of water supplies or for reducing the demand for water. The purpose of Chapter 9 is to show how combinations of the various possible schemes can be put together to meet the forcast deficits. The objective is to show the range of strategic options which are likely to be feasible, rather than to make specific recommendations. The chapter is sub-divided on a region-by-region basis, but this first section considers the situation in the country as a whole.

Table 9.1 summarises the forecast deficits in 2021, assuming water UFW targets are met.

Table 9.1 Forecast Public Supply Deficits in 2021 With and Without Metering (Ml/d)

	Demand 2021	Yield Ml/d	Surplus/Deficit without Metering	Unmeasured demand (% of total)	Surplus/ Deficit with Metering (10% saving on unmeasured demand)
Anglian	2589	2168	-421	57	-273
Nothumbria	1301	2094	+793	50	+858
N-W	2317	2867	+550	50	+666
S-T	2649	2779	+130	48	+257
Southern	1736	1455	-281	48	-198
South West	687	597	-90	58	-50
Thames	5076	4125	-951	65	-621
Welsh	1281	1495	+214	41	+266
Wessex	1307	1042	-265	55	-193
Yorkshire	1583	1596	+13	39	+75
Totals	20526	20218	-308	54	+800
Totals for regions in deficit			-2008		-1270

Demand forecast from Annex B, Table B10. Yield figures from N.R.A. Section 143 Report (8). Percentages of unmeasured demand from Annex B, Table B1.

Table 9.1 shows the forecast deficits for base case average daily demands, with and without metering. As described in Section 6.2, it has been assumed that water metering would reduce previously unmeasured demands by 10%.

Various conclusions can be drawn from Table 9.1:

- although, for the country as a whole, reliable yields and demands will almost balance in 2021, there are big differences between regions;

- without water metering, there will be a total deficit of 2008 Ml/d in the five regions of deficit, Anglian, Southern, South West, Thames and Wessex;

- the introduction of water metering would reduce the total shortfall in the five regions of deficit to 1270 Ml/d, assuming a 10% reduction in previously unmeasured demand. However, all of these five regions would remain in deficit.

For England and Wales as a whole, the forecast deficit on average daily demands in 2021 is only 308 Ml/d, and, with the introduction of water metering, there would be a forecast surplus of 800 Ml/d. If seasonal demand peaks are taken into account, the resource balance moves further into deficit. For example, if it is assumed that, with metering, demand peaks are constrained to 1.15 x average, and that average resources output can be increased by 10% to meet such peaks, the 800Ml/d surplus becomes a deficit of 90Ml/d. Without metering, both the base demand and the peaking factor would be higher.

Earlier sections of this report have highlighted the importance of leakage control and general 'good husbandry' of water resources. This must be the general starting point for a strategic response to demand growth.

Table 9.1 shows that, unless the policy on metering changes, between 39% and 65% of water supplied to customers (ie excluding UFW) will still be unmetered in 2021. However, more information is needed on the water savings and costs relating to metering before its place in the "good housekeeping" approach can be determined; Table 6.7 shows that units costs are very sensitive to assumptions made about water saved. Nevertheless, its potential effect on demand peaks very useful.

With or without improved "housekeeping" and water metering, significant further resource reallocation and/or development is required. It is unlikely that local options will be sufficient in themselves, so that schemes which allow the transfer of water from the regions of surplus to the regions of deficit may be needed.

Water could be transferred to the southern and eastern parts of the country by means of several intercatchment transfer schemes which have been described in Section 8.1:

	Transfer Yield (Ml/d)
Craig Goch and Severn Thames Transfer	1000
Trent-Witham, Ely Ouse Scheme	364
Vyrnwy Redistribution	210
Kielder - Anglian Region Transfer	590
Essex-Kent Transfer	-
Total	2164

These major transfer schemes can meet the projected deficits in 2021, but with little to spare. Therefore, it is likely that the optimum solution for the regions of deficit will involve striking a balance between local schemes and inter-regional transfers. The strategic options available for each region are discussed further in the remaining sections of this chapter.

The licensed abstractions and uptake volumes for private supplies, broken down into usage, types are given in Table 9.2.

Table 9.2 Forecast Private Abstractions for England and Wales

Use	Present Situation		Forecast Uptake		
	Lic'abst Ml/d	Uptake Ml/d	2001 Ml/d	2011 Ml.d	2021 Ml/d
Industry	43,353	9,627	10,662	11,775	13,007
Agriculture	820	355	391	432	478
Irrigation	690	315	502	604	735
Others	16,978	3,556	3,928	4,339	4,793
Total	61,841	13,853	15,483	17,150	19,013

Upper bound forecasts from Annex B, Tables B2, B3, B18 to B25.

The overall growth in private abstraction by 2021 is 3,530 Ml/d, the largest proportion of which (66%) is by private industrial abstraction.

9.2 Anglian Region

9.2.1 Public Water Supply

Table 9.3 Resource Surpluses in Anglian Region

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Base Case	+82	-178	-421
Upper bound	-19	-384	-716
Lower bound	+217	-3	-172

Demand forecast from Annex B, Table B10 and B16.

The forecast deficit in 2021 is 421 Ml/d, but this could vary in the range of 172 Ml/d to 716 Ml/d.

In the Anglian Region, the Rivers Slea, Hiz, Hoffer Brook and Upper Waveney are known to suffer from problems of low flows due to abstraction. It has been estimated that these problems could be avoided by a cut-back in abstraction of 17 Ml/d. Allowing for such a reduction, the base case forecast deficit in 2021 rises to 438 Ml/d.

The range of options available for the Anglian Region are listed in Table 9.4 and illustrated on Figure 21.

Table 9.4 Strategic Options for Anglian Region

Scheme	Potential Yield (Ml/d)	Cost £m/Ml/d
Local Schemes		
Groundwater schemes	480	0.4
Chelmsford effluent re-use	40-50	0.8
Great Bradley reservoir	200	1.5
Wash barrage	450	1.8
Grafham pumped augmentation	75	0.5
Sub-total	1250	
Transfer Schemes		
National grid	>438	3.6
Craig Goch & Severn Thames	300	2.3
* Trent-Witham, Ely Ouse-Essex	364	1.3
Vyrnwy Redistribution	110	6.4
Kielder - Anglian Region	590	1.8
Water Metering	74-221	9.3-3.1

* Excludes Costs For Great Bradley

Section 5.1 of the report has shown that the 2021 level of demand would be approximately equal to the total available regional resources under drought conditions. Therefore, the scope for local schemes is likely to be less than is suggested in Table 9.4. It seems most unlikely that the postulated yield of 480 Ml/d from local groundwater schemes can be realised without environmental damage, although NRA remain of the view that additional groundwater resources are available in some parts of Anglian Region. For present purposes, therefore, the yield of such resources has been written down. Also, the Wash barrage scheme, which would be reliant upon water resources from catchments within the Anglian region, is likely to be fraught with environmental problems.

The three remaining local schemes - re-use of effluents, Great Bradley reservoir and pumped augmentation of Grafham - would each provide significant yields at comparatively low cost and would seem worth pursuing.

These and 160 Ml/d of groundwater development could together provide some 485 Ml/d - sufficient for the lower bound and base case 2021 forecast deficits, but not for the upper bound. Metering would reduce the upper bound deficit to 10-157Ml/d. If Great Bradley were not to proceed, then it is marginal whether the base case could be met, assuming metering is introduced and reduces previously unmeasured demand by 10%. Some transfer scheme should therefore also be addressed.

Of the inter-catchment transfer schemes, either Craig Goch and the Severn Thames transfer, the Trent-Witham/Ely Ouse-Essex scheme or Kielder-Anglian transfer would be capable of meeting all the deficits. Of these, the Trent-Witham/Ely Ouse-Essex scheme is cheapest, followed by the Kielder scheme. However, it should be noted that in this analysis financing costs for Kielder have not been included.

The Craig Goch scheme appears slightly more expensive; on the other hand, the Craig Goch resource can also supply the Thames and Southern regions and may well be better used in that way. The Trent-Witham/Ely Ouse-Essex scheme, which is being actively pursued at present, would appear to be the most attractive inter-regional transfer scheme for the Anglian region.

9.2.2 Private Abstraction

The licensed abstractions and uptake volumes for private supplies, broken down into usage types, are given in Table 9.5. Anglian were the only region to be able to provide forecasts of private abstraction growth.

Table 9.5 Anglian Region Private Abstraction Forecasts

Use	Present Situation		Forecast Uptake		
	Lic' abst Ml/d	Uptake Ml/d	2001 Ml/d	2011 Ml/d	2021 Ml/d
Industry	513	297	356	391	432
Agriculture	68	17	18	20	22
Irrigation	352	145	274	297	322
Others	0	0	0	0	0
Total		459	648	708	776

Upper Bound forecasts from Annex B, Tables B2, B3, B18 to B25

Overall growth in average year uptake is 317 Ml/d, of which the vast majority is for irrigation (56%). Dry-year take-up of irrigation water will be greater than shown above.

The high level of commitment of total resources in Anglian Region has already been highlighted (Section 5.1), and it is clear that any further private abstractions from surface water must be supported by either storage or river regulation. Abstraction for irrigation only occurs for a few months of the year, and provision of storage to support it is now routinely a condition of granting new licences in the Region.

Use of additional groundwater by private abstractors should not be allowed unless the environmental implications can be shown to be insignificant.

9.3 Northumbria Region

9.3.1 Public Water Supply

Table 9.6 Resource Surpluses in Northumbria Region

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Base Case	+946	+876	+793 Ml/d
Upper Bound	+855	+735	+592
Lower Bound	+955	+951	+895

Demand forecasts from Annex B, Table B10 and B16.

Table 9.6 shows that there will be a surplus of resources in the Northumbria Region of at least 600 Ml/d in 2021. There is apparently no need to introduce general metering in the region in order to conserve resources.

No environmental mitigation measures have been identified, and no readjustment has been made in resources.

There is a small 5 Ml/d import of water from Yorkshire Region via Scaling reservoir near Whitby which is operated by Northumbrian Water but is within the Yorkshire NRA Region. Two planned groundwater developments are identified in the Section 143 Report, with a maximum combined future yield of 12 Ml/d. The level of gross resource utilisation in the area is not great (Table 5.1), so that development of local resources is likely to continue.

A large percentage of the surplus water is in Kielder Reservoir. At present, utilisation of the reservoir for public supply via regulation of the Rivers Wear and Tees is negligible, due to the high operational costs involved in pumping water from Riding Mill on the Tyne. Groundwater development is likely to be more economic than large regional water transfers.

In the future, profitable utilisation of the Kielder reservoir must be a priority. Three options exist at present, as shown on Figure 22.

- development of the Tees-Swale link in order to supply Yorkshire Region, if needed, and Anglian Region. Although the present forecast shows that Yorkshire will not have a deficit in 2021, the surplus water in Kielder must be considered seriously as a source to meet deficits in the south-east;

- supplying water for the proposed new BNFL PWR Nuclear Power Station at Chapelcross in Dumfries and Galloway. Approximately 100-200 Ml/d of water would be required by the installation, but the programme for construction is unknown;

- shipment of water from Teeside to either Southern England or Overseas. Northumbrian Water offer a yield of 70 Ml/d raw water or 40 Ml/d treated water which can be directly loaded onto tankers at Teeside.

9.3.2 Private Supply

The following increases in uptake of licensed private abstractions have been identified; they are based on upper bound forecasts.

Table 9.7 Northumbria Region Forecast Increase in Private Abstractions

Year	2001	2011	2021
Industry	+4	+9	+14Ml/d
Agriculture	0	0	0
Irrigation	0	0	0
Others	+1	+2	+3
Total	+5	+11	+17

Based on values from Annex B, Table B9 and Tables B23, B24, B25 upper bound case.

The total water abstracted in the region by 2021 will have risen by 236 Ml/d, based on water company forecasts (upper bound) for public water supply and upper bound predictions for private abstractions. This figure represents an 11% increase in gross usage of the region's total resource in a drought year, giving a total forecast of 41% (see Table 5.1).

The relatively low volumes of private abstraction in the region and the forecast that uptake in 2021 will not exceed present licensed amounts suggest there will be no difficulty in meeting the demand in the future.

9.4 North West Region

9.4.1 Public Water Supply

Table 9.8 Resource Surpluses in North West Region

Year	2001 (Ml/d)	2011 (Ml/d)	2021 (Ml/d)
Base Case	+584	+567	+550
Upper Bound	+667	+589	+510
Lower Bound	+911	+939	+965

The surpluses shown in Table 9.8 take into account inter-regional transfers. The region receives a net import of 833 Ml/d. An import of 639 Ml/d is received from abstractions on the river Dee in the Welsh Region, and a further 210 Ml/d comes from Vyrnwy in Severn Trent Region. The balance of 16 Ml/d comprises minor local exports.

Two problems of low river flows caused by abstraction are known in the region, on the Rivers Lowther and Wyre. The estimated readjustment for present and future schemes is 10 Ml/d.

The forecasts for the region show a decline in population and related decline in public water supply demand. The present unaccounted for water (UFW) percentage is 33.2%, and the 2011 target for UFW is 24.8%. The UFW levels are among the highest levels of all the regions.

Introduction of metering to conserve resources is not essential.

The falling demand in the region will create a resource surplus which has the potential to be used to meet deficits in the south-east of the country. The redeployment of Vyrnwy, as described in Section 8.1.5, will allow 210 Ml/d to be transferred. At present, no other major schemes to transfer water away from the north-west are known. However, with about 600 Ml/d being potentially available by 2021, the surplus should be considered as a serious alternative to the transfer of Kielder Water or a Craig Goch scheme as a major source for the south east. Another possibility is to supply Liverpool from Cumbria, replacing the existing imports from North Wales and the Severn-Trent Region.

In addition to transfer of the forecast surplus, the North West Region has the potential for further resource developments which could be transferred out of the region. Improvements to the quality of discharges to the Mersey from sewage works and industry could allow up to 320 Ml/d to be abstracted in the future, if the considerable water quality problems can be overcome (see Section 5.2.3 above). The development of reservoirs or, in neighbouring Welsh Region, a Dee Barrage would provide an estimated yield of 200 Ml/d (see Figure 23).

It is clear that more work is needed to investigate the feasibility of the export of water from the North West region.

9.4.2 Private Supplies

The upper bound projected increase in uptake of private licences has been estimated as:

Table 9.9 North West Region Upper Bound Forecast Increase in Private Abstractions

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Industry	+117	+247	+390
Agriculture	+1	+1	+2
Irrigation	+1	+3	+6
Others	+4	+8	+13
Total	+123	+259	+411

Upper Bound forecasts from Annex B, Tables B18-21.

The growth in private sector demand of 411 Ml/d compares with the 257 Ml/d decline in public demand. Thus the total water abstracted in the region by 2021 is predicted to rise by 154 Ml/d, based on water company forecasts for public water supply and upper bound forecasts for private supply. The additional private demand is therefore not significant within the framework of this study.

9.5 Severn Trent Region

9.5.1 Public Water Supply

Table 9.10 Resource Surpluses in Severn-Trent Region

Year	2001 (Ml/d)	2011 (Ml/d)	2021 (Ml/d)
Base Case	+288	+210	+130
Upper Bound	+294	+160	+22
Lower Bound	+567	+567	+570

Note: Figures include 225 Ml/d from Carsington and exclude future phases of the Shropshire groundwater scheme.

The figures shown in Table 9.10 take into account inter-regional transfers. The region exports a net 366 Ml/d. Major exports of water include transfer to the North-West Region from Vyrnwy reservoir (210 Ml/d), Wessex Region via the Gloucester and Sharpness Canal (175 Ml/d), Anglian Region with a transfer from the River Trent to the River Witham (max 136 Ml/d) and Yorkshire Region from the Peak district reservoirs (152 Ml/d). Potable water from the Welsh region is supplied directly to Birmingham from Craig Goch reservoir in the Elan Valley (max 360 Ml/d).

There are currently six identified problems of low river flows in the region - on the Battlefield, Black, Dover and Leomansley Brooks and on Rufford Lake and River Worfe. The estimated future readjustment in resources is a reduction of 60 Ml/d.

After allowing for this 60 Ml/d reduction, the region is still forecast to be in surplus in 2021. The surplus could be increased by about 130 Ml/d with metering.

The Severn-Trent Region lies in the zone of transition between the northern and western areas of surplus and the southern and eastern regions of deficit. The region's role in future strategic resource development will be to assist in transfer of water in a south-easterly direction. For example, the region is at the hub of the Severn-Thames transfer schemes the Gloucester-Sharpness Canal transfer and the Trent-Witham Transfer (see Sections 8.1.2 and 8.1.3).

The following strategies in the region have been identified and are shown on Figure 24.

- regulation of the River Severn by the Shropshire groundwater scheme, up to 1000 Ml/d from Craig Goch, and/or 210 Ml/d from Vyrnwy. This would feed transfers from the Severn at Tewkesbury to the Thames catchment;

- increased abstractions from the Gloucester and Sharpness Canal of up to 110 Ml/d to feed the forecasted demands for Wessex Region may also require regulation from an upper catchment source;

- increased abstraction of 364 Ml/d from the Trent at Torksey could be used to feed the Anglian Region's demands;

- with the improvement in water quality in the Trent future river abstractions may be able to help meet the demands in the North and East Midlands which are currently supplied to a large degree by the Derwent-Dove system.

The 95-percentile low flow in the Lower Trent is 2500 Ml/d, and the lowest recorded daily flow is 1270 Ml/d in 1976. The extent to which this resource can be developed with or without supporting storage will depend upon the environmental requirements for low river flows downstream into the Humber estuary, including dilution requirements to overcome quality problems. It has been assumed above that 500 Ml/d (364 Ml/d plus the existing 136 Ml/d) can be abstracted. This supposition and the potential for further abstraction need to be investigated.

9.5.2 Private Supply

The following increases in uptake of licensed private abstractions have been identified, based on upper bound forecasts.

9.11 Severn Trent Region Upper Bound Forecast Increase In Private Abstraction (Ml/d)

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Industry	+233	+491	+776
Agriculture	0	+1	+1
Irrigation	+19	+44	+77
Others	0	+1	+1
Total	+252	+537	+855

Upper bound forecasts from Annex B, Tables B18-B21.

The total water abstracted in the region is predicted to rise by 1083 Ml/d by 2021, based on water company forecasts for public water supply and upper bound forecasts for private supply. The growth in public water supply demand of 228 Ml/d is small in comparison with growth in industrial demand of 776 Ml/d.

The upper bound forecast for industrial abstractions is based upon a +1% pa growth in demand. In the Severn-Trent Region, where a large proportion of the industrial demand is taken by the electricity generating companies, the forecast is probably not appropriate. The power industry is striving to use water more efficiently in its power stations, and therefore the lower bound forecast of a mild reduction in industrial demand given by a -1% growth until 2021 may be more accurate.

This lower bound industrial forecast would lead to a decline in private sector water demand of about 500 Ml/d.

9.6 Southern Region

9.6.1 Public Water Supply

Table 9.12 Resource Deficits in the Southern Region

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Base Case	22	-121	-281
Upper Bound	-34	-254	-508
Lower Bound	+132	+15	-113

The figures in Table 9.12 take into account inter-regional transfers. There is a net export of 134 Ml/d from the region. The R Darent and R Cray catchments lie within the NRA Southern Region, but the resources have historically been utilised by Thames Water. Southern estimate 145 Ml/d is exported to Thames in this way.

Three rivers with low flow problems - the River Stour, the River Darent and Wallop Brook - have been identified. An adjustment of 30 Ml/d has been made to meet present and future abstraction constraints.

Allowing for this 30 Ml/d reduction in yield, the estimated deficit in 2021 rises to 311 Ml/d. Table 9.13 gives details of strategic options for meeting Southern Region's deficits (see Fig 25).

Table 9.13 Strategic Options for Meeting Southern Region Deficits

Scheme	Potential Yield (Ml/d)	Cost £m/Ml/d
Local Schemes		
Yalding intake	25	0.5
Broad Oak reservoir	70	1.3
Darwell enlargement	40	1.1
Gaters Mill	22	1.0
Crowhurst Bridge	4	0.4
Chillerton Reservoir	8	1.3
Darent Effluent Re-use	75	0.9
Sub-total	244	
Water metering	42-125	11.2-3.8
Transfer Schemes		
Severn-Thames	100	2.4
Essex-Kent	100	4.0
France-Kent	100	2.9

Although in the above analysis effluent re-use is shown as a cheap option, the costs depend heavily on the quality of the sewage discharges. In this study only the minimum required treatment has been costed; the unit price can therefore be expected to be higher, especially where effluent includes discharges from industrial users.

It is estimated that water metering could reduce the demands in the Southern Region by about 83 Ml/d. The local schemes shown in Table 9.13 total 244 Ml/d, including a nominal allowance of 75 Ml/d for an effluent re-use scheme which would transfer water from Long Reach STW. on the Thames to the River Darent. The total of 327 Ml/d from the local schemes and water metering is estimated to meet the 2021 deficit of 311 Ml/d. However, if upper bound pws demands forecasts are realised, or a major local scheme such as the Darent re-use project is not pursued, then some form of inter-regional transfer will be needed. The cheapest of these appears to be the Craig Goch based Severn-Thames transfer.

Section 5.1 has shown how the Southern Region is already making heavy demands upon its natural water resources. Many of the local schemes identified in Table 9.13 entail relatively less damaging developments such as increased surface water storage, pumped augmentation and head of tide abstractions. However, some care will be needed in establishing their operating rules so that adverse impacts of new schemes are minimised, and where possible the opportunity is taken to reduce the effects of existing schemes.

9.6.2 Private Supply

The increases in uptake of licensed abstractions in the region based on upper bound forecasts are given below.

Table 9.14 Southern Region Forecast increase in Private Abstraction

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Industry	+97	+204	+322Ml/d
Agriculture	+1	+3	+4
Irrigation	+8	+18	+31
Others	+18	+37	+59
Total	+124	+262	+416

Upper bound forecasts from Annex B, Table B18-B21.

The 2021 increase in public water supply based on water company forecasts, plus the upper bound forecast of private supply gives a total increase in demand of 744 Ml/d.

Reference to Table 5.1 suggests that, under drought conditions, it is very uncertain that this extra demand could be met from resources within the region. This emphasises the need to consider supporting Southern with an inter-regional transfer before 2021.

9.7 South West Region

9.7.1 Public Water Supply

Table 9.15 Resource Deficits in South West Region

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Base Case	+81	-1	-90
Upper Bound	+36	-69	-186
Lower Bound	+96	+31	-38

These figures have taken into account an export of 32 Ml/d from the region through the transfer from the Wimbleball scheme.

Low flows problems have been identified in a number of rivers throughout the region (15). Further work is needed to quantify their implications in resource terms; however, for present purposes, an adjustment of 24 Ml/d has been made to meet present and future environmental constraints. This would raise the forecast deficit in 2021 to 114 Ml/d. Abstractions for public supply are believed to have caused low flow problems on the River Tavy in the past; however, this issue is addressed in the yield assessment for the Roadford scheme.

Options for meeting this deficit are shown in Table 9.16 and on Figure 26.

