WATER RESOURCES DEVELOPMENT STRATEGIES

London, 20th April 1994

Organised by

NRA
National Rivers Authority

The Institution of Water and Environmental Management

in conjunction with the

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Symposium organised by the Institution of Water and Environmental Management (IWEM), in conjunction with the National Rivers Authority (NRA)

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Published by The Institution of Water and Environmental Management (IWEM), 15 John Street, London, WC1N 2EB

Printed and bound by The Chameleon Press Ltd, London

ROBERT GRAHAM SHARP, BSc, FICE, FIWEM

This volume of symposium papers is dedicated, at the request of the organising committee, to the memory of GRAHAM SHARP, whose sudden death on 8 July 1993, aged 65, ended a long and distinguished career in water resources.

Graham attended Leighton Park School, Reading, before studying civil engineering at London University. In 1951 he began his career specialising in water services engineering and planning with Herbert Lapworth Partners, a firm known for its work on impounding reservoirs and dams. Early work included association with the Thames Groundwater Scheme, the Weir Wood Scheme for Crawley and the Adlington treatment works for Macclesfield. Graham was also involved on design of the concrete buttress dam for Lamaload reservoir, near Macclesfield, before gaining site experience as Assistant Resident Engineer at Lower Drift Dam in West Cornwall, and as Resident Engineer at Lamaload.

The implementation of the Water Resources Act 1963 led to the formation of the Water Resources Board, which Graham joined in its early stages. He took charge of the collection and publication of hydrometric data, working on controversial reservoir studies in South Wales and on Dartmoor before being promoted to Superintending Engineer in 1971. He headed a new planning division, formed for preparing the Board's National Study on Water Resources in England and Wales, which was published just prior to the formation of the Regional Water Authorities in 1974.

From 1974 until his retirement in 1988, effectively as Chief Water Resource Officer of Severn Trent Water Authority, Graham led teams of engineers and scientist in the formulation of the original water resources policies. He was involved in proposals for Craig Goch reservoir enlargement, and appeared as a professional witness at two lengthy public enquiries for the Shropshire Groundwater Development Scheme and the Carsington Reservoir in Derbyshire. Steering the Carsington promotion to a successful conclusion was his finest professional achievement.

In 1988 he became a consultant, initially as advisor to the embryo National Rivers Authority. He was later associated with consulting engineers Howard Humphreys Ltd.

Graham Sharp's career followed the best tradition of the English civil engineer. A cultured and dignified individual, he was a practical and ambitious professional with a high degree of integrity. He was a conscientious and energetic manager and an eminent author of national and international conference papers. Graham had a memorable influence on the careers of many IWEM members.

He is survived by his devoted wife Audrey and daughter Jane.

Edward Price

(Copy reproduced from IWEM Newsletter - December 1993)

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DEMAND MANAGEMENT - NRA PERSPECTIVES

By Peter W Herbertson, MSc, CEng, MICE, MIWEM
and Geoff A Burrow, BSc, CEng, MICE, MIWEM
National Rivers Authority

SUMMARY

With the publication of the NRA's national water resources development strategy, demand management is for the first time recognised as having a major role in planning. The paper reviews the background and reasons for this important change in attitude since the last national water resources strategy was published by the Water Resources Board. Of particular significance was the coincidence of the recent severe drought in UK with the growth of the international movement for sustainable development. The effects of overabstraction on the number of rivers were dramatically displayed during the drought and gave rise to considerable public concern. Demand management is no longer the sole preserve of economists; their ideas have now sunk deep into political consciousness.

Reflecting its statutory duties for water resources, the NRA has adopted a broad definition of demand management, including all those measures which could affect the removal of water from the natural environment. Demand forecasting methodology is central to managing demand and the NRA's approach is described. The resulting forecast scenarios and their demand management components have a crucial impact on the scale of a national development strategy. With the achievement of NRA demand management assumptions, leading to a low forecast, there is no need for major strategic resource developments. The relative importance of contributing components of demand management are discussed.

Delivering demand management can best be achieved by agreement between water companies, their customers and the regulators. The NRA and OFWAT have made it clear they will use their powers if necessary, but success will come more easily as water companies and their customers appreciate that some demand management measures are cheaper than new source development. When these have been exploited rising demand can only be met by either more expensive sources, such as reservoirs and cross country transfers, or by the more costly forms of demand management such as domestic metering.

Demand management is the key to achieving sustainable water resources development. Its success will depend on continued monitoring and reporting of water consumption and loss statistics for all users. This is the first step to a better understanding of the scope, practical achievability, environmental impact and relative cost of the various measures. With better information, users (water companies, households, industry) are more likely to moderate water use to the benefit of the environment we all share.

IWEMconf/nra.herbert.sam(05/04/94)

WATER RESOURCES: A SCOTTISH PERSPECTIVE

by P WRIGHT, BSc, C Eng, MICE

(To be presented at the Water Resources Development Strategies Symposium, London, 20 April 1994)

ABSTRACT

Following a summary of the administrative arrangements in Scotland relating to water resources, details are given, for 1992-93, of the available yield of sources developed for public water supply, together with information on the types of sources used by water authorities. The overall water demand position is described, details given of the components of demand, including "unaccounted for water", and comment made on the demand/yield position for the country as a whole. The outcome of two previous national surveys of existing and future water resources is reviewed and a description given of the third such survey which has commenced recently. This latest survey will draw on the results of the domestic water consumption study which The Scottish Office reported on in 1993; a summary of this study and its findings are given. Proposed changes to institutional arrangements in Scotland are outlined.

Key words: Scotland; water resources; demand; yield; water consumption; unaccounted for water.

INTRODUCTION

Many people picture Scotland as a country consisting principally of mountains and lochs where it rains a great deal. While there is considerably more to the country than this, these features are nonetheless important prerequisites for a plentiful supply of water. However, these physical attributes are but a start. Man has intervened to refine and develop the natural storage capacity available and to construct the infrastructure to convey water from the upland gathering grounds to where it is used by the domestic and industrial consumer.

This development process started last century, and present and future generations have benefited from a significant engineering legacy. This should not be taken for granted. The water supply infrastructure needs to be operated, maintained and, where found necessary, upgraded - an ongoing task which will continue to place demands on engineering, scientific, management and financial resources. Information on water resources and the demand on that resource is essential if timely decisions are to be taken to ensure an adequate supply of water in the future. The Scottish Office, in conjunction with the water authorities and river purification authorities, has an important role to play in maintaining an overview of Scotland's water resources. It has embarked recently on the third national study designed to assess future water demands through to 2016 and the resources available to meet this demand.

ADMINISTRATIVE ARRANGEMENTS

In view of the different institutional and legislative arrangements in Scotland, compared with England and Wales, it is relevant to summarise the Scottish arrangements here. The Secretary of State for Scotland's responsibility for water resources is set out clearly in the Water (Scotland) Act 1980 (the 1980 Act)[1]:

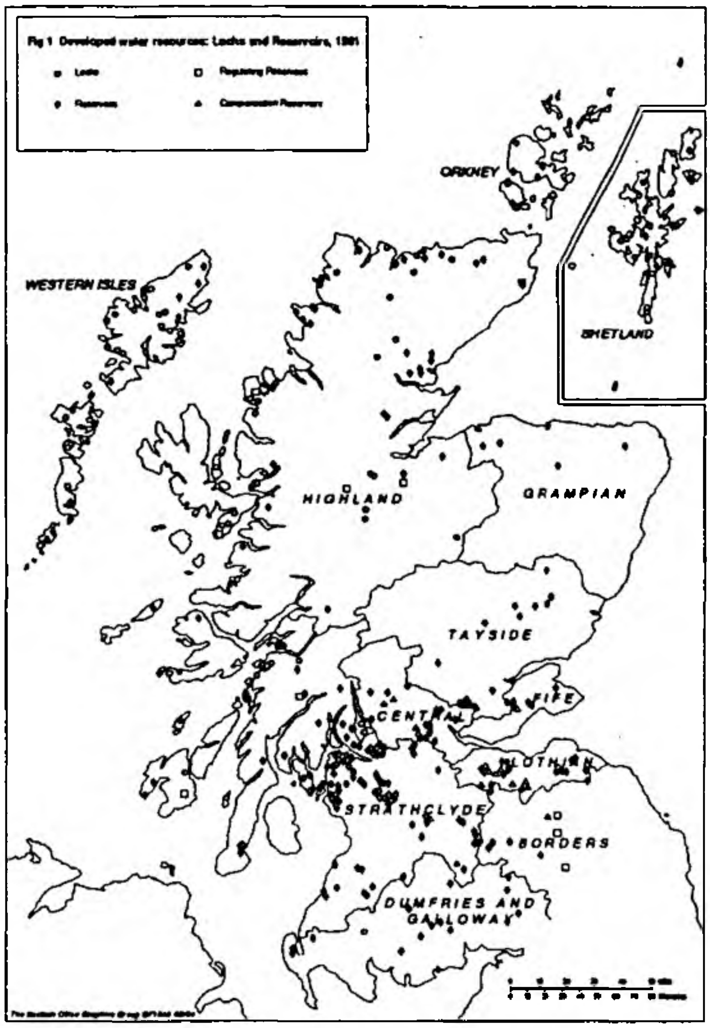
> "It shall be the duty of the Secretary of State -
>
> (a) to promote the conservation of the water resources of Scotland and the provision by water authorities and water development boards of adequate water supplies throughout Scotland; and
>
> (b) to secure the collection, preparation, publication and dissemination of information and statistics relating to such water resources and water supplies."