Table 9.16 Options for Meeting Deficits in the South West Region

Scheme	Potential Yield (Ml/d)	Cost £m/Ml/d
Local Schemes		
Wimbleball pumped storage	40	0.97
Axe reservoir	24	1.3
Roadford pumped storage	50?	0.97
River Exe Licence Review	32	0.5
Sub-total	146	
Water Metering	20-60	8.9-3.0
Transfer Schemes		
None appropriate		

The Wimbleball pumped storage scheme and the Axe reservoir are being studied by South West Water at present. The possible pumped augmentation of Roadford reservoir has never been investigated, but it is anticipated that the present yield of the scheme could be increased by roughly 50% in this way. The Wimbleball and Roadford schemes could between them go some way towards meeting the forecast deficit of 114 Ml/d (see Figure 26).

It should be borne in mind that the options shown in Table 9.16 address average daily deficits, rather than seasonal peaks. The latter are a major factor in water resource planning generally, and in South West Region particularly, due to the importance of tourism there. This, coupled with the relatively small groundwater resources and consequently "flashy" rivers, means that reservoir storage and other ways of increasing baseflow, such as effluent re-use, are important in the South West.

The introduction of water metering, although much more expensive than the local schemes, could provide for an equivalent yield of perhaps around 40 Ml/d and avoid the need for one of the three local schemes.

Table 9.16 shows that local schemes are sufficient to meet needs to 2021. Therefore no options for meeting the deficits by external transfers of water have been considered. Furthermore, in Section 5.1 it is shown that at present the South West Region uses only a small proportion of its natural water resources, so it would seem appropriate that the Region's future deficits should be met from within. Should any transfer scheme become necessary, the logical step is to re-allocate to South West Region the current 32 Ml/d export to Wessex Region from Wimbleball. For such a scheme to proceed, it would be necessary first to assure alternative supplies to Wessex, probably by means of a transfer from the River Severn supported by Craig Goch.

9.7.2 Private Supply

The increases in uptake of licensed abstractions in the region based on upper bound forecasts have been identified.

Table 9.17 South West Region Forecast Increase in Private Abstraction

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Industry	+34	+71	+112
Agriculture	+3	+6	+10
Irrigation	+1	+2	+24
Others	0	0	0
Total	+38	+79	+126

Upper bound forecasts from Annex B, Table B18-B21.

The 2021 increase in public water supply based on water company forecasts plus the upper bound forecast of private supply gives a total increase in demand of 344 Ml/d. Since the 2021 upper bound forecast for gross usage of the total regional resources in a drought year is only 14%, there should be no problem in meeting these demands, provided adequate storage is introduced to cushion the effects of summer abstractions (eg for irrigation).

9.8 Thames

9.8.1 Public Water Supply

Table 9.18 Resource Deficits in the Thames Region

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Base Case	-228	-583	-951
Upper Bound	-201	-760	-1341
Lower Bound	+246	-76	-390

The figures in Table 9.18 have taken into account inter-regional transfers. There is currently a net import of 163 Ml/d into the region. The River Darent and River Cray catchments (145 Ml/d) are within the water supply boundaries of Thames Water Utilities Ltd but also within Southern NRA resource management boundary. Therefore water from these catchments used in London represents a resource import into Thames Region. Water is also imported from Grafham reservoir in Anglian Region (73 Ml/d) and from Bough Beech Reservoir (35 Ml/d) in Southern Region. Water is exported from Lee Valley to the Essex Water Company (90 Ml/d) in the Anglian Region.

The major measures to alleviate low flows are needed on the Letcombe Brook, Rivers Misbourne, Wey Pang and Ver, although problems may also exist on other rivers such as the Cotswold Coin. An estimated 198 Ml/d readjustment in resources is required to meet present and future environmental constraints. This includes resource cut-backs of 30 Ml/d on the River Darent and 69 Ml/d on the remaining five rivers, with the 99Ml/d total figure being doubled to account for future problems. The forecast deficit in 2021 is thus increased to 1149 Ml/d.

Strategic options for meeting this deficit are shown in Table 9.19 and Figure 27.

Table 9.19 Strategic Options for Deficits in the Thames Region

Scheme	Potential Yield (Ml/d)	Cost £m/Ml/d
Local Schemes		
Artificial recharge in London	180	0.28
Major reservoir in Upper Thames	200	1.55
* Gatehampton groundwater	55	0.29
Redevelopment of existing reservoirs	100	1.60
Various local groundwater schemes	100	0.29
Review of licence conditions	91	0.55
Deephams effluent re-use	150	0.84
Sub-total	876	
Water Metering	165-495	8.1-2.7
Transfer Schemes		
National grid	>1099)	4.3
Severn-Thames transfer	1000)Max	1.4
Transfer from Great Bradley reservoir	450)Yield	3.0

* Gatehampton G.W. scheme has now been licensed.

Local options totalling 876 Ml/d have been identified (see Figure 27). If combined with the savings due to water metering of, say 330 Ml/d, the whole of the base case forecast deficit in 2021 could be met. However, most of these local schemes have inherent environmental or technical problems and they could be difficult to promote. It would seem unrealistic to assume that more than, say, 500 Ml/d could be obtained from these schemes. Even if combined with water metering, there would still be a shortfall of 320 Ml/d in 2021. It would therefore appear prudent to give serious consideration to options involving transfer of water to the region.

Aside from the national grid, which is expensive, the two options for importing water are the Severn-Thames transfer and Great Bradley reservoir. Of these, the former is the cheaper option. If the whole of the Severn-Thames transfer were made available to the Thames region, there would be a yield increase of 1000 Ml/d. However, it seems likely that if the transfer were to go ahead, at least 200 Ml/d would be used by the Southern Region (see Section 9.6.1). Similarly, the yield of 450 Ml/d from Great Bradley reservoir assumes that the whole of the yield available from the Trent-Witham Ouse scheme would be used for the Thames Region.

In reality, it is likely that the solution to the water supply deficits in the Thames region will lie in a combination of all strategies, ie local schemes, water metering and external transfers.

9.8.2 Private Supply

The increase in uptake of licensed abstractions in the region based on upper bound forecasts have been identified.

Table 9.20 Thames Region Forecast Increase in Private Abstraction

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Industry	+34	+71	+113
Agriculture	+1	+3	+5
Irrigation	+4	+10	+17
Others	+20	+42	+66
Total	+59	+126	+201

Upper bound forecasts from Annex B, Table B18-B21.

The 2021 increase in public water supply based on water company forecasts plus the upper bound forecast of private supply gives a total increase in demand of 1253 Ml/d. This corresponds to a 32% increase in gross usage of total regional resources in a drought year and gives a 2021 usage of 154%.

This figure does not account for indirect re-use of effluent or private abstraction returns, but it does indicate the degree of water utilisation in the region. In order to reduce this level of usage there are three options available - to prevent further increases in demand, to import water into the region or to increase further the already high level of effluent re-use there (see Section 7.5). Preventing altogether further increases in demand would require more significant measures than have been identified in this report, and might thus impose unacceptable constraints upon economic development of the region.

9.9 Welsh Region

9.9.1 Public Water Supply

Table 9.21 Resource Surpluses in the Welsh Region (Ml/d)

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Base Case	+300	+259	+214 Ml/d
Upper Bound	+299	+214	+122
Lower Bound	+437	+424	+410

These figures take into account a net export of 1005 Ml/d from the Region. The two major exports are from the River Dee to North-West Region (639 Ml/d) and from the Elan Valley to Severn-Trent Region (328 Ml/d). There are no major imports of water. No readjustment has been made for future environmental constraints, as there are no currently identified problems of low river flows.

Dŵr Cymru are the only water company so far to have stated that in the foreseeable future they do not intend to adopt a general metering policy. However, domestic metering throughout the region would increase the surplus developed resources in 2021 from 214 Ml/d to 266 Ml/d.

The extent to which the surplus developed resources could be transferred to the south-east of England is not known. It seems likely that they are somewhat fragmented, and that it will be practicable to export only a relatively small proportion.

The major potential role of the Welsh region at a national level would be the provision of a water source for the Severn-Thames transfer scheme. There are two possible sources of water (excluding the re-deployment of Vyrnwy, which is discussed in Section 8.1.5):

- the Craig Goch scheme. A new dam constructed on the site of the existing reservoir could be the source of an increase in yield of up to 1000 Ml/d to the River Severn for transfer to the Thames;
- a transfer from the River Dee to the River Severn. If leakage control in the North West Region provides a large surplus as discussed in Section 9.4, the water resources of the Dee, which include several river regulating reservoirs, could be used to make a pumped transfer to regulate the River Severn. Such a scheme could obviate the need for the new reservoir at Craig Goch.

Dŵr Cymru are at present investigating some six developments with a total yield of about 45 Ml/d. These are to solve local resource problems and are not significant at the national level (see Fig 28).

9.9.2 Private Supply

The following increases in uptake of licensed private abstraction have been identified, based on upper bound forecasts.

Table 9.22 Welsh Region Forecast Increase in Private Abstractions (Ml/d)

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Industry	+322	+678	+1071
Agriculture	+12	+25	+39
Irrigation	+2	+5	+9
Others	+325	+684	+1080
Total	661	1392	2199

The figures for industrial uptake have to be treated with caution, due to the inclusion of demands from hydropower electric generating stations in the Department of Environment returns, upon which these data are based.

This being so, the total increase in water abstracted in the region by 2021 based on water company forecasts for public water supply and upper bound forecasts for private supply, is 2298 Ml/d. This corresponds to a 10% rise in gross usage of the total regional resource available in a drought year and gives a 2021 usage of 44% compared with the present 34% (see Section 5.1). This figure is somewhat misleading, due to the inclusion of the very high hydropower demand, which represents a non-consumptive use of water resources.

9.10 Wessex

9.10.1 Public Water Supply

Table 9.23 Resource Deficits in the Wessex Region

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Base Case	-12	-130	-265
Upper Bound	-84	-254	-452
Lower Bound	40	-54	-162

The figures in Table 9.23 have taken into account a net import of 161 Ml/d into the Region. Water is imported from Wimbleball Reservoir (32 Ml/d) in the South-West Region and from the River Severn via the Gloucester and Sharpness Canal (175 Ml/d). There is a 'raw' water export to the British Petroleum refinery at Fawley, located in the Southern Region, of 46 Ml/d.

Two significant low river flow problems are known in the Region, on the Rivers Allen and Piddle; problems on other rivers, such as the Malmesbury Avon, may also be due to current rates of groundwater abstraction. A readjustment of resources of 40 Ml/d has been estimated to meet these present and possible future environmental constraints. This would increase the forecast deficit in 2021 to 305 Ml/d.

Options for meeting this deficit are shown on Table 9.24 and Figure 29.

Table 9.24 Options for Deficits in the Wessex Region

Scheme	Potential Yield (Ml/d)	Cost £m/Ml/d
Local Schemes		
Hampshire Avon Schemes:		
Bournemouth bankside storage	53	1.3
W Hants bankside storage	6	1.3
Blashford Lakes	20	1.3
Bristol Avon pumped storage schemes		
Wessex scheme at Bath	30	1.3
Chew pumped augmentation	55	1.0
Bristol Avon effluent re-use	50	1.1
Sub-Total	184	1.3
Water Metering	36-108	9.0-3.0
Transfer Schemes		
Severn/Sharpness Canal: Phase 1	55	1.33 +
Phase 2	55	1.33 +
Wimbleball transfer	16	0.97

\+ Includes pro-rata costs for Craig Goch

With the exception of effluent re-use, the local schemes listed in Table 9.24 are all similar in concept and thus cost. The Bristol Avon effluent re-use scheme has not previously been investigated, but could possibly provide a yield of about 50 Ml/d.

Domestic water metering would reduce the deficit by about 72 Ml/d, but even if all the local schemes were to be adopted there would still be a shortfall in 2021.

Transfers from the Severn via the Sharpness Canal already take place, and there are plans for a further extension of a total of 110 Ml/d. The water resources for this would be provided by the Shropshire groundwater scheme. There are also plans to transfer an additional amount up to 16 Ml/d from Wimbleball if the pumped augmentation of the reservoir takes place; however, it has not yet been resolved whether the best use of the extra yield from Wimbleball would be to supply Wessex or to meet deficits in the South West Region (see Figure 29).

It is shown in Section 5.1 that the water resources of the Wessex Region are moderately used at present. This is partly a reflection of the environmental sensitivity of groundwater development in the Region, and also the shortage of suitable sites for development of large reservoirs. Previous studies have investigated development of the River Parrett (35) with a possible yield of 40 Ml/d and a large pumped storage reservoir near Bath, yielding up to 150 Ml/d (36). The Avalon Lakes scheme, with a yield of 30 Ml/d, has recently been the subject of detailed investigations but the project has been found too expensive (37).

9.10.2 Private Supply

The following increases in uptake of licensed private abstractions have been identified, based on upper bound forecasts.

Table 9.25 Wessex Region Forecast Increase in Private Abstraction (Ml/d)

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Industry	+14	+30	+47
Agriculture	+16	+33	+53
Irrigation	+17	+39	+69
Others	+4	+9	+15
Total	+51	+111	+184

The total water abstracted in the region by 2021, based on water company forecasts for public water supply and upper bound forecasts of private supply, is predicted to rise by 587 Ml/d. This corresponds to a 13% increase in gross usage of the total regional water resources in a drought year, giving a forecast usage for 2021 of 45%.

9.11 Yorkshire

9.11.1 Private Water Supply

Table 9.26 Resource Surpluses in Yorkshire Region (Ml/d)

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Base Case	+105	+9	+13
Upper Bound	+213	+67	+28
Lower Bound	+370	+315	+354

These figures have taken into account inter-regional imports of 134 Ml/d. The majority is taken from the Peak District reservoirs in Severn-Trent Region (152 Ml/d) with 9 Ml/d abstracted from North-West springs and boreholes. A total of 24 Ml/d is exported to Northumbrian, North West and Severn Trent Regions.

No measures for alleviation of low flows have been identified in the region and no adjustment to resources has been made for future environmental constraints.

There is apparently no need to apply general metering in the region purely in order to conserve resources within the 2021 horizon, unless demand grows faster than currently forecast.

The water companies' average predicted unaccounted for water in 2021 is 27.3%, the highest of all the regions. Due to this high figure, the deficits for the base case are lower than those for the upper bound forecast, which is based on a UFW level of 20%.

No specific strategic options have been identified for the region except for the transfer of water from Kielder via the rivers Ouse and the Swale (see Section 8.1.4), see Figure 29. The Tees-Swale link allows transfer of water to regulate the River Ouse, from where it is abstracted, and up to 590 Ml/d to the Anglian Region.

Groundwater schemes totalling 220 Ml/d have been identified for the region. Their viability in environmental terms is not known at this stage.

9.11.2 Private Supply

The following increases in uptake of licensed private abstractions have been identified, based on upper bound forecasts.

Table 9.27 Yorkshire Region Forecast Increases in Private Abstraction (Ml/d)

Year	2001 Ml/d	2011 Ml/d	2021 Ml/d
Industry	+120	+253	+400
Agriculture	+1	+3	+4
Irrigation	+7	+17	+30
Others	+0	+0	+0
Total	+128	+273	+434

The total increase in water abstracted in the region by 2021, based on water company forecasts for public water supply and upper bound forecasts for private supply is 587 Ml/d. This corresponds to an 11% rise in the usage of the total regional water resource available in an average year, giving a 2021 usage of 52%.

10 CONCLUSIONS

10.1 Concerning Current Practices

1. Water has traditionally been viewed in England and Wales as a cheap commodity which is expensive to move. This has led to:

   - a preoccupation with local solutions to demand/resources deficit problems, to the extent that, in some areas, resources are developed beyond what is sustainable in environmental terms;

   - mobilising gravity by taking water from upper catchments, and returning the effluent lower down;

   - an indifference to proper accounting for water, and general profligacy with it among suppliers and consumers alike.

   Growing understanding of the environmental implications of over-abstraction is causing the commodity to become more highly prized.

2. There are regional differences in approach in key areas, such as yield assessment methods and accounting for water, which need to be overcome in the interests of developing a clear and strategic understanding of resource development needs. In particular, there appears to be no reaslistic overview of available groundwater resources.

10.2 Concerning Current Levels of Demand

1. Overall, some 73% of current public water demand is either unmeasured (about 47%) or unaccounted for (26%). These figures relate almost entirely to treated water; losses from raw water aqueduct systems between points of abstraction and treatment works are often not measured. There are exensive raw water aqueduct systems in some areas.

2. Levels of unaccounted for water are generally high in the eyes of the public, who expect action on this before further resource developments are approved.

3. Reported per capita domestic water demand in England and Wales is among the lowest in Europe.

4. Since the early 1970's when comparable work was last undertaken, the growth in demand then forecast has failed to materialise. In particular there has been a marked decline in industrial water use in the last twenty years.

5. Although this study has confined itself to average daily demands and source outputs, seasonal peaks are of great importance in water resources planning at local level.

10.3 Concerning the Forecast Need for More Water

1. Demand forecasting could be carried forward with greater confidence with better data on existing demand. A more comprehensive breakdown of user groups within the unmeasured sector, and better information on UFW assessment within the different regions, are needed. Forecasts are sensitive to varying assumptions about control of UFW.

2. There are striking regional differences in the forecast deficits or surpluses for public water supplies in 2021. The five regions which lie to the north-west of a line joining the Severn Estuary to the Humber (including Severn Trent) are forecast to be in surplus. The five regions in the south-east are forecast to be in deficit.

3. The two regions of greatest pubic supply surplus are Northumbria (790 Ml/d) and North West (550 Ml/d). The two regions of greatest deficit are Thames (950 Ml/d) and Anglian (420 Ml/d).

4. Taking the country as a whole, the forecast public water average daily demand (ie, excluding seasonal peaks) in 2021 of 20,526 Ml/d is almost balanced by the present yield of 20,218 Ml/d.

5. For the five regions of deficits in the south-east of the country, the total forecast public supply deficit in 2021 is 2,008 Ml/d. The upper and lower bounds for the forecast deficits for these five regions are 3,203 Ml/d and 875 Ml/d respectively.

6. Future private abstraction has been difficult to forecast and it is unclear whether uptake will actually grow or decline following the significant decrease over the last 20 years. Growth in private abstraction is likely to be modest, if it occurs at all, and may be accommodated in areas of heavily committed resources by provision of storage.

7. Allowance should be made in resource planning for cut-backs at existing, environmentaly damaging abstractions as new sources are developed. This "low flows debit" is difficult to estimate, but is likely to be several hundred megalitres per day.

10.4 Concerning Strategic Options for Meeting Deficits

1. Better "housekeeping" is needed. Levels of unaccounted for water should be brought down, by improved measurement and reduced leakage. This latter is shown to be a relatively cheap option, at about £0.12m/Ml/d (3p/m^3).

2. There are as yet insufficient data to give a clear indication of water savings achievable by metering. Unit costs of this option are highly sensitive to the savings assumed. Although relatively expensive (£2.7m - £11.2m/Ml/d or 66p-272p/m^3), metering has the potential to:

- encourage water economy in the home, by introducing volume-related charging;

- reduce the severity of seasonal demand peaks, by means of appropriately weighted tariffs.

3. There are a number of conventional local development options, and these will continue to play a role in responding to demand growth, provided:

- the need is proven;

- the environmental impact can be clearly shown to lie within acceptable limits.

In Anglian, Southern and Thames Regions overall resources (rainfall less evapotranspiration) are already heavily committed, so avoidance of adverse impact with new local schemes will be difficult.

4. Better use can be made of existing resources by:

- working to improve river quality, where it is at present deemed untreatable for public supply;

- disposing of effluent to inland waters;

- locating abstractions near to tidal limits;

- further integration of existing sources;

- pumped augmentation of existing reservoirs;

- provision of more storage;

- use of storage for river regulation rather than direct supply,

subject to environmental assessment of specific schemes.

5. Despite the opportunities noted above, problems may remain in meeting forecast deficits in Anglian, Southern, Thames and Wessex Regions. Against this eventuality, consideration should be given to transfer of water to these regions from Wales or the North of England.

6. A National Water Grid, involving the piped distribution of treated water, could accomplish the required re-distribution of resources. However, the unit cost of £4.2m/Ml/d (£1.02/m^3) makes it economically unattractive.

7. An effect similar to that obtainable from the National Water Grid could be achieved by schemes involving inter-regional transfers of raw water using rivers (such as the Trent, Severn and Thames) and existing canals as conveyors. The potential sources of raw water for such transfers are:

   - surpluses in Northumbria Region (Kielder) 800 Ml/d
   - surpluses in North West Region 550 Ml/d
   - enlarged Craig Goch reservoir 1,000 Ml/d.

8. There are various combinations of inter-regional transfer schemes, using some or all of the above sources, which can meet the forecast deficits in all the regions.

9. The optimal solution to the regional deficits is likely to lie in a combination of improved housekeeping, local schemes and inter-regional transfers.

10. Investigations into the potential for water metering and feasibility studies of numerous local schemes are being actively pursued by the water undertakers at present. However, there is little work being done on potential major inter-regional transfers. Decisions on the promotion of local resource schemes should be made in the light of information on the available inter-regional alternatives.

10.5 Concerning Costs of Strategic Options

1. The unit costs of the range of strategic options are shown in Table 10.1. The unit costs are expressed in £ million per Ml/d increase in resource yield. The costs include operating costs amortised over a 30 year period; they are of necessity simplistic, but provide a means of comparison between options which differ widely in nature.

2. The local schemes are generally cheaper than the major inter-regional transfers. This may discourage local water undertakings from taking a broad and long term view of resource developments.

3. Effluent re-use schemes appear economically attractive as well as being sound in resource terms.

Table 10.1 Unit Costs of Strategic Options

Option	Unit Cost	
	£m/Ml/d	p/m^3
i) Options reducing the demand		
Leakage control	0.12	3
Water metering	5.4	131
ii) Local options for water supplies		
Groundwater	0.35	9
Direct river abstraction	0.5	12
Impounding reservoir schemes	0.55-1.75	13-42
Effluent re-use	0.85	21
Desalination	3.50	85
iii) Water transfer schemes		
National grid	4.2	102
Inter-regional transfer schemes	1.0-5.0	24-122
Transfer from Europe	2.9	70
Water shipment	20.5	498

10.6 Recommendations

1. Work is needed to develop NRA national standards for:

   - evaluation of demand, to include an appropriate breakdown by use type, and method of assessment for each;
   - evaluation of available resources;
   - assessment of source outputs.

2. Continuing investment in leakage control should be given a high priority in all regions, embracing major raw water aqueducts as well as treated water distribution systems.

3. NRA should closely follow and note the findings of the national metering trials now in progress.

4. Effort should continue to be directed towards improving water quality in rivers which are currently unusable for potable supplies.

5. Where possible, all new resource developments should be planned to allow reduction or cessation of the abstractions identified as causing environmental problems.

6. Further studies are needed of the inter-regional transfer schemes. With major local water resource schemes being actively pursued (Broad Oak Reservoir and Thames Water's Oxfordshire Reservoir Scheme, for example) the studies of the inter-regional transfers are needed as a matter of urgency.

GLOSSARY

Alleviation of low flows: (ALF). Collective measures to ensure groundwater abstraction rates are not detrimental to base flows in adjacent rivers.

Artificial Recharge: The enhancement of groundwater storage by recharge from surface water either by pumping or the use of infiltration reservoirs.