In fulfilling the Secretary of State's duty for (b) The Scottish Office Environment Department has, since 1975, collected information from water authorities and published an annual report on water supplies in Scotland. This paper draws heavily on the most recent of the annual reports, that for 1992-93[2].

Since local government re-organisation in 1975, the water authorities have been the nine regional and three islands councils (See Figure 1). They have a duty to provide a wholesome supply of water where it is required for domestic purposes and can be done at reasonable cost and, subject to certain conditions, to give a supply of water for non-domestic purposes[1].

The Central Scotland Water Development Board (CSWDB) was established in 1967[3] to develop new sources of water supply for the purpose of providing bulk supplies to two or more of the water authorities within the central belt of Scotland. The Board operates two major water supply schemes, Loch Turret and Loch Lomond, and its area extends to five authorities (Tayside, Fife, Lothian, Central and Strathclyde).

River purification authorities also have an important role in conserving water resources (as far as practicable), a duty given them by the Rivers (Prevention of Pollution) (Scotland) Act 1951[4]. Their powers allow them to carry out surveys and to gauge and keep records of volume, flow and other characteristics of water bodies and to record rainfall.



CONTROL OF ABSTRACTIONS

In Scotland, the right to abstract water from surface and underground sources is founded in common law and on specific statutes which govern abstractions for specific purposes. Under the common law of Scotland, where a stream rises in and flows to the sea within the lands of one owner, he has absolute proprietary rights over the water within the stream. Apart from this situation, running water is not the exclusive property of any one person, but a riparian owner is entitled, subject to the rights of other riparian proprietors, to make use of water in a stream flowing through his land, provided he returns it unpolluted in quality and unaffected in force and quantity at or before the point where the stream leaves his lands, except insofar as the water has been consumed for primary purposes such as domestic use and for certain agricultural purposes (but not irrigation). For public water supplies the 1980 Act[1] makes provision for water authorities to apply to the Secretary of State to make an order either approving an agreement to acquire water rights, or authorising them to acquire water rights compulsorily.

Rights to abstract water for purposes such as industrial use can be conferred by Acts of Parliament but such Acts are now rare. Water for industrial purposes is most often obtained through the agency of the statutory water authority although, recently, some industrial concerns have developed their own ground water sources, on the basis that water from boreholes generally belongs to the owner of the ground. The Natural Heritage (Scotland) Act 1991[5] contains provisions enabling the control of abstraction of water for irrigation for commercial agriculture or horticulture. Under these provisions river purification authorities can seek a control order for a specified area from the Secretary of State; where an order is granted they can subsequently control relevant abstractions for irrigation through a licensing system. As at March 1994, only one such control order has been granted in Scotland.

TABLE 1 : DEVELOPED WATER RESOURCES IN SCOTLAND 1992/93

Number and Yield(Ml/d) of Sources in each category

	Reservoirs			River Intakes		Underground Sources				All Sources		Total incl. Comp. Res.
	All	Res/Lochs	Feed Int			Boreholes		Springs				
Year	Yield	No	No	Yield	No	Yield	No	Yield	No	Yield	No	No
1971	2257	380		259	212	22	22	84	199	2622	813	
1977	2793	383		249	214	12	19	68	178	3222	794	
1978	2921	386		257	223	13	19	65	175	3256	803	
1979	2912	366	25	262	227	12	18	67	166	3253	802	
1981	2906	365	28	262	223	15	21	63	159	3246	796	
1982	2992	356	28	264	225	19	28	63	157	3338	794	
1983	2993	368	28	262	222	37	28	67	154	3359	800	
1984	3031	358	29	258	236	36	28	68	162	3393	813	
1985	2973	360	29	409	248	36	29	44	156	3462	822	
1986	2954	345	30	401	238	47	30	41	148	3443	791	
1987	2932	345	31	386	237	56	39	37	161	3411	813	831
1988	2988	345	27	415	252	51	40	61	169	3516	833	852
1989	2993	355	30	405	247	55	49	62	165	3515	846	864
1990	2971	357	30	403	246	55	51	57	160	3486	844	862
1991	2982	353	30	402	242	55	52	56	153	3495	830	850
1992 by Authority												
BORDERS	24	5	4	16	12	8	7	2	10	50	38	39
CENTRAL	189	15	0	4	11	0	1	1	1	195	28	30
D & G/WAY	91	14	0	5	9	13	5	2	2	111	30	30
FIFE	162	14	3	0	0	14	6	0	0	176	23	24
GRAMPIAN	18	5	1	212	12	12	6	13	64	255	88	88
HIGHLAND	176	61	3	143	122	1	2	7	34	326	222	222
LOTHIAN	349	18	9	0	0	0	0	25	2	374	29	37
ORKNEY	20	10	0	0	0	1	3	0	2	20	15	15
SHETLAND	27	23	0	1	6	0	0	0	3	29	32	32
STRATHCLYDE	1272	119	7	12	47	1	4	4	12	1289	189	195
TAYSIDE	136	7	0	33	13	2	1	0	1	171	22	22
W. ISLES	24	37	2	1	5	0	0	0	0	24	44	44
CSWDB	540	2	0	0	0	0	0	0	0	540	2	2
1992 TOTAL	3028	330	29	427	237	51	35	54	131	3560	762	780

Note: a) Column 2 gives yield of Reservoirs, Lochs, Feeder Intakes and Regulating Reservoirs.
b) Column 3 is a count of Reservoirs, Lochs and Regulating Reservoirs (Feeder Intakes are counted in column 4).
c) Compensation Reservoirs are excluded except in the extreme right-hand column where they are included in the count.
d) Pre-1992 the number of sources recorded included multiple sources at a single location. In 1992 multiple sources at a single location were counted as one.

SOME BASIC FACTS

RAINFALL

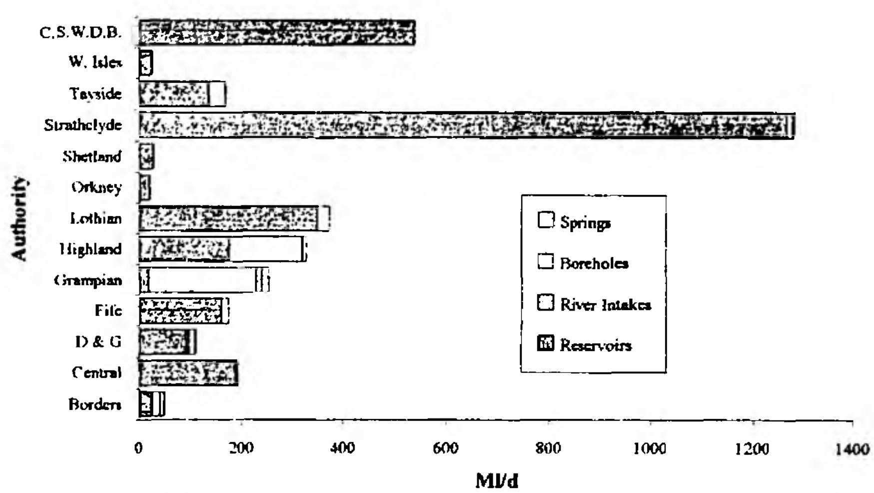
Across Scotland the long term (1941-70) average rainfall was 1431 millimetres per year, but variations occur locally ranging from some 270 per cent of the average in the highlands of Wester Ross, to just over 40 per cent in the East and South-East of the country. After allowing for evaporation and other losses, the available surface water run-off is about 70 million megalitres per year. The corresponding figure for

England and Wales together is about the same. Of the total run-off in Scotland, just over 1 per cent is used for public water supply.