Compensation Water: A prescribed release from a reservoir to maintain the downstream low flow river regime.

Conjunctive Use: The joint use of different facets of the water resource in a single operational strategy, for example the joint use of groundwater and reservoirs.

Critical Period: The period during which a reservoir passes from a full condition to empty, without spilling in the intervening period.

Direct Supply Reservoir: Generally an upland storage supported by natural catchment inflow: Raw water is released to a pressure conduit for gravity fed direct supply.

Drought Reliable Yield: Defines the output capacity of a reservoir, reservoir system, conjunctive use scheme etc. It is the amount that can just be sustained in a design drought period by the combination of infow and usable storage. 1976 is generally regarded as the critical historical sequence with a risk of occurrence of 1:50 years.

Gross Available Resource: The total volume of effective rainfall over a region, ie mean annual rainfall minus mean annual evaporation. Provides an estimate of the total regional contribution by rainfall to river-flow and groundwater.

Minimum Acceptable Flow (MAF): A prescribed flow in a river set in order to ensure the riverine and fisheries environment and/or the acceptable dilution of effluent discharges.

Net-Use: Gross supply minus effluent return to water resource system.

Private Abstraction: Abstractions, subject to licence, that are not integrated into the distribution system.

Public Water Supply: Bulk water supplied to the distribution system.

Pumped Storage: Classically bunded off-channel reservoirs where there is little or no natural inflow, and where water is pumped from the adjacent river for storage.

Resource Integration: The combination of water supply components, for example rivers, reservoirs and groundwater into an increasingly complex linked system to achieve operational benefits.

River Regulation: Generally refers to reservoir storage that is used wholly or partially for the augmentation of dry weather flows in the downstream catchment in order to support direct river abstractions.

Strategic Option: A scheme or combination of schemes which individually provides a partial but effective response to projected changes in demand for water in England and Wales, and collectively overcomes the problems which may arise by 2021 if no action were taken.

Unaccounted for Water (UFW): Generally refers to leakage. Cannot be determined directly unless public supply is metered. Definitions vary but is generally the discrepancy between water supplied and that used, or the balancing item once metered and unmetered domestic and industrial demands are subtracted from the volume of total supply.

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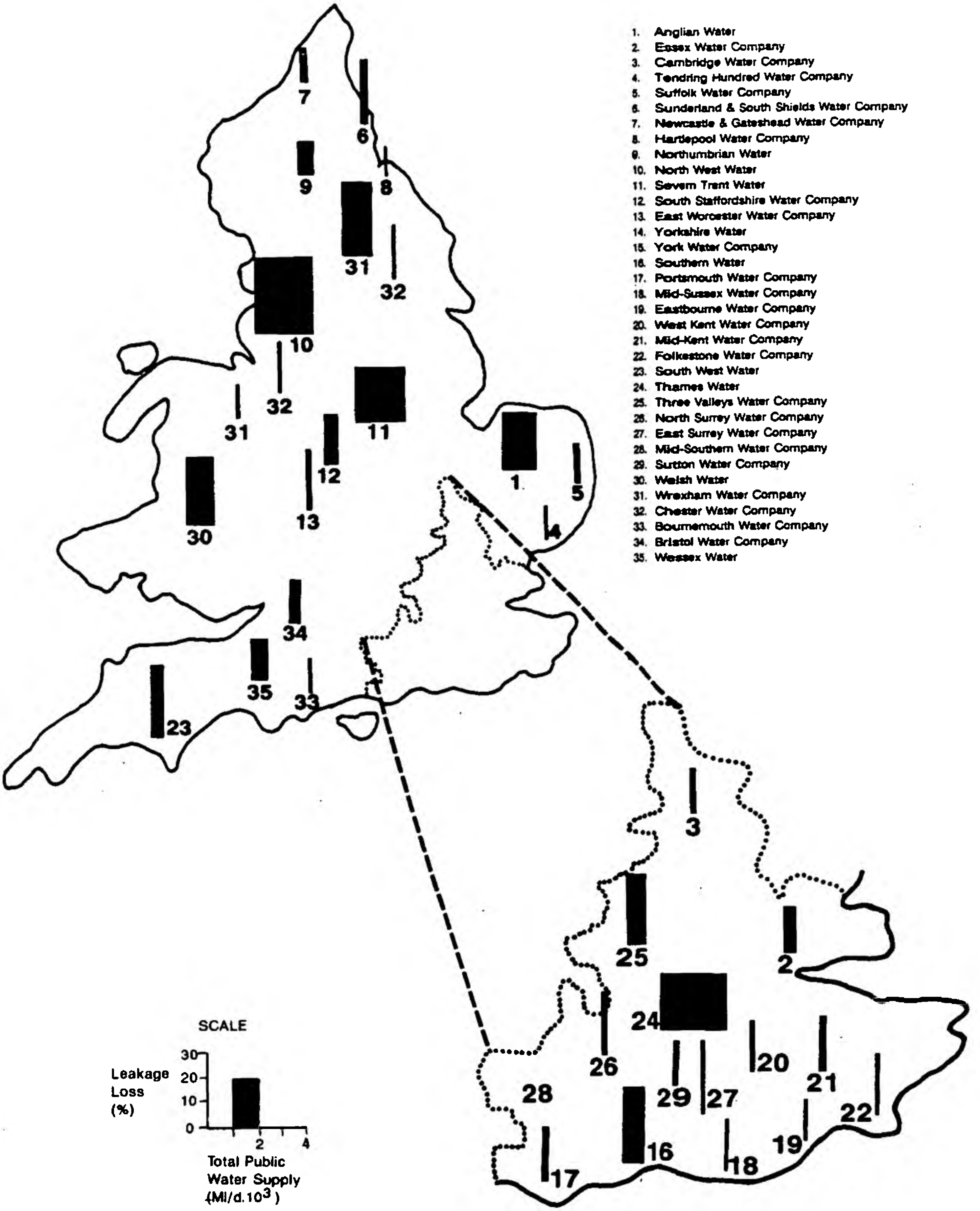
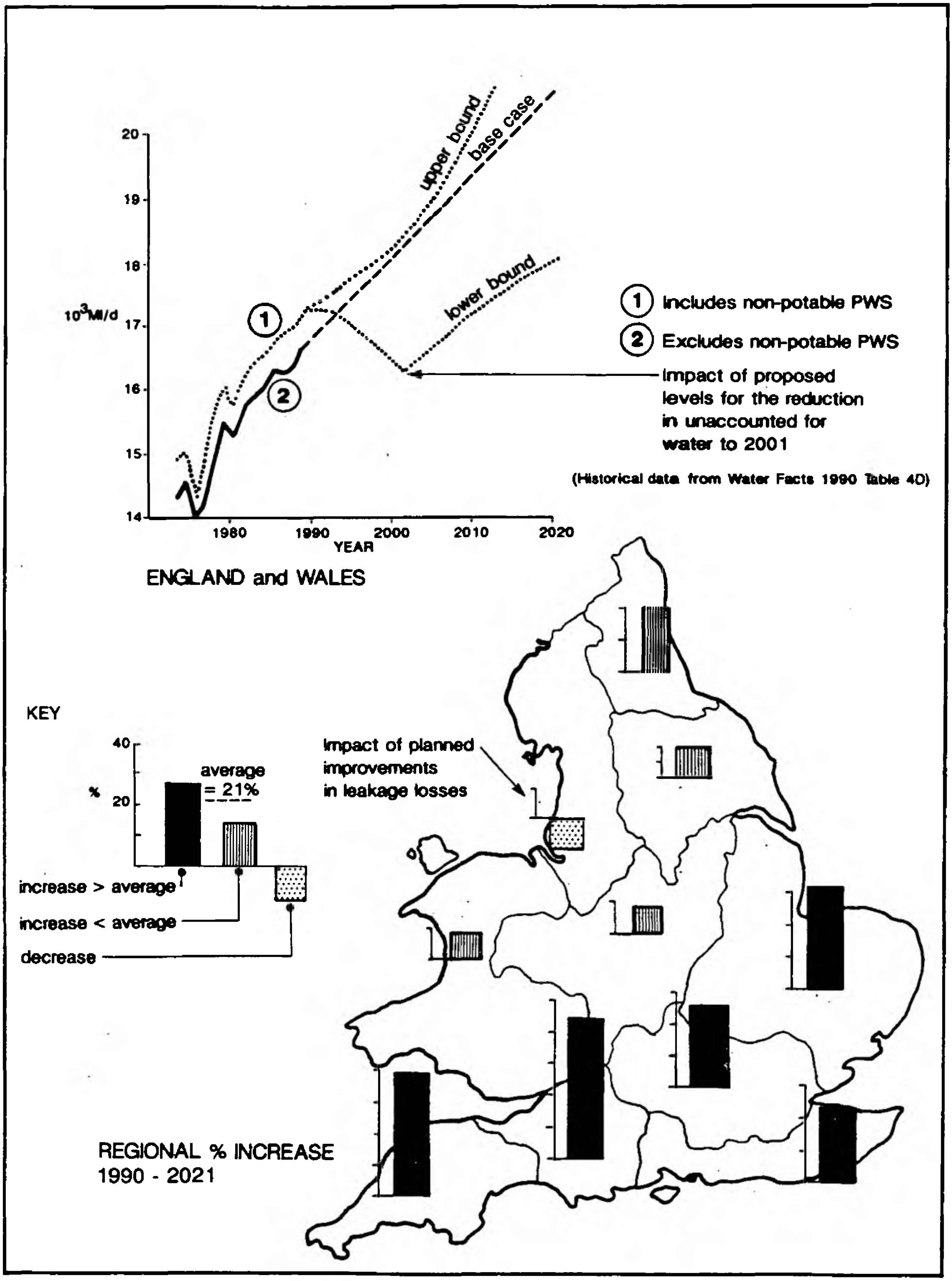
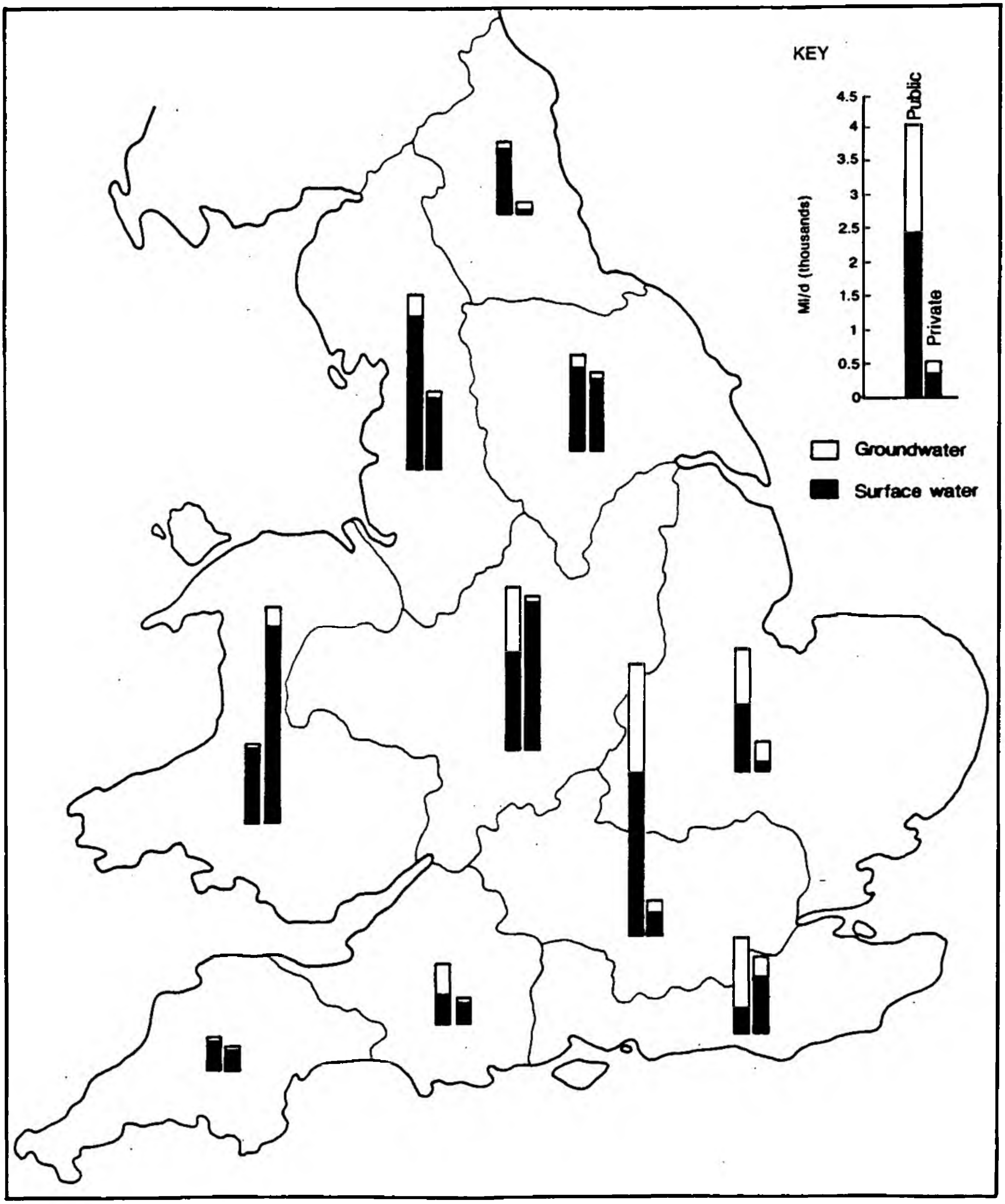
Figure 1



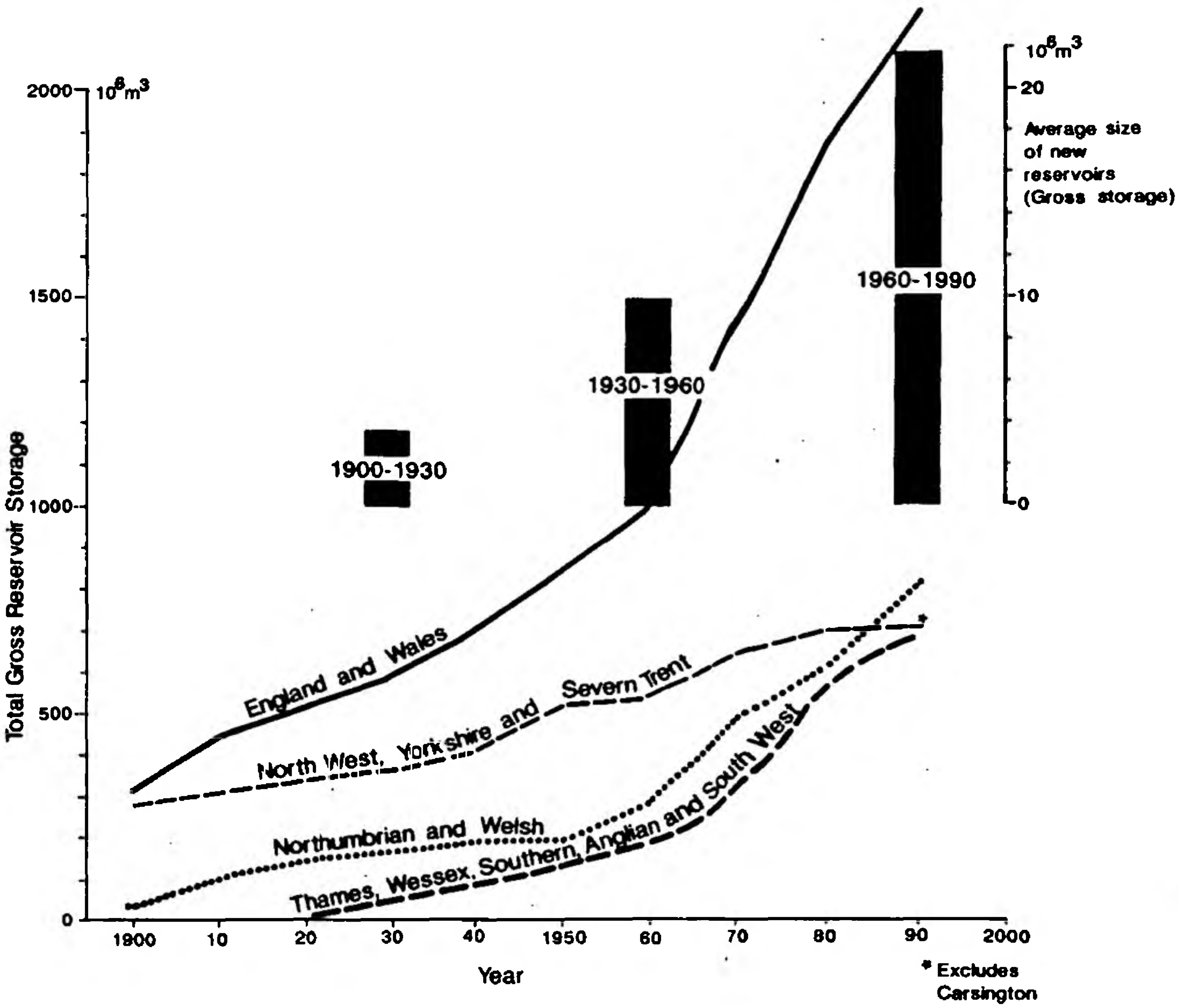
WATER LOSSES UNACCOUNTED FOR BY WATER COMPANIES



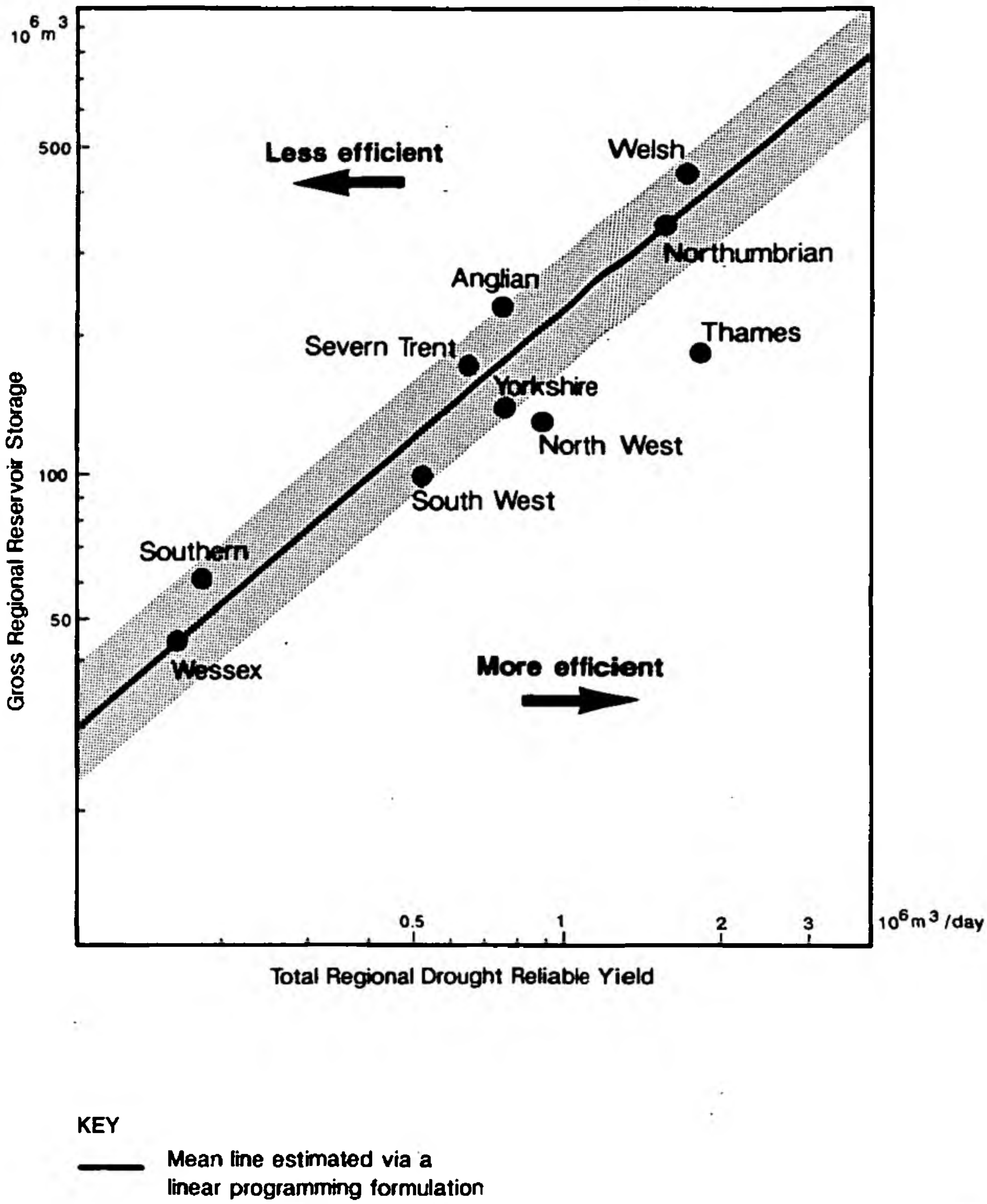
PROJECTED INCREASE IN PUBLIC WATER SUPPLY