POPULATION DISTRIBUTION

Of Scotland's total population of some 5.1 million (8.8 per cent of the UK population), about 70 per cent is concentrated in the central belt between the Clyde, Forth and Tay Estuaries. The land area of Scotland, including Orkney, Shetland and the Western Isles, is 77,080 square kilometres which is approximately one third of the area of Great Britain. About half of the country is above the 180 metre contour; this area contains only about 100,000 inhabitants. The substantial quantities of water obtainable from these upland areas are therefore relatively unpolluted.

Fig.2 : Available Yield by Source Type



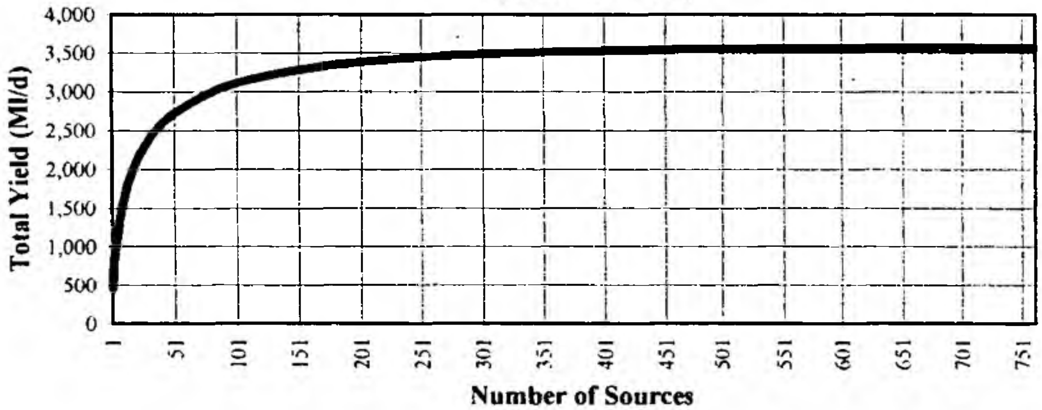
RESOURCES

Before proceeding it is worth emphasising that, in general, when the term "resources" is used it refers to those resources which have been developed for public water supply use and tends not to be used in the wider sense adopted in England and Wales. In 1992-93, the total available yield of developed public supply sources in Scotland was 3560 Ml/d. Just over 97% of this was derived from surface sources, the balance coming from groundwater sources. Of the total of 762 sources used for public supply, 596 (78%) are surface water sources and 166 (22%) groundwater sources. By way of example, Figure 1 shows the distribution of lochs and reservoirs developed for water resources. Table I gives a detailed breakdown of all source types for each water authority and Figure 2 illustrates the relative importance of each source type within each authority area.

The reliance which certain authorities place on river intakes for public supply, eg Grampian and Highland, contrasts with the position in, for instance, Lothian where no public supplies are taken direct from river intakes. Instead, virtually all of Lothian's water supplies are drawn from reservoirs. Groundwater sources also tend to be of relatively greater importance in some authority areas compared with others. For example in Dumfries and Galloway and Borders Regions the available yield from groundwater sources constitutes about 14 per cent and 20 per cent respectively of the total yield available. It is the relatively low groundwater use (3 per cent) across Scotland as a whole, which stands out in comparison with the position in England and Wales where some 30 per cent of all public water supplies are derived from groundwater and the position in other European countries where the usage made of groundwater sources is even higher.

As well as differences in source type there are considerable differences in the size of developed sources, from the largest - Loch Lomond - with a yield of 455 Ml/d, through to the smallest - some 107 sources each with a nominal yield less than 0.01 Ml/d. The 15 largest sources provide some 53 per cent of the total available yield in Scotland and the top 90 (12 per cent of total number) just over 85 per cent. Figure 3 illustrates the overall significance of the few very large sources compared with the large number of small sources.

Fig.3 : Cumulative Yield of All Public Supply Sources
(Total No. = 762)