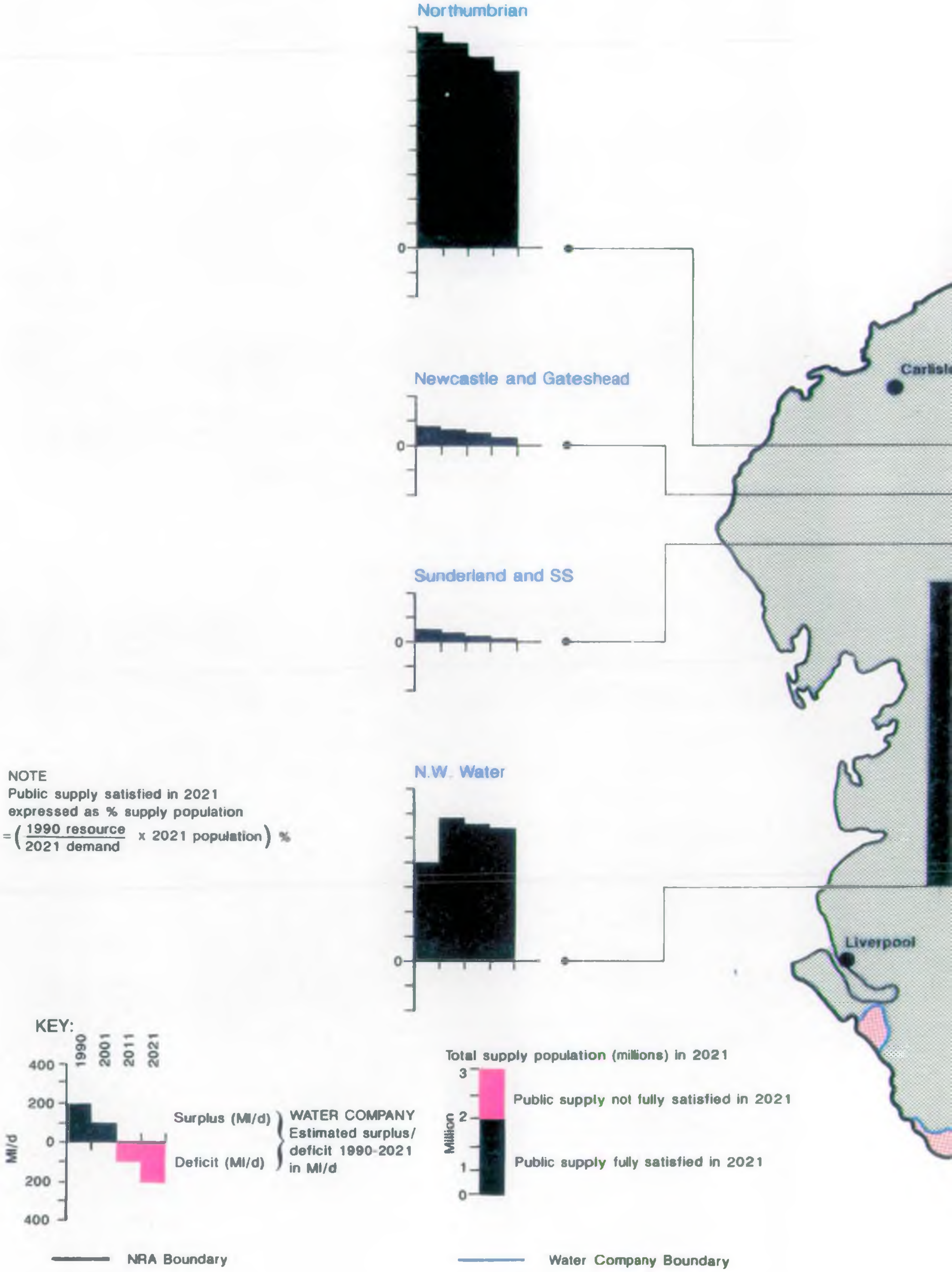
RELIANCE ON SURFACE AND GROUNDWATER
FOR PUBLIC AND PRIVATE WATER SUPPLY



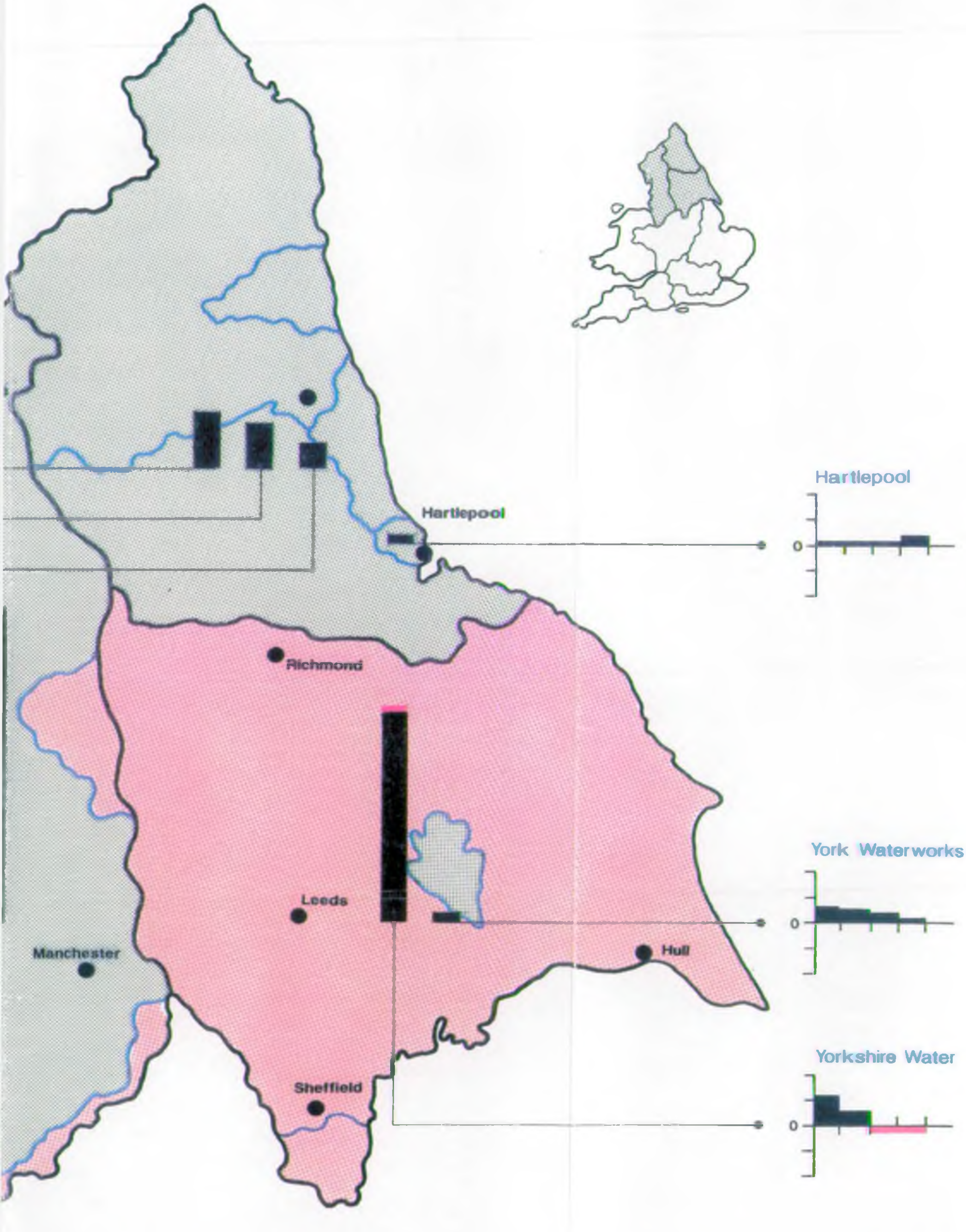
RESERVOIR CONSTRUCTION IN
ENGLAND AND WALES 1900 - 1990



REGIONAL RELATIONSHIP BETWEEN TOTAL RESERVOIR STORAGE AND TOTAL DROUGHT RELIABLE YIELD

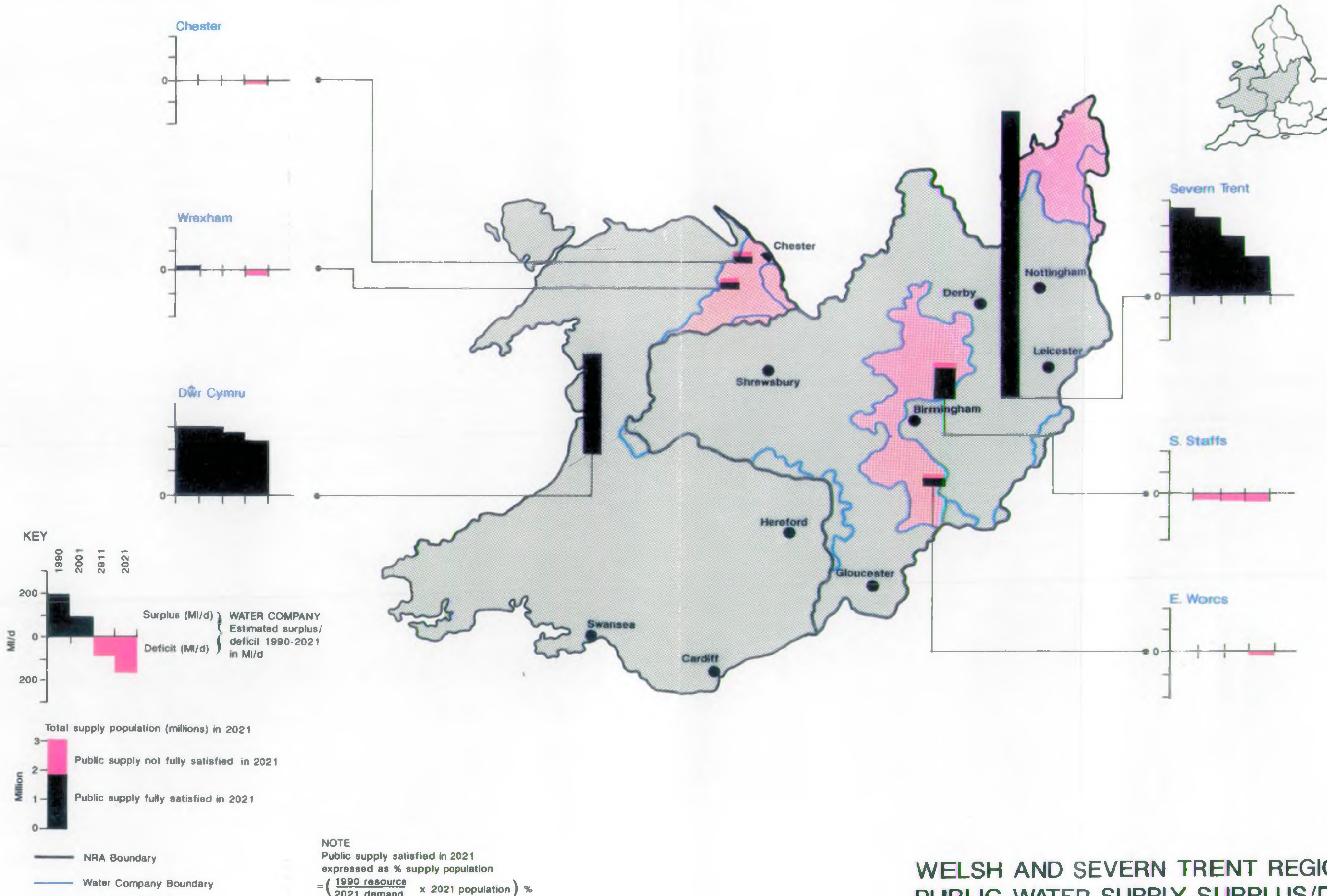


Northumbrian
0
Newcastle and Gateshead
0
Carlisle
Sunderland and SS
0
N.W. Water
0
Liverpool
NOTE
Public supply satisfied in 2021
expressed as % supply population
$=\left(\frac{\text{1990 resource}}{\text{2021 demand}} \times \text{2021 population}\right)\%$
KEY:
1990
2001
2011
2021
400
200
0
200
400
Ml/d
Surplus (Ml/d)
Deficit (Ml/d)
WATER COMPANY
Estimated surplus/
deficit 1990-2021
in Ml/d
Total supply population (millions) in 2021
3
2
1
0
Million
Public supply not fully satisfied in 2021
Public supply fully satisfied in 2021
NRA Boundary
Water Company Boundary



NORTHUMBRIA, NORTH WEST AND YORKSHIRE REGIONS : PUBLIC WATER SUPPLY SURPLUS/DEFICIT

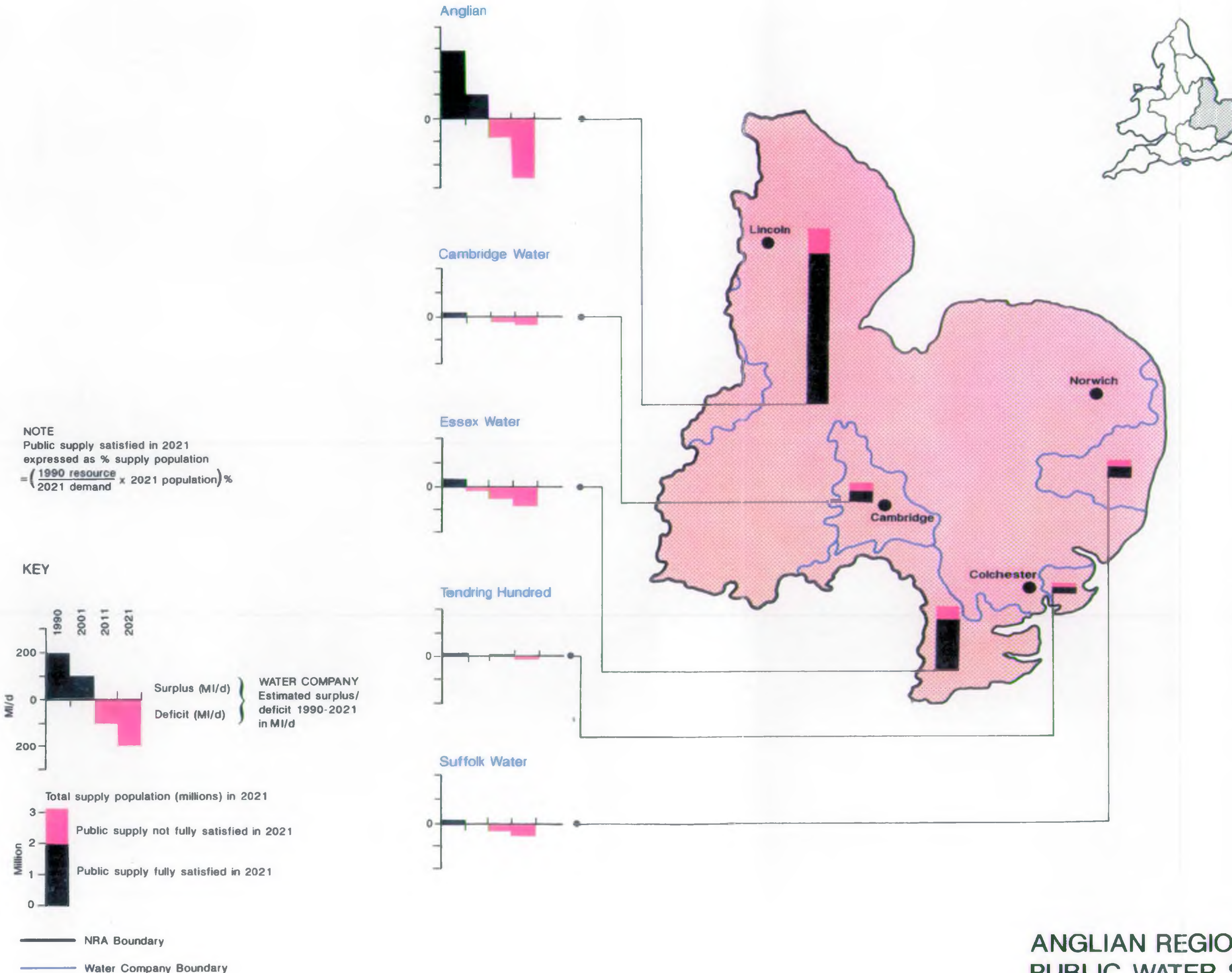
Figure 7



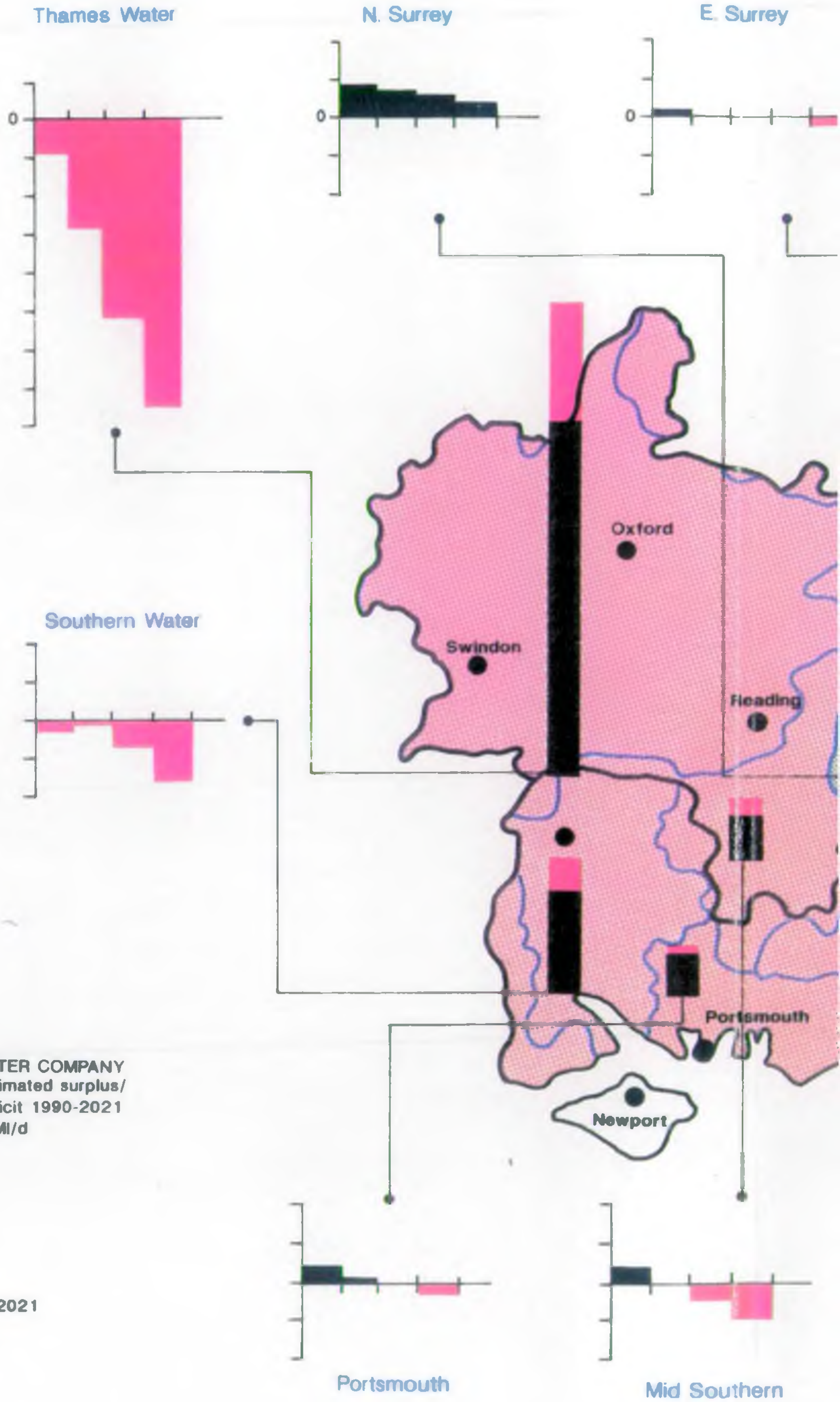
NOTE
Public supply satisfied in 2021 expressed as % supply population

$$= \left(\frac{\text{1990 resource}}{\text{2021 demand}} \times \text{2021 population} \right) \%$$

WELSH AND SEVERN TRENT REGIONS: PUBLIC WATER SUPPLY SURPLUS/DEFICIT



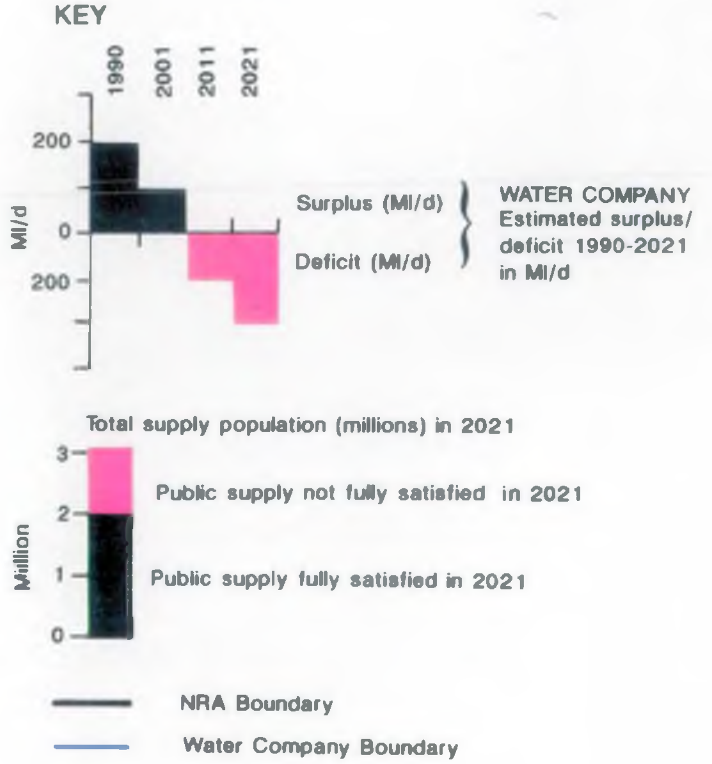
ANGLIAN REGION: PUBLIC WATER SUPPLY SURPLUS/DEFICIT

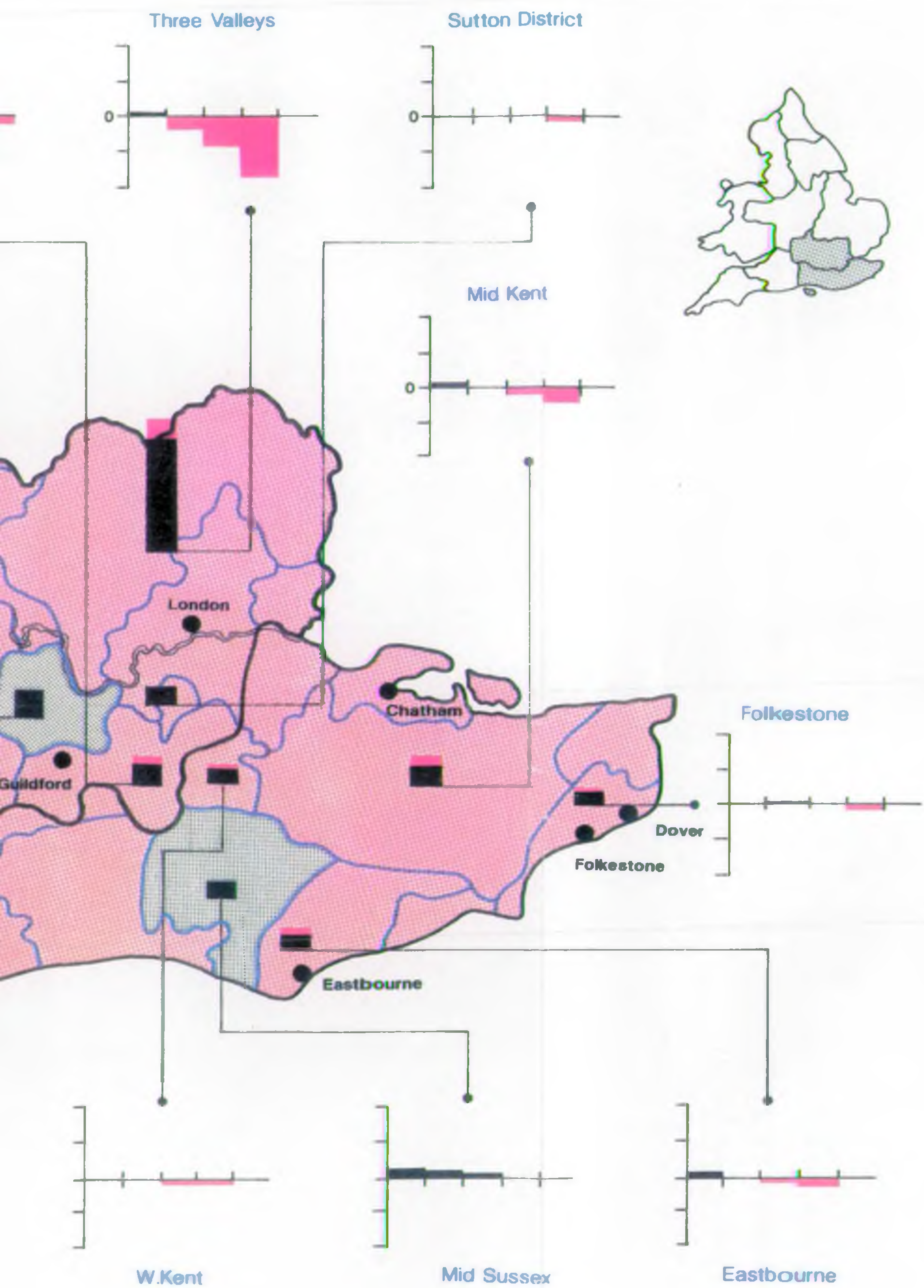


NOTE
Public supply satisfied in 2021
expressed as % supply population

$$= \left(\frac{\text{1990 resource}}{\text{2021 demand}} \times \text{2021 population} \right) \%$$

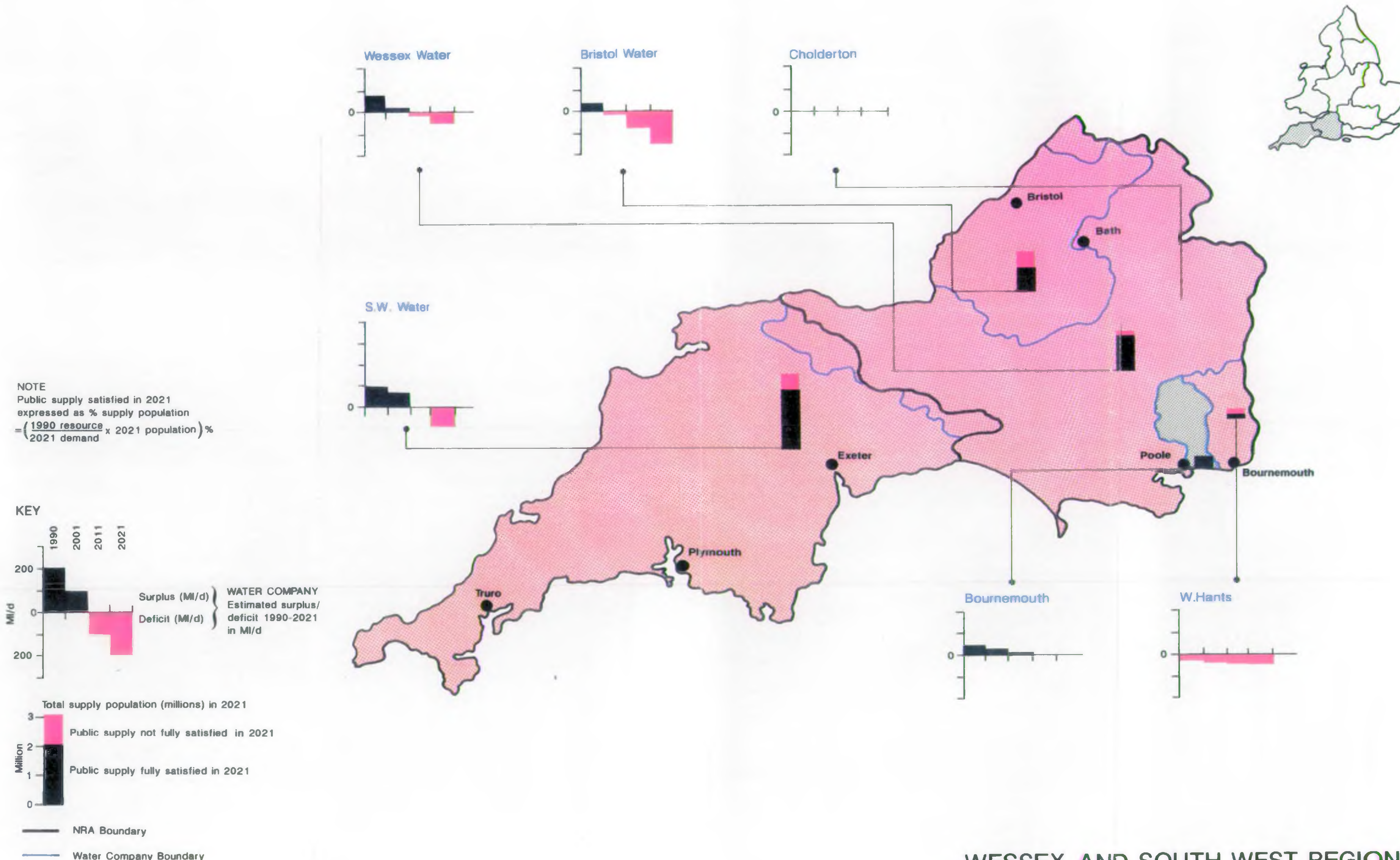
KEY



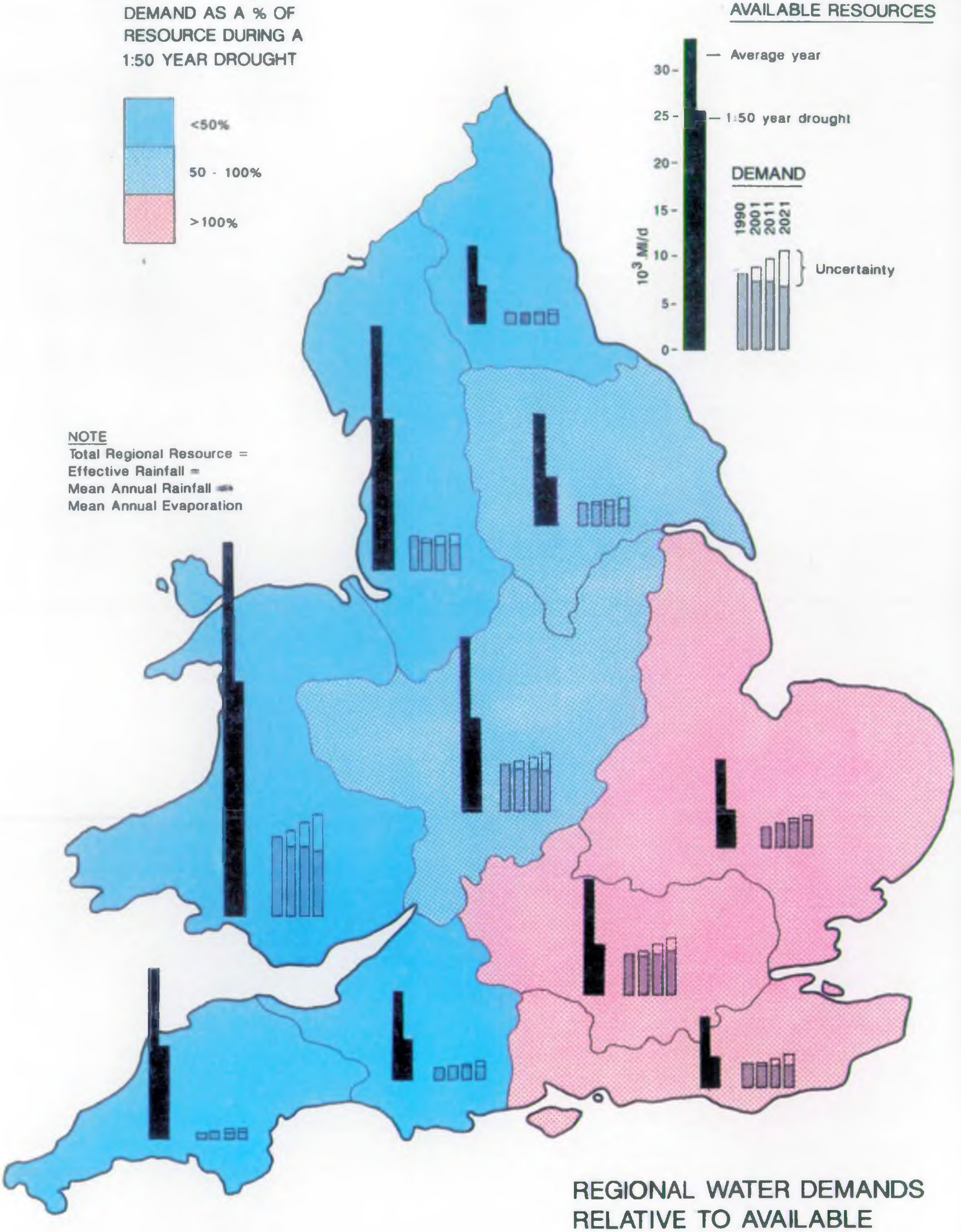


THAMES AND SOUTHERN REGIONS:
PUBLIC WATER SUPPLY SURPLUS/DEFICIT

Figure 10



WESSEX AND SOUTH WEST REGIONS: PUBLIC WATER SUPPLY SURPLUS/DEFICIT



REGIONAL WATER DEMANDS RELATIVE TO AVAILABLE RESOURCES 1990 - 2021

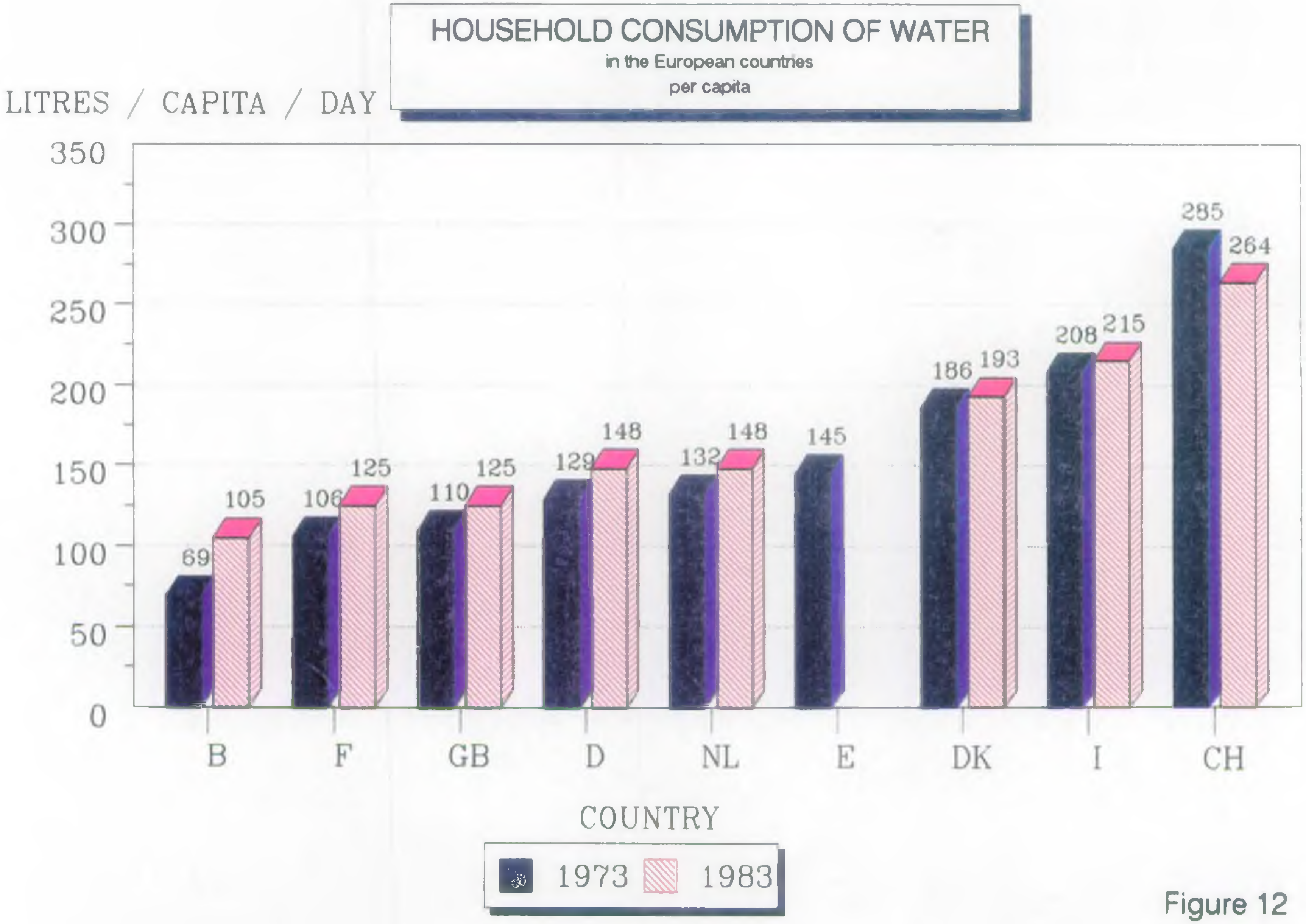

HOUSEHOLD CONSUMPTION OF WATER
in the European countries
per capita
LITRES / CAPITA / DAY
350
300
250
200
150
100
50
0
69
105
106
125
110
125
129
148
132
148
145
186
193
208
215
285
264
B
F
GB
D
NL
E
DK
I
CH
COUNTRY
1973
1983

Figure 12

Average Household Water Use.

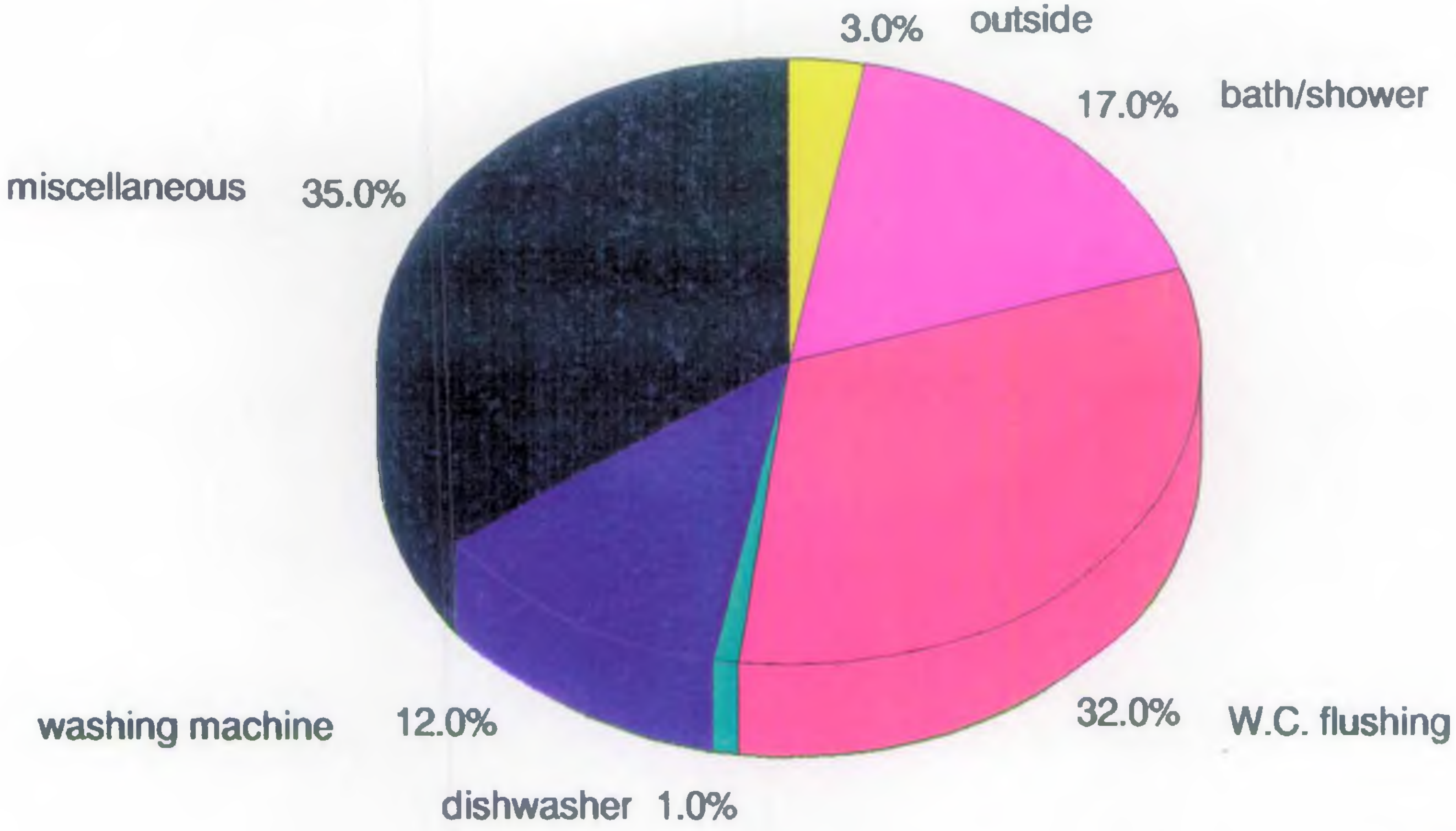
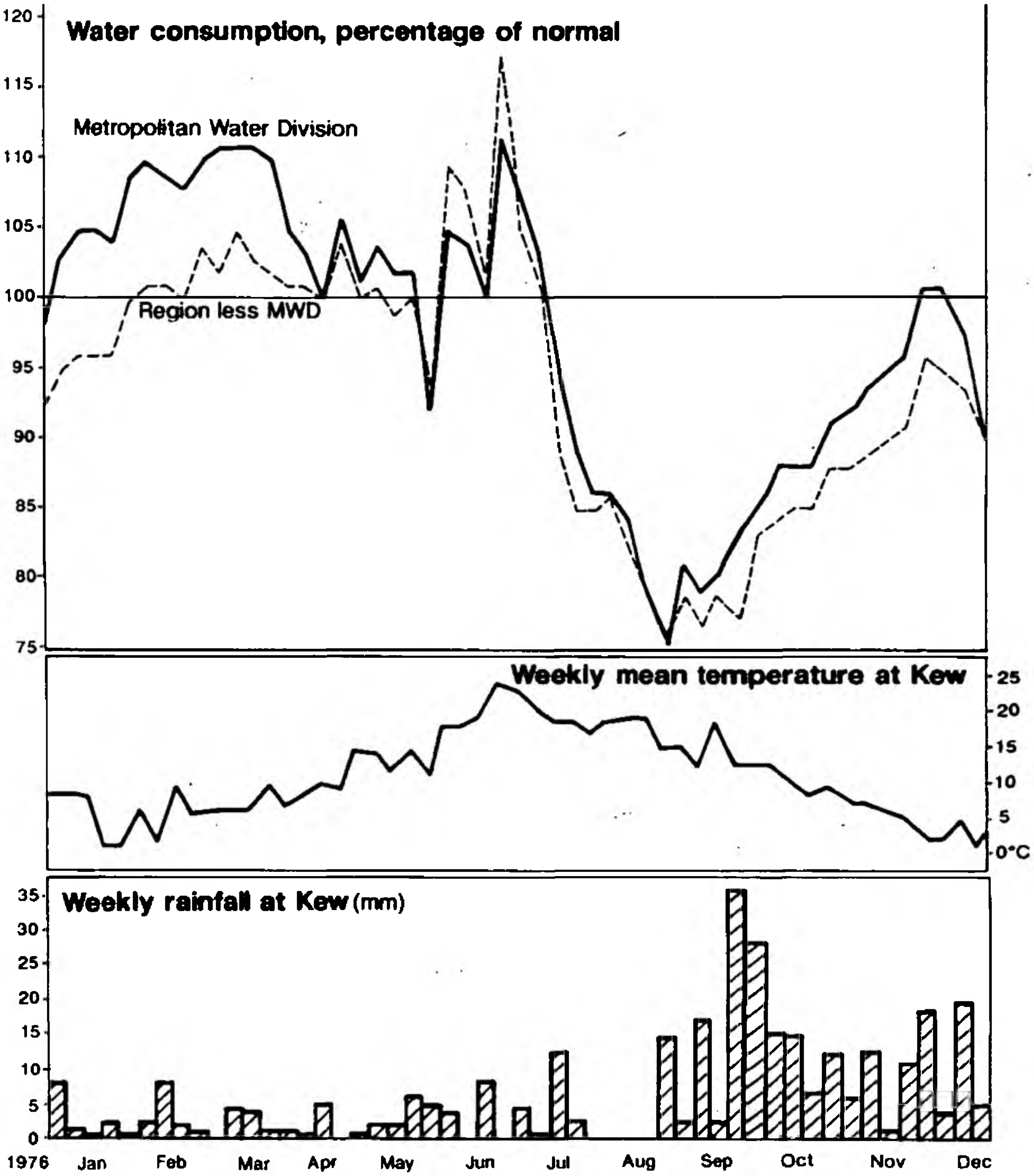


Figure 13



Notes:

1. Water consumption included.

WATER SUPPLY CONSUMPTION 1976 IN THE THAMES REGION (As percentage of normal)