DEMAND

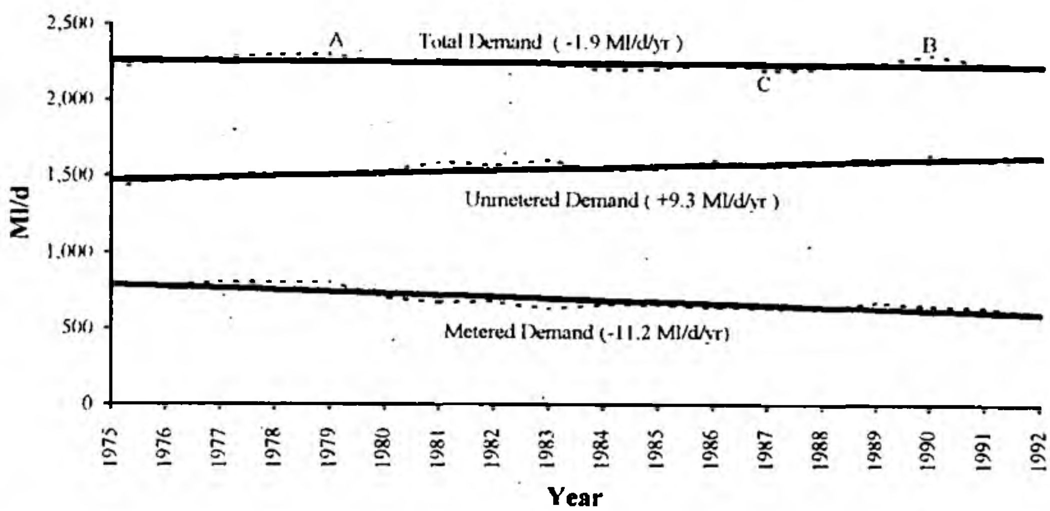
TOTAL DEMAND

During 1992-93, the average daily demand for water in Scotland was 2206 Ml/day. Industrial supplies (metered plus non-potable) represented 27% (603 Ml/d) of the total, with domestic and other unmetered demand accounting for the balance of 73% (1603 Ml/d). Table II gives details of the average demand (ie water put into supply) in each water authority's area over this period.

TABLE II : PUBLIC SUPPLIES AVERAGE DAILY DEMAND (Ml/d) 1992/93					
	Total	Potable			
Authority	Demand	Total	Unmetered	Metered	Non-potable
BORDERS	34.5	34.5	25.0	9.5	0.0
CENTRAL	212.8	210.9	121.4	89.5	1.9
D & G/WAY	72.6	72.6	52.0	20.6	0.0
FIFE	144.1	144.1	101.8	42.3	0.0
GRAMPIAN	169.2	169.2	119.4	49.8	0.0
HIGHLAND	100.4	93.5	76.9	16.6	6.9
LOTHIAN	281.6	281.6	213.4	68.2	0.0
ORKNEY	11.3	11.3	7.5	3.8	0.0
SHETLAND	12.3	12.3	9.5	2.8	0.0
S/CLYDE	1028.3	1019.7	775.7	244.0	8.7
TAYSIDE	125.5	125.5	89.1	36.5	0.0
W. ISLES	13.2	13.2	11.7	1.5	0.0
1992 TOTAL	2205.8	2188.4	1603.3	585.0	17.5

Comparison with the total demand figure for 1991-92 indicates a reduction in demand between the years of some 1.5%; this follows a 2.7% reduction in demand the previous year. The most recent reduction can be linked directly to the fall-off in metered demand of about 6% - a reduction in this component being recorded by 10 out of 12 water authorities.

Fig.4 : Scotland's Water Demand Trends



Note: a) Peak demand over period was 2301 Ml/d recorded for 1979/80 and 1990/91 (A and B)
b) Lowest demand over period was 2194 Ml/d recorded for 1987/88 (C)

Figure 4 illustrates the fluctuations in total demand recorded since 1975-76, the peak demand having occurred in 1979-80 and 1990-91 (2301 Ml/d) and the lowest (2194 Ml/d) in 1987-88. It is of interest to note that unmetered demand in 1979-80 was, over the period, at the low end of the range for this component, whereas the metered demand that year was the highest over the 18-year period. Over the period the balance between unmetered and metered potable demand has shifted - the ratio having changed from (in percentage terms) 67:33 in 1979-80 to 73:27 in 1992-93. This changing ratio is also reflected in the long term trends (1975-1992) for the two components, that for metered potable demand being on a downward profile of - 11.2 Ml/d/yr and that for unmetered demand on a rising profile of +9.3 Ml/d/yr. As can be seen from Figure 4 the total demand trend for the same period is falling at -1.9 Ml/d/yr. However, the 10-year trend up to 1992-93 suggests a growth in demand of +1.7 Ml/d/yr and the 5-year trend a growth of +6.1 Ml/d/yr. While these figures appear to convey slightly different signals, it should be noted that +6.1 Ml/d/yr still only constitutes a growth per year of one quarter of one per cent.