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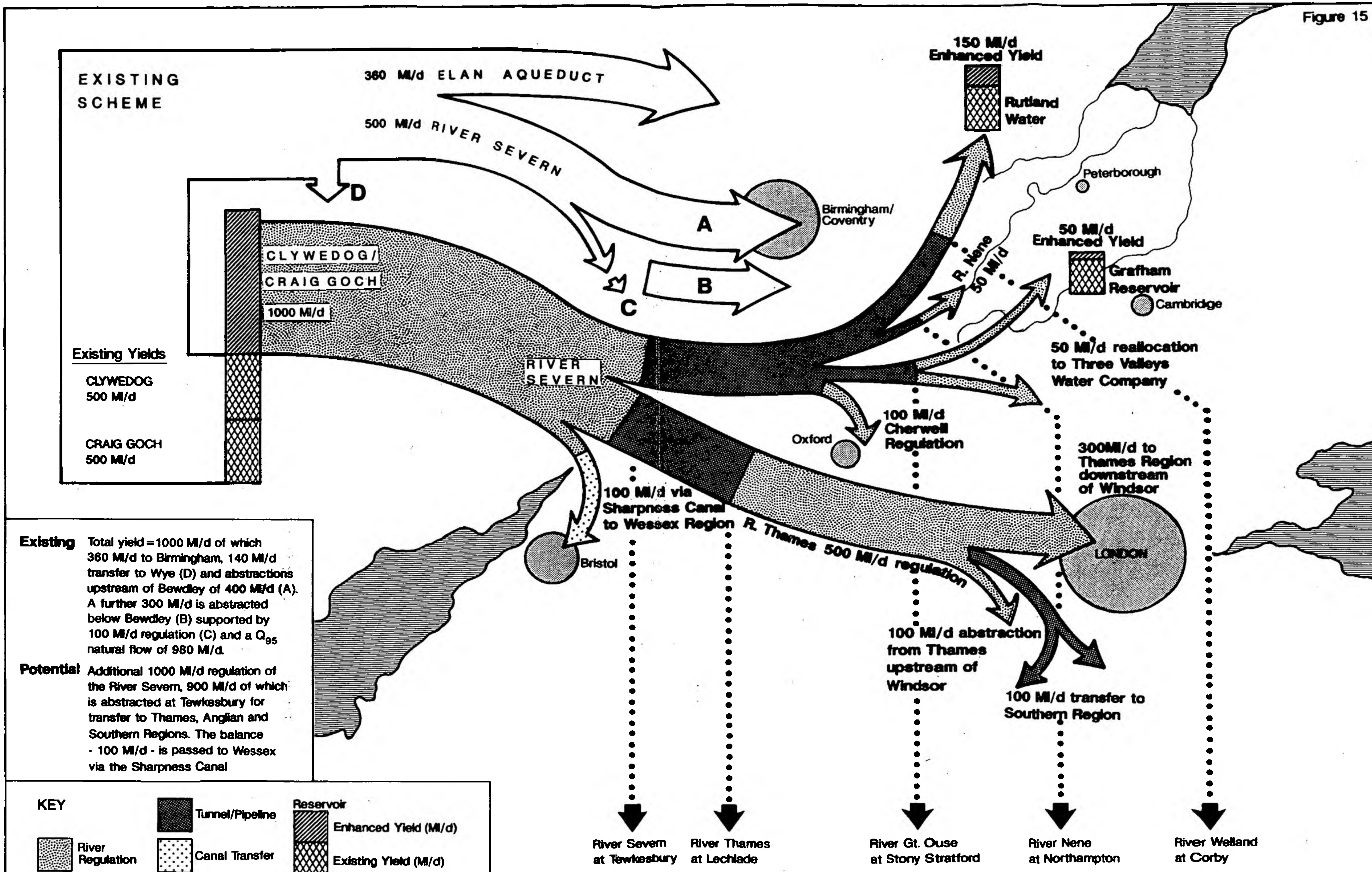
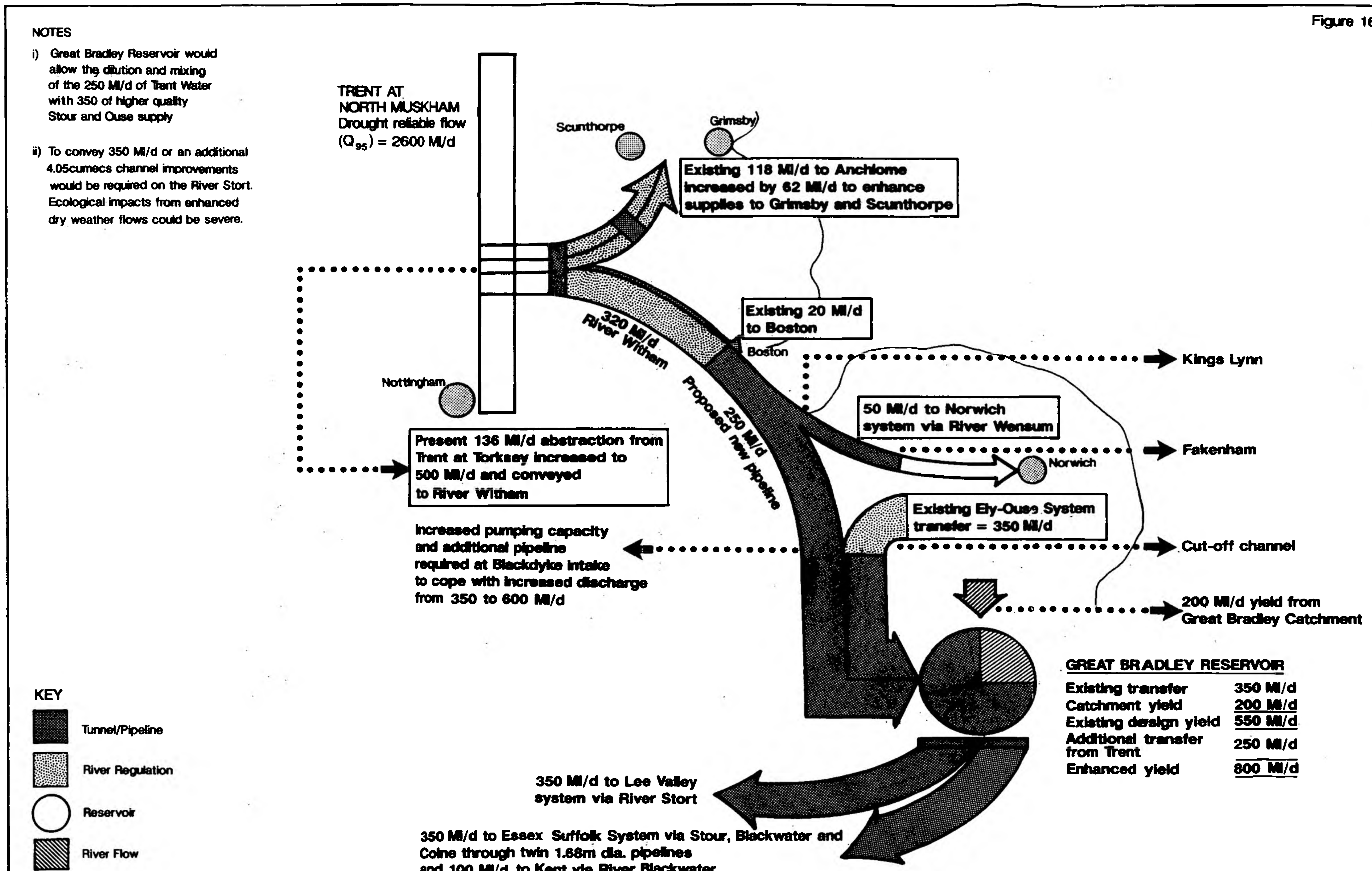
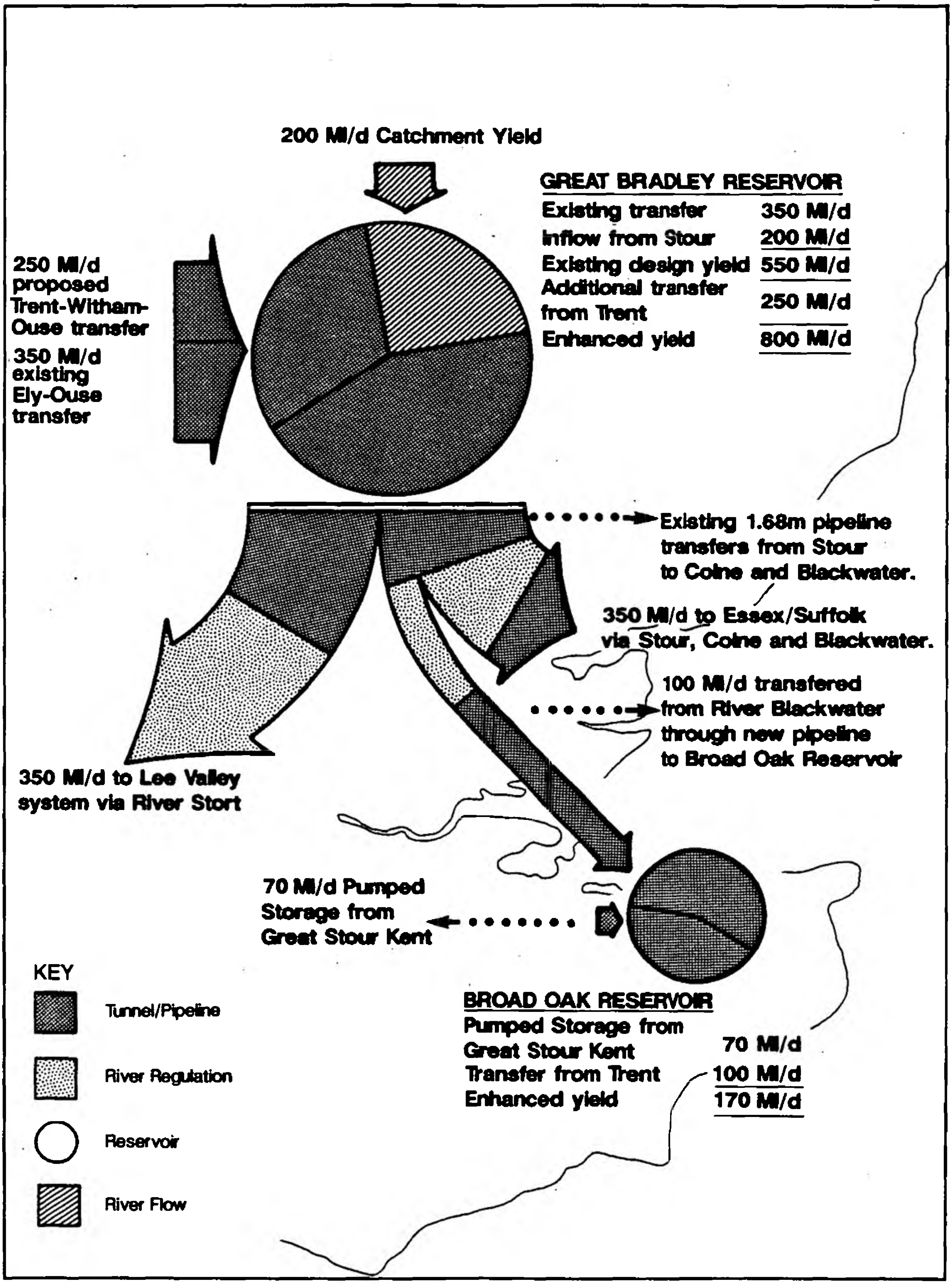


MID CAMBRIAN SCHEME

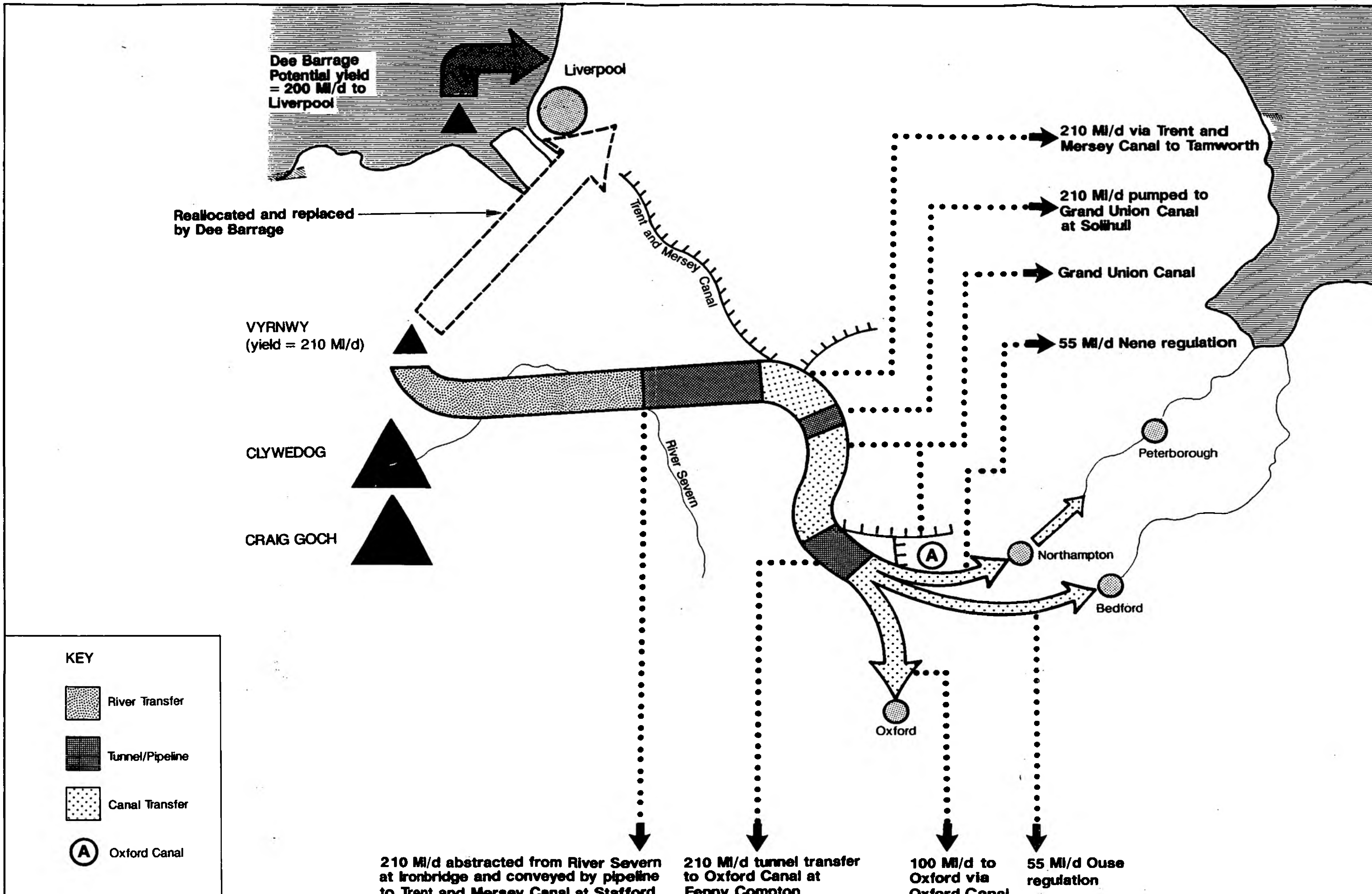
Figure 16



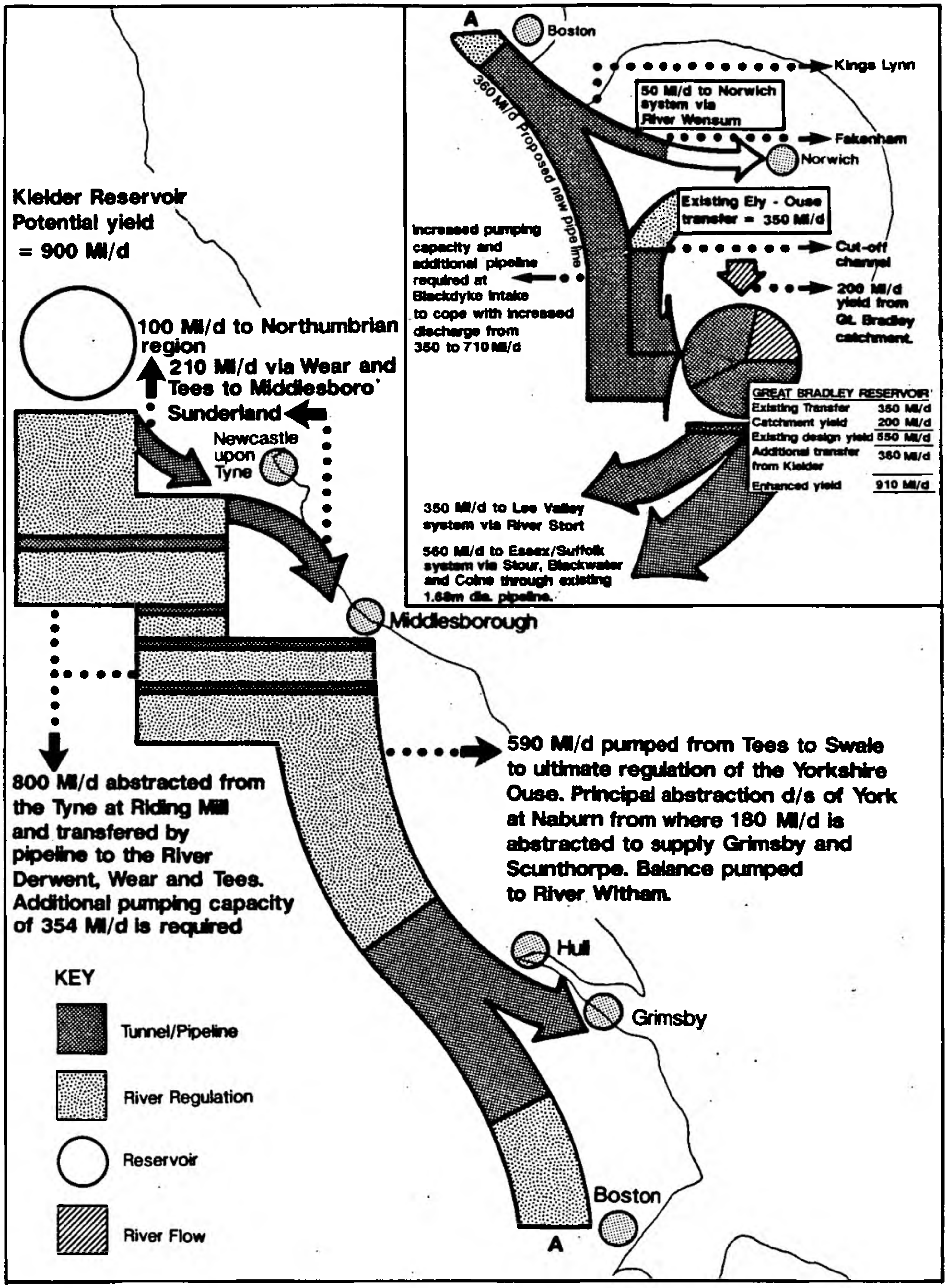
COMBINED TRENT - WITHAM - OUSE SYSTEM



ESSEX - KENT TRANSFER

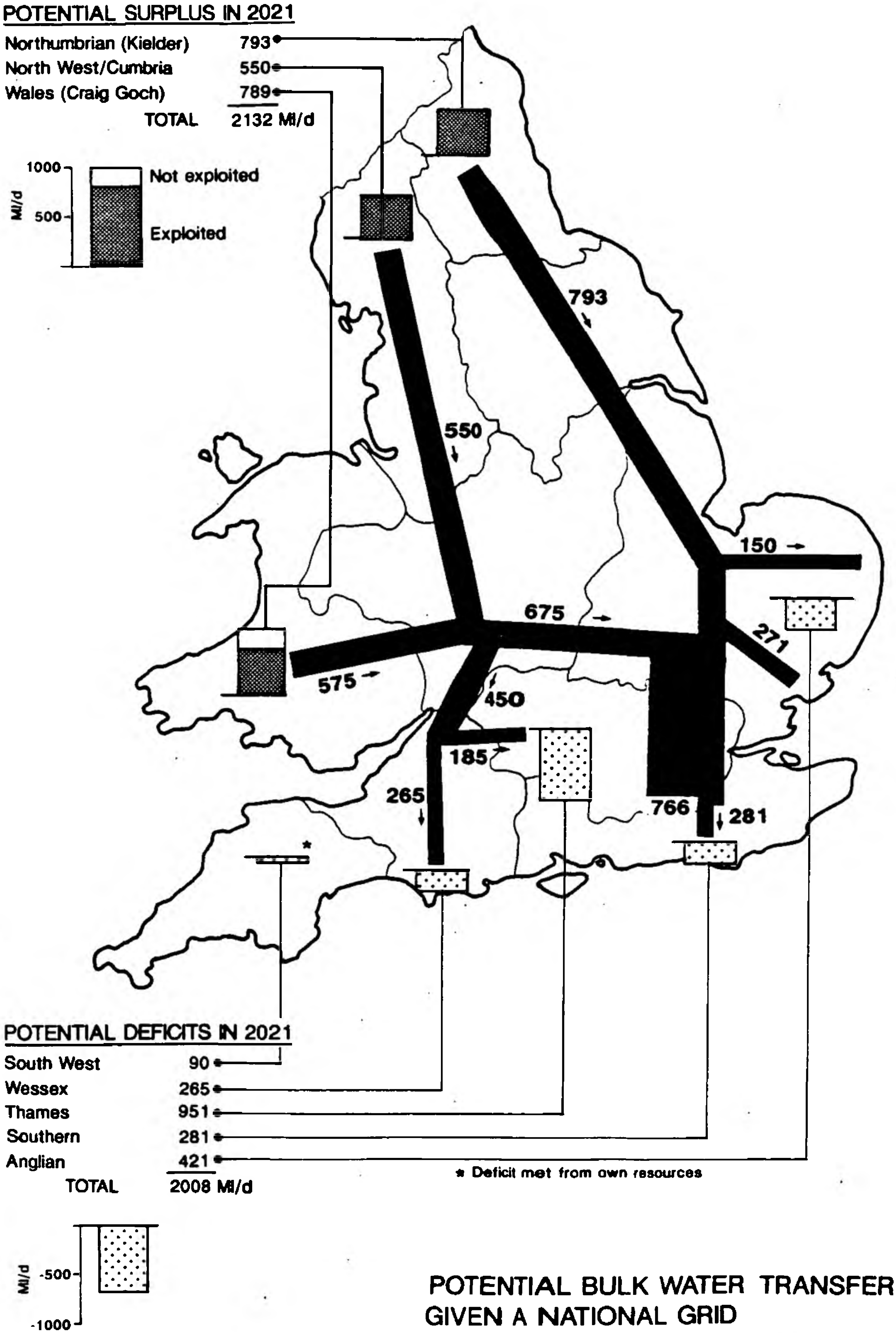


VYRNWY SUPPLY DISTRIBUTION



KIELDER - ANGLIAN REGION TRANSFER

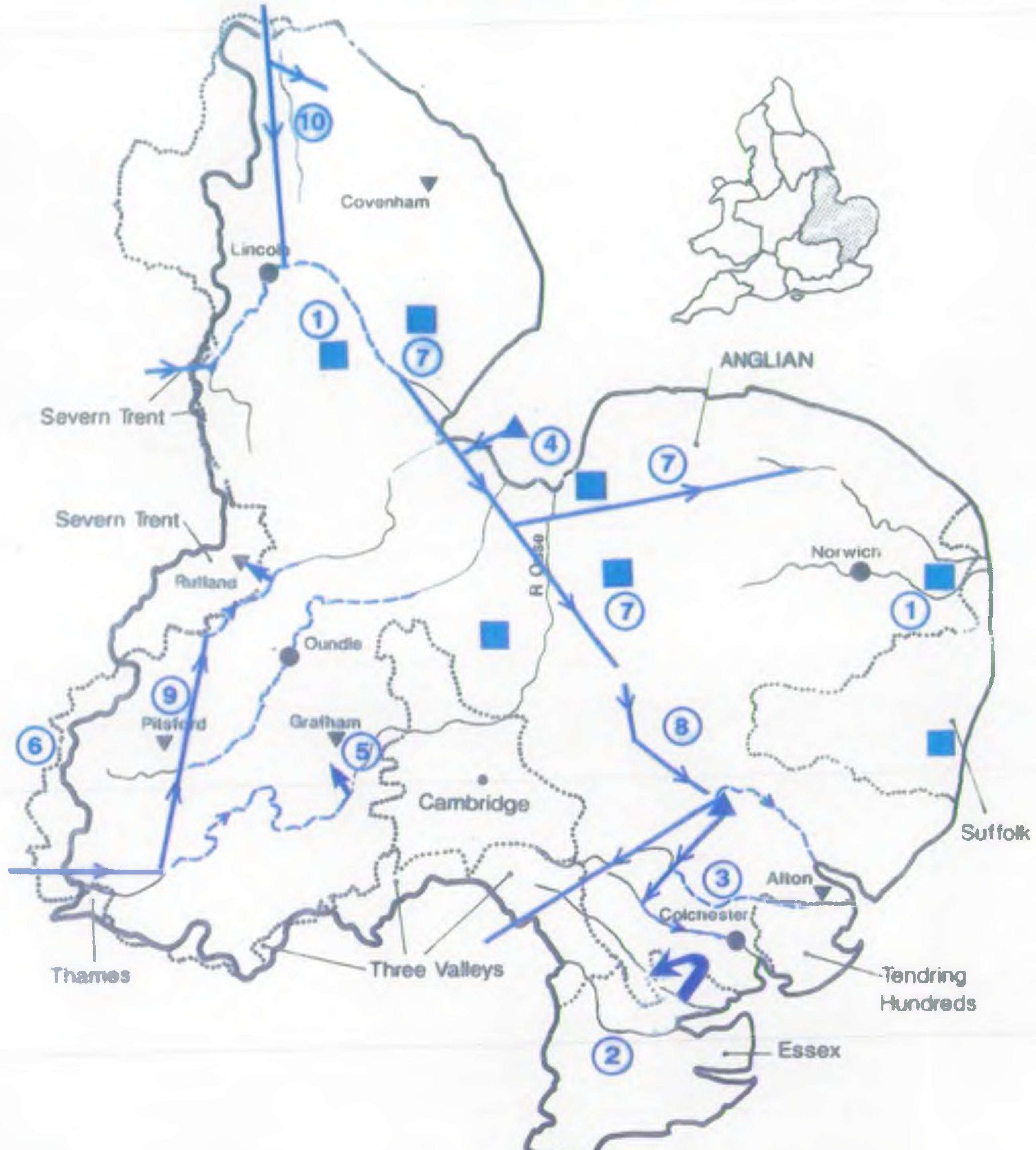
Figure 20



POTENTIAL BULK WATER TRANSFER GIVEN A NATIONAL GRID

Figure 21

ANGLIAN STRATEGIC OPTIONS



KEY

- N.R.A. Region Boundary
- Water Company Boundaries
- Principal Reservoirs & Lakes

STRATEGIES

- Reservoir and Barrage
- Groundwater
- River Regulation
- Aqueducts and Pipelines
- Reuse Scheme
- Section 143 Schemes

	Potential Yield	Ml/d		Potential Yield	Ml/d
1	Groundwater	480	6	Craig Goch and Severn Trent Transfer	300
2	Chelmsford Effluent Reuse	45	7	Trent-Witham Transfer *including 250 Ml/d for 8	364*
3	Great Bradley Reservoir	200	8	Ely Ouse - Essex System Enhancement	250
4	Wash Barrage	450	9	Vyrnwy Redistribution	110
5	Grafham Pumped Augmentation	75	10	Kielder - Anglian Region Transfer	590

ANGLIAN N.R.A. REGION

Figure 22

NORTHUMBRIAN STRATEGIC OPTIONS

KEY

- N.R.A. Region Boundary
- Water Company Boundaries
- Principal Reservoirs & Lakes

STRATEGIES

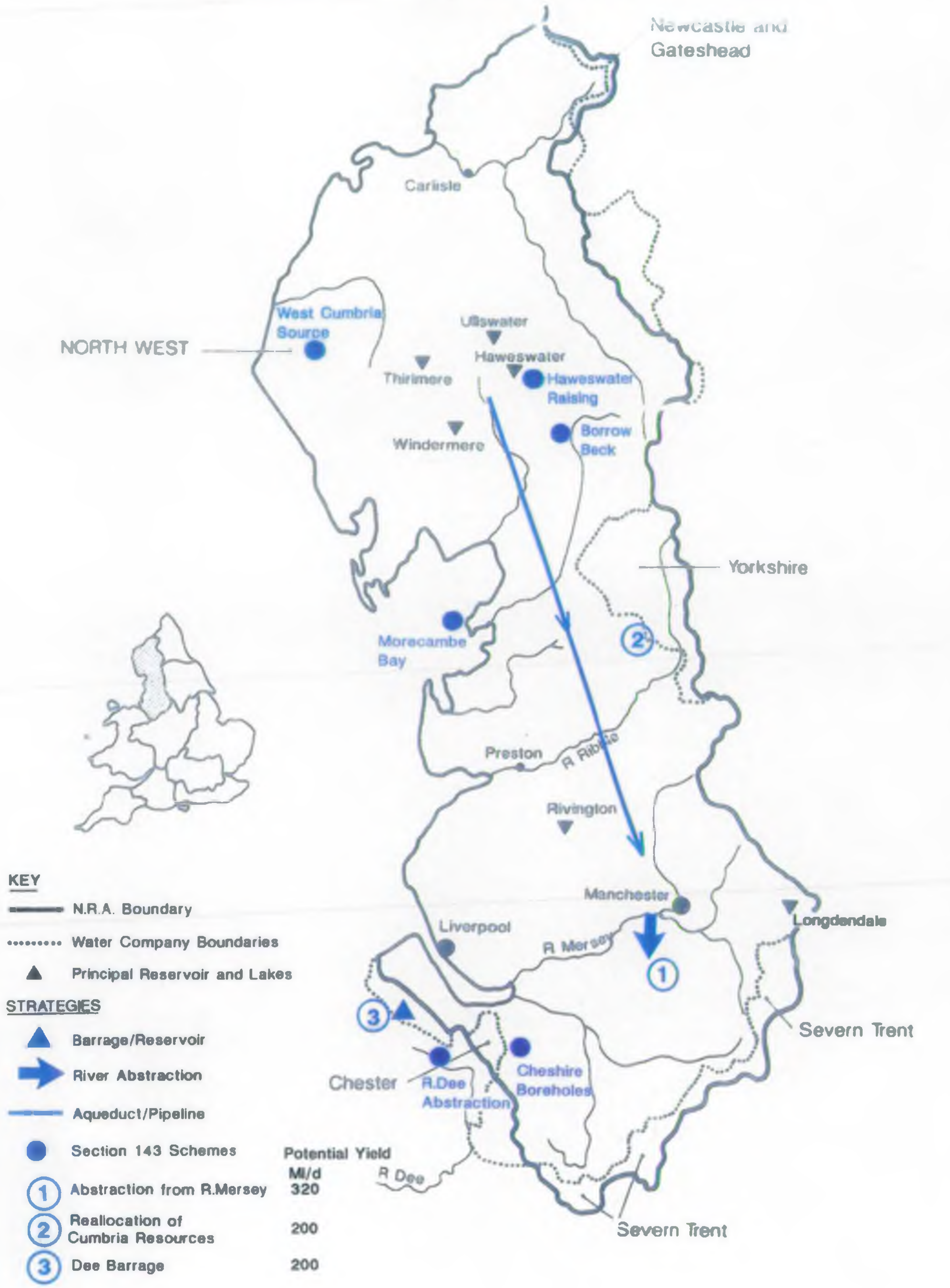
- River Regulation
- Aqueduct/Pipeline
- Water Shipment
- Section 143 Schemes

	Potential Yield	Ml/d
1	Tees-Swale Link	590
2	Chapel Cross Transfer	100-200
3	Shipment of Water	max 70

NORTHUMBRIA N.R.A. REGION

Figure 23

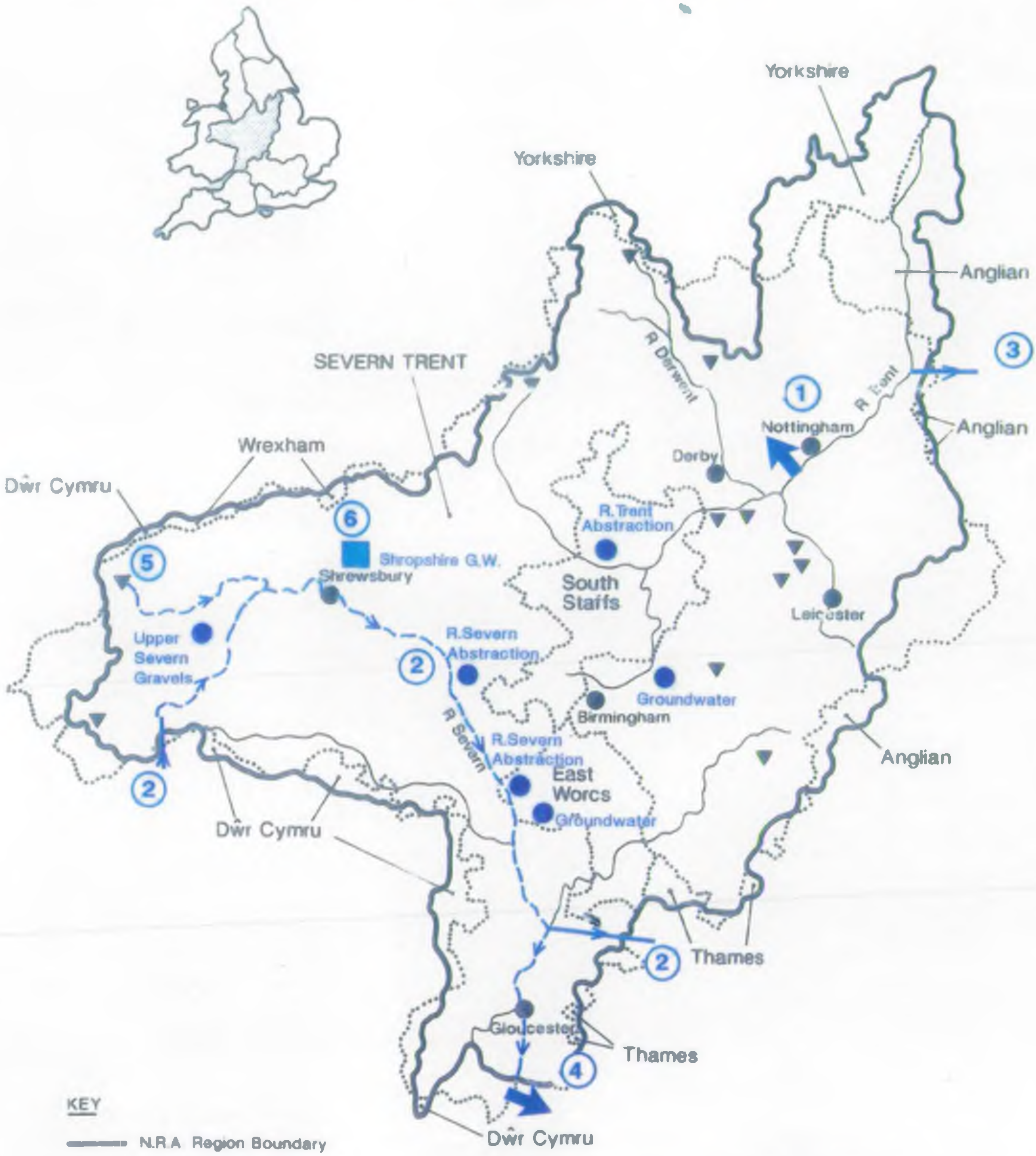
NORTH WEST STRATEGIC OPTION



NORTH WEST N.R.A. REGION

Figure 24

SEVERN TRENT STRATEGIC OPTIONS



KEY

- N.R.A. Region Boundary
- Water Company Boundaries
- Principal Reservoirs & Lakes

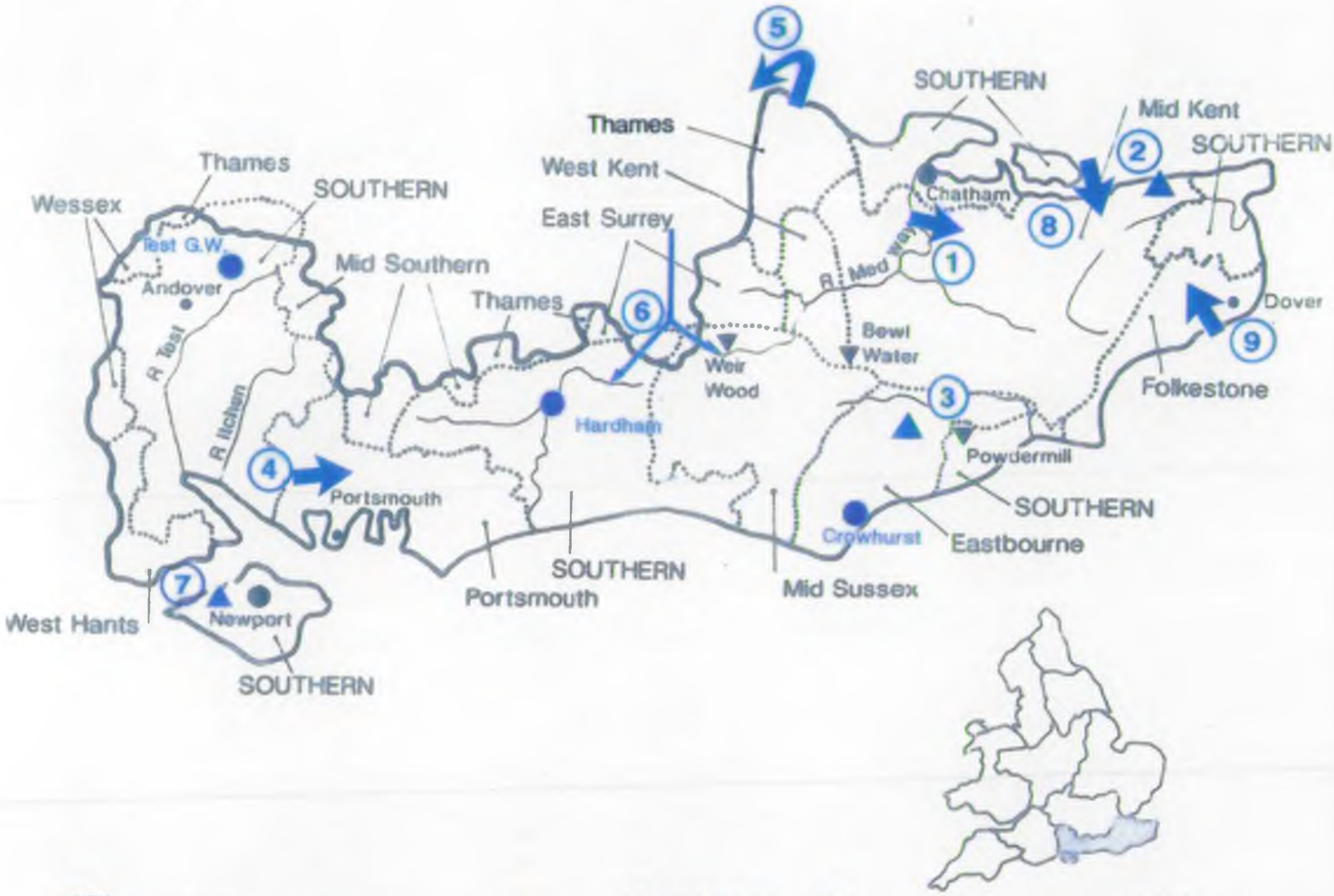
STRATEGIES

- River/Canal Regulation
- River Abstraction
- Aqueduct/Pipeline
- Groundwater
- Section 143 Schemes

	Potential Yield	Ml/d
1	Future Abstraction from River Trent	–
2	Craig Goch and Severn-Thames Transfer	1000
3	Increased Trent-Witham Transfer	+364
4	Increased Abstraction from Gloucester and Sharpness Canal	+110
5	Vyrnwy Reallocation Scheme	210
6	Future Shropshire Groundwater Developments	99

SEVERN TRENT N.R.A. REGION

SOUTHERN STRATEGIC OPTIONS



KEY

- N.R.A. Region Boundary
- Water Company Boundaries
- Principal Reservoirs & Lakes

STRATEGIES

- Reuse Scheme
- Aqueduct/Pipeline
- Reservoir
- Groundwater
- River Abstraction
- Section 143 Schemes

	Potential Yield	Ml/d
1	Yalding Intake	25
2	Broad Oak Reservoir	70
2	Darwell Enlargement	40
4	Gaters Mill	22
5	Darent Effluent Reuse	75
6	Severn-Thames Transfer	200
7	Chillerton Reservoir	8

		Ml/d
8	Essex - Kent	100
9	France - Kent	100

Figure 26

SOUTH WEST STRATEGIC OPTIONS

KEY

- N.R.A. Region Boundary
- Water Company Boundaries
- Principal Reservoirs

STRATEGIES

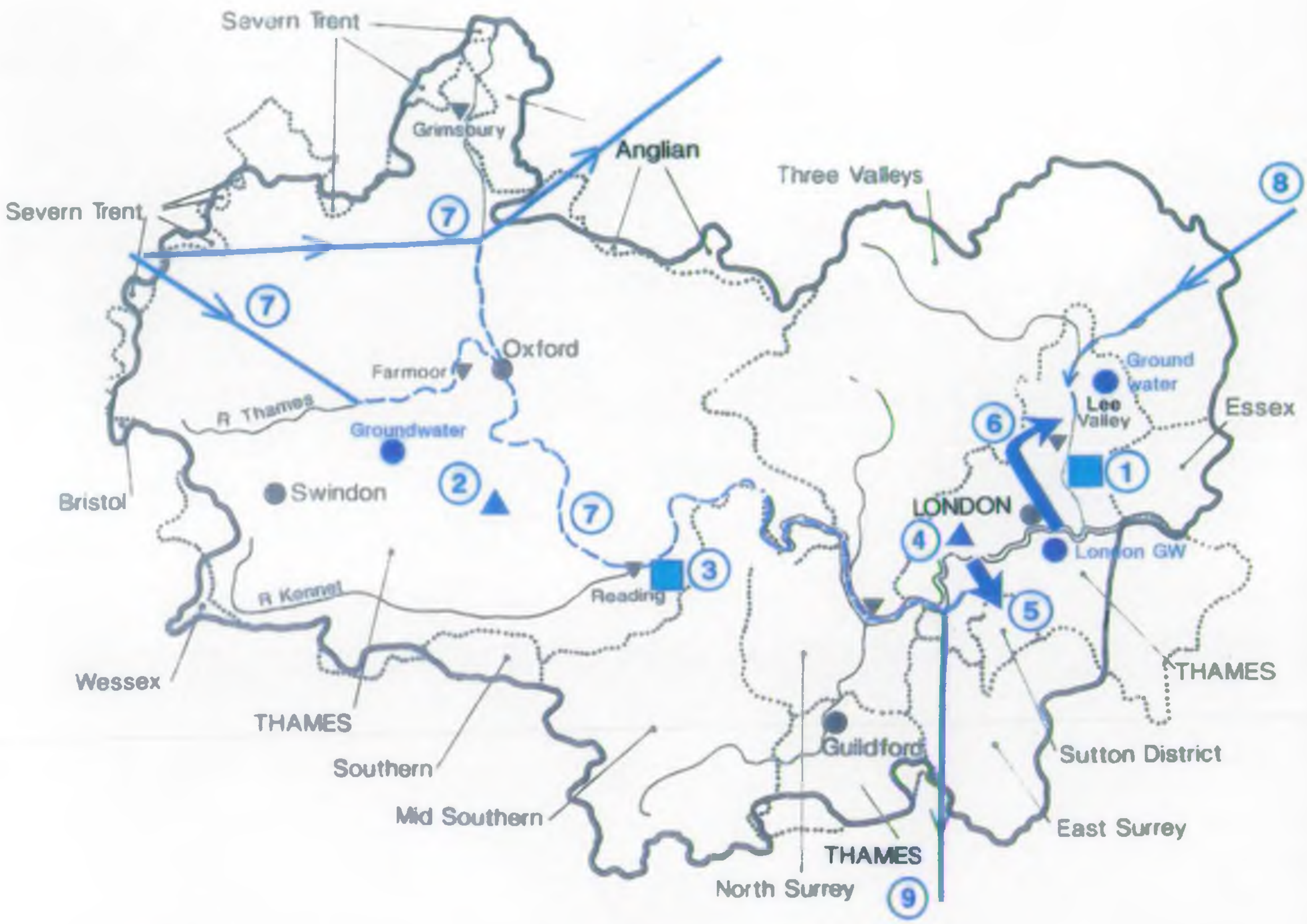
- Reservoir
- Section 143 Scheme

	Potential Yield	Ml/d
1	Wimbleball	40
2	Axe Reservoir	24
3	Roadford	50

SOUTH WEST N.R.A REGION

Figure 27

THAMES STRATEGIC OPTIONS



KEY

- N.R.A. Region Boundary
- Water Company Boundaries
- Principal Reservoirs & Lakes

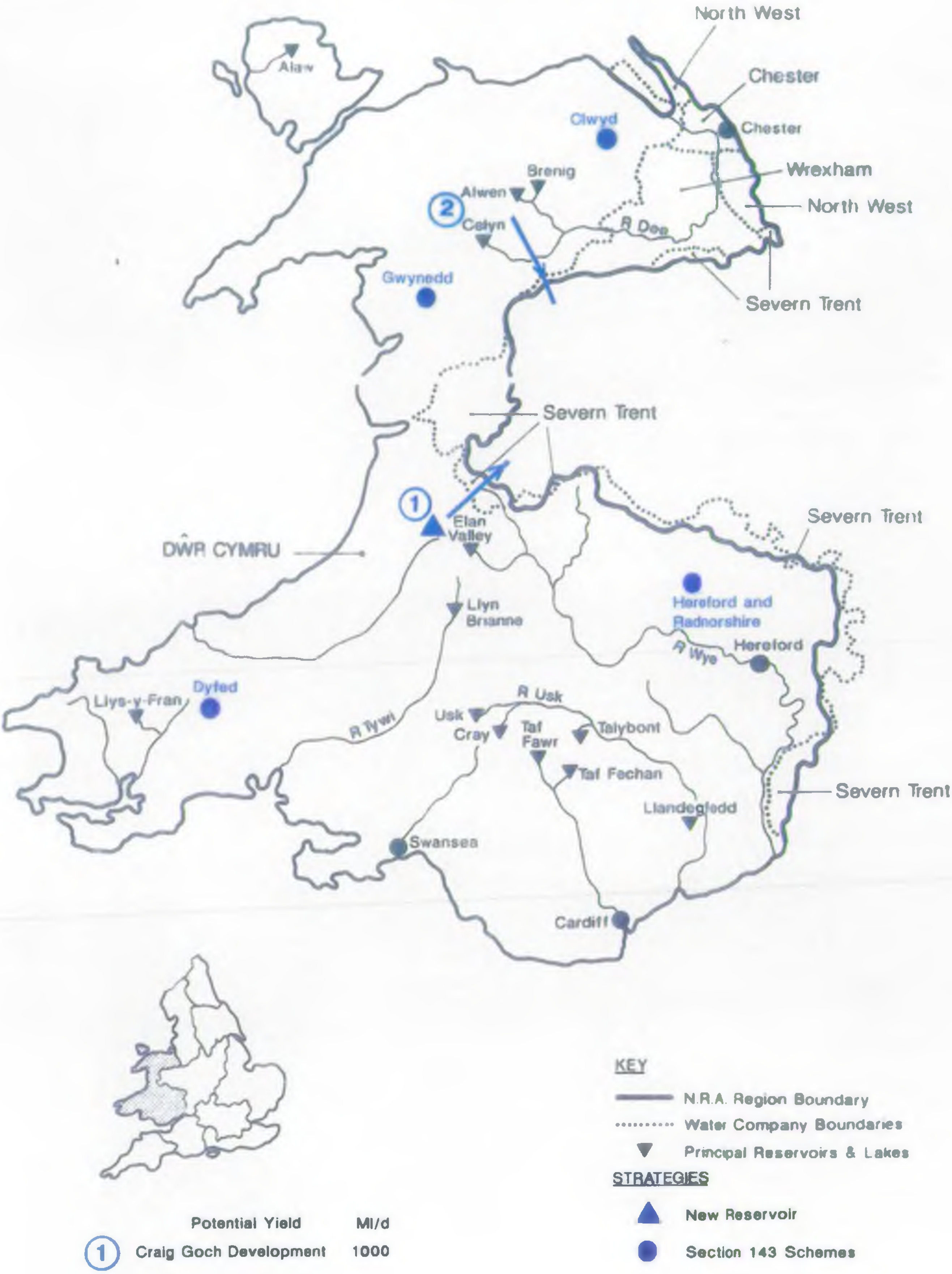
STRATEGIES

- Reuse Scheme
- Aqueduct/Pipeline
- River Regulation
- Groundwater
- Reservoirs
- River Abstractions
- Section 143 Schemes

	Potential Yield	Ml/d
1	Artificial Recharge in London	180
2	New Reservoir in Upper Thames	200
3	Gatehampton Groundwater	55
4	Redevelopment of Existing Reservoirs	100
5	Increased Thames Abstractions	91
6	Deephams Reuse Scheme	150
7	Severn-Thames Transfer	600
8	Transfer from Great Bradley	350
9	Transfer to Southern Region	100

THAMES N.R.A. REGION

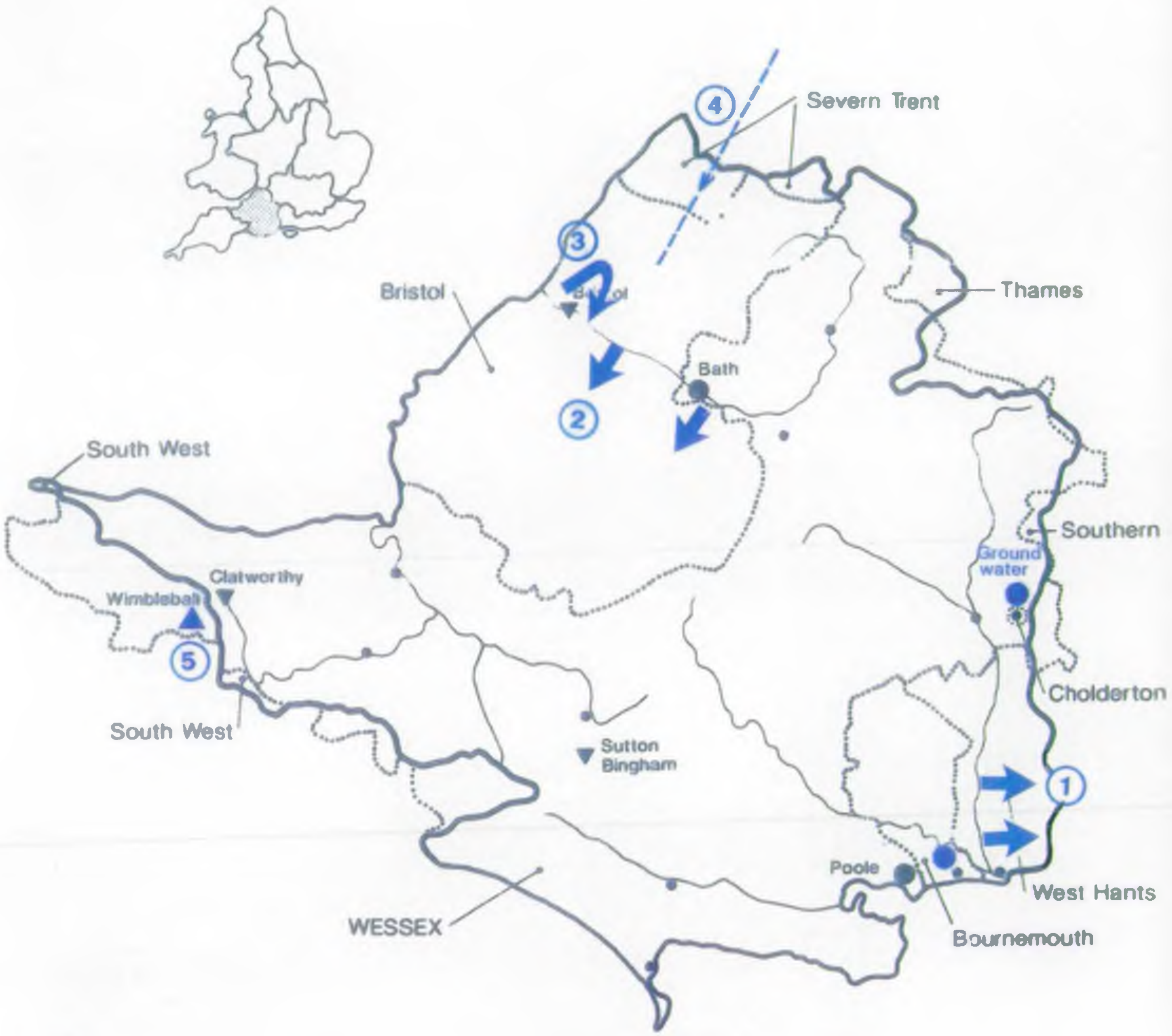
WELSH STRATEGIC OPTIONS



	Potential Yield	Ml/d
1	Craig Goch Development	1000
2	Dee Reservoir Supply	600

WELSH N.R.A REGION

WESSEX STRATEGIC OPTIONS



KEY

- N.R.A. Region Boundary
- Water Company Boundaries
- ▼ Principal Reservoirs and Lakes

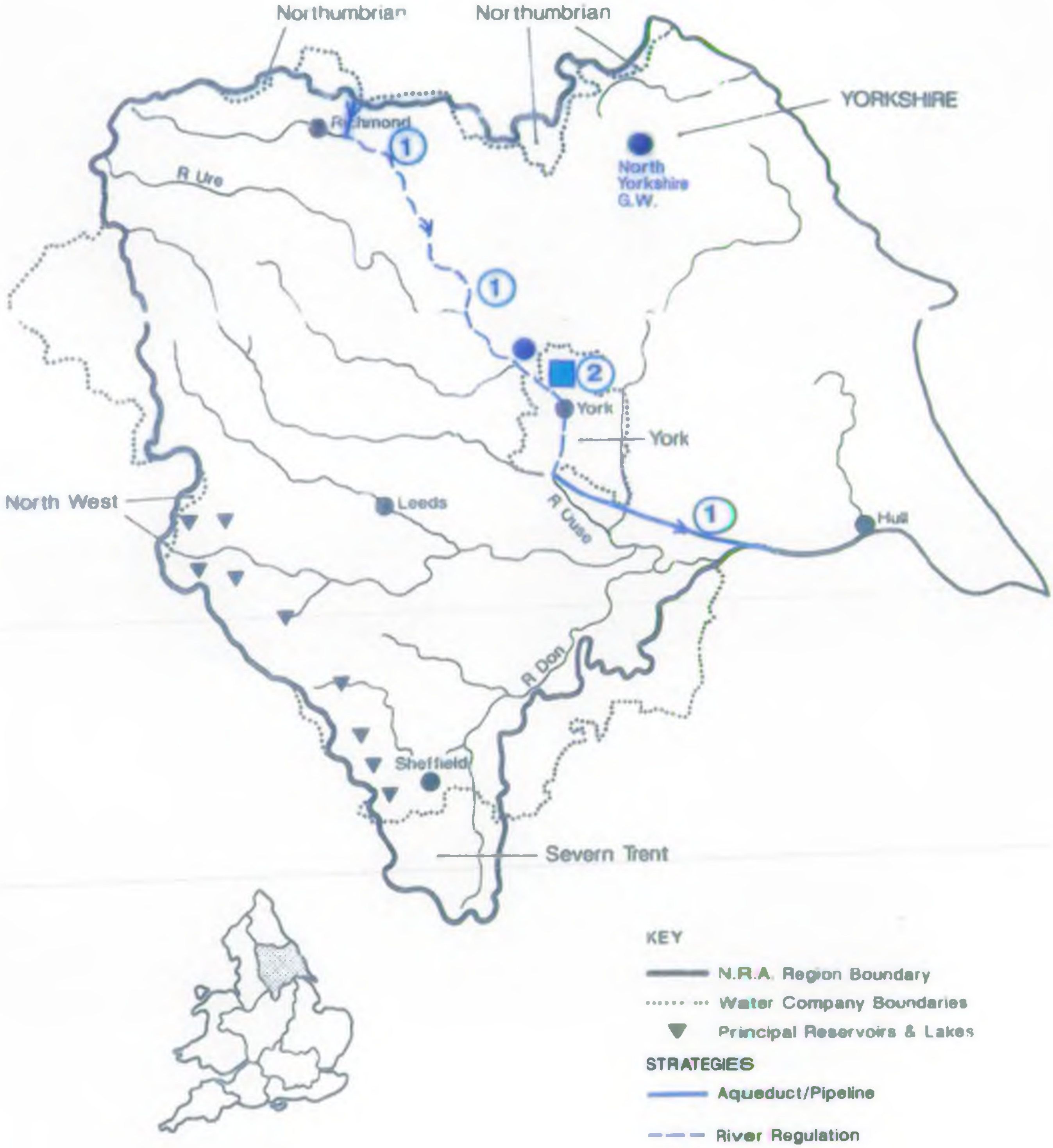
STRATEGIES

- Reuse Scheme
- Canal Regulation
- River Abstraction
- Reservoir
- Section 143 Schemes

	Potential Yield	Ml/d
1	Hampshire Avon Schemes	79
2	Bristol Avon Pumped Storage Schemes	85
3	Bristol Reuse Scheme	50
4	Severn/Sharpness Canal Transfer	110
5	Wimbleball Transfer	16

WESSEX N.R.A. REGION

YORKSHIRE STRATEGIC OPTIONS



Potential Yield	Ml/d
(1) Tees-Swale Link	590
(2) Vale of York Groundwater	200

Appendix A

LETTER OF INVITATION AND TERMS OF REFERENCE

HALCROW

NRA

Mr. J. Lawson
Sir William Halcrow & Partners
Burderop Park
Swindon
Wilts SN4 OQD

11 December 1990

Dear Mr. Lawson,

Water Resources Planning - Strategic Options

1. You are invited to submit proposals in accordance with the enclosed technical brief and as further detailed below.

2. Three copies of the proposal are required by 12 noon on Friday 18 January 1991.

3. Minimum requirements for the proposal are that it should contain:-

   - A summary of the consultant's understanding of the scope of the study
   - How the consultant proposes to carry out the study
   - An indication of the proposed extent and form of liaison with NRA regions
   - Programme of key activities
   - Staffing proposals with CV's of key staff
   - Information relating to similar or relevant studies carried out by key staff who are included in the proposal.
   - Proposed method of payment
   - Proposed contractual basis

4. In addition you may make comments on the technical brief and include suggestions on how the study may be improved.

5. You are asked to prepare your bid assuming a fixed price of £80,000 + VAT. The successful consultant will be selected on a comparison of these bids but subsequently the NRA may wish to amend the technical brief in the light of comments or suggestions made by the consultant, and then negotiate a contract with the successful consultant.

6. The proposed duration of the study is 6 months and it is intended to let the contract to the selected consultant in January or February 1991.

NRA

7. Brief progress reports will be required on a monthly basis.

8. 20 copies of progress and study reports will be required.

9. Please confirm your intention to bid within 3 days of receipt of this invitation.

Yours sincerely,

J. Sherriff

J. SHERRIFF
Water Resources Manager

NATIONAL RIVERS AUTHORITY
WATER RESOURCES DEVELOPMENT OPTIONS

Technical Brief for Consultancy Project

1. Introduction and Objective

1.1 The National Rivers Authority (NRA) is required under S.143 of the Water Act 1989 to publish water resources strategy proposals.

1.2 The objective of this Consultancy Project is to provide the general basis and feasible water resource development options to enable the NRA subsequently to formulate a National Water Resources Planning and Development Strategy, following consultation with other parties on the issues and options identified.

2. Terms of Reference

The Terms of Reference for the Consultancy Project are:

2.1 Carry out a review of the prevailing development and use of water resources in each NRA region of England and Wales in meeting existing demands for water. The review would be based principally on information and data provided to the Consultants by the NRA.

2.2 Collate and review estimates of future demands for water in each NRA region for all requirements involving abstraction up to the year 2021 in 10 year steps. The Consultant is required to consider the basis and consistency of the estimates which would be based principally on information and data provided to the Consultant by the NRA.

2.3 On the basis of the reviews of current development and use of water resources (2.1) and of future demand estimates (2.2), consider the scope and options available to the NRA to formulate a sustainable policy and plans for developing and augmenting water resources to meet existing and estimated future demands for water in England and Wales to 2021.

2.4 Assess and review the balance of advantages and disadvantages of the various options and proposals considered, together with the extent and circumstances in which they may be appropriate. These assessments would take into account environmental requirements and other relevant criteria (including in-situ needs in terms of water level, quantity, quality and environmental aspects) whilst also giving due weight to cost and economic considerations.

2.5 The broad scope and steps envisaged in the Project are set out in the remainder of this Technical Brief.

2.6 Submit an overview report on the foregoing assessments, forecasts and options by 28 June 1991 with two interim reports at agreed prior dates on the provisional assessments in respect of 2.1 and 2.2 respectively.

3. Present Resource/Demand Balance

3.1 The objective of this part of the study is to identify and quantify the use of abstracted water in each of the NRA regions (or sub-regions as appropriate) and quantify the resources presently available for meeting the abstraction demands, including identification of circumstances of surplus or deficits.

3.2 It is emphasised that the purpose of this part of the study is to obtain a meaningful overview of the balance between resources and demands rather than seeking detail and precision.

3.3 Information should be presented on the broad categories of use within the region or sub-region [eg. public water supply, industry, agriculture, (excluding spray irrigation), spray irrigation] including estimates of total abstraction, net abstraction, re-use and discharges to tidal waters. A breakdown between surfacewater and groundwater abstractions should be included.

3.4 The Consultant is required to collate information on the level of existing resources available within each NRA region (or sub-region) which would include reliable yield estimates of the major sources/systems. However the Consultant is not intended to undertake his own reliable yield estimates.

3.5 The views of the Consultant are sought on the magnitude of the major existing source/system yield estimates in the light of their capability to operate effectively during drought conditions and of their environmental impact.

3.6 Information for this part of the study will be made available by the NRA and will include abstraction licence data, resource estimates and miscellaneous reports relating to resources and demands.

4. Future Demands and Resulting Deficiency of Existing Abstraction and Resource Capability

4.1 The first step in this "future" stage of the Project is to obtain a broad overview estimate of future likely demands for water that is meaningful and consistent without being detailed or aiming at second order precision.

4.2 The NRA through its regional units will endeavour to collect public water supply forecasts as seem appropriate following consultation with the Consultants who will be required to collate and review the forecast data thus obtained.

4.3 It is envisaged that the Consultants will be required to make his own forecasts of net abstractions for industry and agriculture including spray irrigation.

4.4 The forecasts are required as far as possible for the years 2001, 2011 and 2021 at least for each region of the NRA as a whole for the above categories of use. Where sub-regions within a region are adopted for data collected under Section 3 above, every effort should be made to collect the future demand data for the same areas. However this may not be feasible in all cases and some aggregation into regional forecasts may be necessary.

4.5 Considerable advantage is seen in making alternative higher and lower trend forecasts to produce a future demand envelope. This would make it possible to test the robustness/sensitivity and also the timing of potential solutions for meeting the range of demands postulated.

4.6 The Consultant will be required to collate and review the range of forecasts obtained as set out in paragraphs 4.2-4.5 above, identifying the catchments, use categories, net call on resources, date the forecast relates to, and whether high or low trend. Graphic presentation will be favoured wherever practicable. The Consultants will be required to identify any anomalies. If these cannot be accounted for by particular circumstances they will be asked to put forward alternative data more consistent with similar data applying elsewhere. The aim must be to present broadly consistent demand forecasts relevant to resource use and development, avoiding significant double counting or double omissions of foreseeable needs for abstracted water.

4.7 From the foregoing collation of future demand estimates/trends, the Consultants will be required to deduce the resulting deficiency of (a) existing abstraction and (b) resource capability in meeting such future demands and thus derive the scale of resource development required to meet estimated future demands.

5. Review of Options for Future Resource Strategy

5.1 The Consultants will be required to identify and review various potential options for meeting the deficiencies identified under Section 4 above, i.e. the future excess of demands at various future dates for abstracted water over existing actual and potential resource capacity in each NRA region as broadly quantified by the steps outlined above.

5.2 The following are regarded as options that require to be considered, reviewed and commented upon by the Consultants. It is recognised that they may not all be considered as technically, environmentally or economically feasible and would not therefore merit subsequent more detailed consideration. The following list is not intended to be either exhaustive or mutually exclusive. Indeed the likely eventual outcome following conclusion of the Project is seen as a strategy including a combination of options and proposals as appropriate for the various circumstances and requirements to be met.

(i) Enhanced general development of "local" sources within a region or catchment

This option envisages a continuation, where feasible, of meeting increased future demands within a region or main catchment by a general enhanced development of river abstraction, surface reservoir and/or groundwater sources as appropriate. In all cases the NRA regional water resources managers will be able to identify the nature and extent of future resource development considered to date together with the constraints and limitations likely thereon. This should be the main focus of the Consultants' review of this option, although they will be expected to put forward any additional proposals as candidates for inclusion in this category. The Consultants are not expected or required to carry out any detailed hydrological/yield assessment or cost studies - only those sufficient to satisfy general output capability, technical feasibility and cost range.

(ii) Inter-Regional Transfers

This transfers option would be applicable where resource capacity, environmental and/or economic considerations appeared to favour transfers from regions with existing or potential surplus water resources capacity to provide imports to those regions/catchments where resource development is required.

5.3 Within these basic options of "regional" or "inter-regional" development are several potential subsidiary options as set out below which relate to one or other or both of the above and which relate to means of storage, means of transmission, or means of influencing demand levels:

(iii) Demand Management

Given, as is believed to be the case, that Demand Management alone, however energetically pursued would in itself be insufficient to meet future resource deficiencies, it is necessary to consider this as a contributory or off-setting factor to be adopted to an appropriate level in association with resource development. The main aspects to consider in this project are (i) those elements of demand management likely to be most effective and viable and (ii) the extent that feasible and cost effective demand management may contribute to closing the resource output/demand balance. Principal elements of demand management thought to be relevant in this context are leakage/wastage reduction, increased re-use and re-cycling of water, and tariff structuring.

The Consultants are asked to consider and comment upon the extent of demand reduction that seems realistic and appropriate to take into account following investment in this course, and to ensure a reasonably consistent approach between regions in corresponding circumstances.

(iv) Groundwater Development

The Project should include consideration of the scope for further development of groundwater in the light of constraints relating to natural recharge, environmental consequences of abstraction, and water quality for use as drinking water. In particular the Consultants should consider the feasible scope for artificial recharge as a means of extending the use of aquifers and off-setting the above constraints.

(v) Strategic Surface Water Storage

This would be seen mainly as a likely component of option (ii), transfers, for wide deployment. There are both advantages and disadvantages in concentrating storage in a strictly limited number of larger sources. The Project should include a review of the scope, suitable general locations, general costs and output as well as main advantages and disadvantages of this contributory option.

(vi) Multi-Source Interlinking and Conjunctive Use

This contributory option envisages continuation of a trend now well established in several regions whereby sources of different categories, size and characteristics are interlinked into a catchment wide or inter-catchment resource system, collectively meeting demands in various locations and for several purposes. In some respects this may be regarded as a regional "water-grid". The Consultants should review the advantages and disadvantages of this approach and the scope and desirability for extending it. Such an approach is capable of inclusion in both main options (i) and (ii) above.

(vii) Re-use of sewage effluents

Considerable quantities of sewage effluent are discharged to locations which make the water unavailable as a future water resource. Opportunities should be sought for re-use of such effluents as a water resource either by diverting such discharges to a water resource or by direct use of the effluent. The advantages and disadvantages of the re-use of sewage effluent should be included in the Consultant's report.

(viii) Review and Update of Other Previous Options and Proposals

Several options and proposals have been considered in the past by the Water Resources Board, or advocated by other parties in relation to a national water resources strategy.

These include:

- Desalination of sea water;
- Barrage storage in the Wash, Dee Estuary and elsewhere;
- Use of the canal system for long distance conveyance of water.

The Consultants are asked to update previously published leading data on the desalination and estuary storage proposals, particularly with regard to need, costs and environmental impact. In the case of the use of canals, feasibility for conveying water as well as costs and environmental aspects should be briefly considered and commented upon.

(ix) National Water Grid

This may include co-ordinated interlinking of existing and possible future multiple source systems, including inter-catchment links and transfers to the extent that such an interconnected system covers the regions of England and Wales as a whole. The Consultants are asked to review and comment upon the need for and viability of such an option - regarded as a limiting case of basic option (ii) - with an indication of feasibility and costs. The main purpose of this part of the study is to objectively respond to enquiries from the media and others on the feasibility of a 'national water grid'.

6. Environmental Considerations and Constraints

6.1 The project should include a review of the weight and implications of environmental requirements and constraints attaching to the various options and proposals, with a view of these being built into the overall evaluation of each. It is not envisaged that the Consultants should be involved in extensive enquiries or canvassing of opinions from environmental groups or other third parties. The exercise should be limited generally to collating information from the NRA regional and Head Office staff concerned with Environmental Quality and Conservation, together if necessary with limited consultation with other parties on specific proposals if so agreed with the NRA.

6.2 Environmental aspects include:

- (i) Minimum residual flows necessary whether as statutory MAF's or otherwise;
- (ii) Groundwater levels, especially the effects of abstraction on these and influence on base flows. Effects of changes at ground level such as on springs, ponds and lakes;
- (iii) Groundwater quality - critical trends and influence of enhanced abstraction;
- (iv) River water quality especially towards downstream of rivers and suitability for treatment for potable supplies;
- (v) Environmental impact constraints on resource development eg dams, groundwater abstraction, estuarial impoundments, lowered flows and water levels, changed water quality effects.
- (vi) Fisheries, Conservation, Recreation and Amenity and Navigation implications

7. Climatic Change

7.1 Traditionally water resource planning has been based on estimates or projections of future demand set against resources output derived from analysis of historic hydrological data, i.e. assuming future weather will be essentially of similar severity and variability as in the past. However, recent predictions of the possible effects of global warming in particular give cause for questioning this basis in future. It may be that within the time horizon of the review, perceptible changes will have occurred to the climate and sea levels for England and Wales having a bearing on the water resources strategy.

7.2 These changes may include:

- (i) possible greater weather variations with time between seasons;
- (ii) possible greater variations with location between the north and west on the one hand and south and east of England on the other;
- (iii) sea level variations affecting estuarial impoundment requirements and tidal/freshwater interfaces;
- (iv) possible impacts on demands for water.

7.3 The project should build such considerations into the evaluation of the options and the report should indicate the likely significance of these effects on the nature and timing of implementation of a development strategy.

8. Economic/Cost Assessments

The project is not intended to entail detailed costing or economic assessments but rather "broad brush" meaningfully consistent comparisons sufficient to categorise costs of development as low, medium or high per unit of source output capacity. The Consultants are asked to consider and define the thresholds used for these cost indicators, and to put forward a simplified basis for broadly consistent costing appropriate both for cost comparisons between differing proposals and also to facilitate a consideration of costs in relation to benefits. An indication of timing of expenditure would be useful, but in this project no "present value" comparisons discounting future expenditure or benefits are required.

NRA
December 1990

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