TABLE III : PER CAPITA DAILY WATER DEMAND 1992/93

Year			Population (x1000)	Unit Demand (l/h/d) Total	Unit Demand (l/h/d) Un-Metered	Unit Demand (l/h/d) Metered and Non Potable	Demand % Un-Metered	Demand % Metered and Non Potable
1971			5228	407	266	142	65	35
1973			5212	421	269	152	64	36
1975			5206	425	274	151	64	36
1976			5205	431	281	150	65	35
1977			5196	439	283	156	65	35
1978			5179	443	288	155	65	35
1979			5167	445	289	156	65	35
1980			5153	434	298	137	69	31
1981			5149	439	308	131	70	30
1982			5166	435	304	131	70	30
1983			5150	434	311	123	72	28
1984			5146	427	300	127	70	30
1985			5137	428	301	127	70	30
1986			5121	438	313	125	71	29
1987			5112	429	304	125	71	29
1988			5094	433	309	124	71	29
1989			5090	442	309	133	70	30
1990			5102	451	322	129	71	29
1991			5100	439	313	126	71	29
1992 by Authority	Population (x1000)	Added areas adjustment						
BORDERS	104		104	331.4	239.9	91.5	72.4	27.6
CENTRAL	273	113	386	551.7	314.7	236.9	57.0	43.0
D & G/WAY	148		148	491.5	352.1	139.5	71.6	28.4
FIFE	349	9	358	402.7	284.5	118.2	70.6	29.4
GRAMPIAN	516		516	328.1	231.6	96.5	70.6	29.4
HIGHLAND	204		204	491.9	376.8	115.1	76.6	23.4
LOTHIAN	751		751	375.0	284.1	90.9	75.8	24.2
ORKNEY	20		20	577.7	383.9	193.8	66.5	33.5
SHETLAND	23		23	544.8	420.6	124.2	77.2	22.8
S/CLYDE	2298	-113	2185	470.6	354.9	115.6	75.4	24.6
TAYSIDE	393	-9	384	326.9	231.9	94.9	71.0	29.0
W.ISLES	29		29	448.6	397.6	51.0	88.6	11.4
1992 TOTAL			5107	431.9	313.9	118.0	72.7	27.3

Note: a) The "Added Areas" in Scotland are defined in the Water (Scotland) Act 1980 (Part II, Section 3). An "Added Area" extends the limit of supply of a water authority beyond the regional council boundary for the purposes of water supply.

PER CAPITA DEMAND

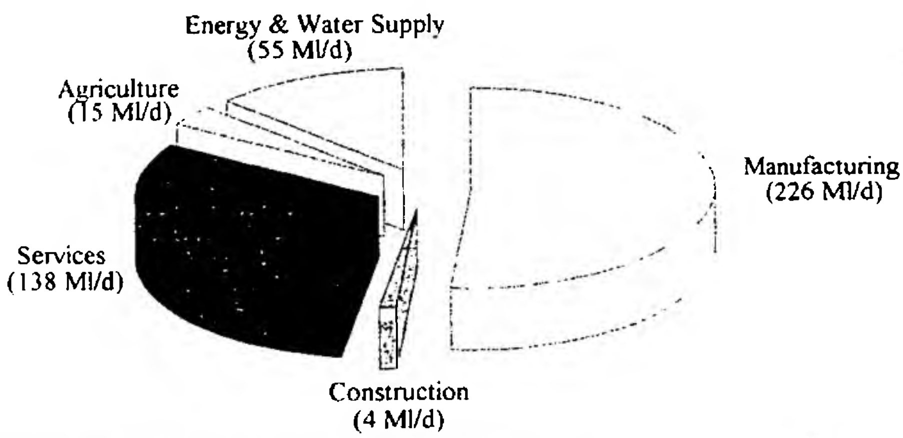
Considering total demand in a little more detail Table III translates this into per capita demand in each authority area for total demand and for the three components of that demand. The total demand per capita for

1992-93 of 432 l/head/d is a decrease of 1.6% on the corresponding figure for 1991-92 and is the second consecutive year in which per capita demand has fallen. In that there has been little change in Scotland's population over recent years, this reduction reflects the decrease in metered and non-potable demand mentioned earlier under Total Demand.

NON-HOUSEHOLD DEMAND

The annual survey also seeks details of the types of metered, non-household demand. Figure 5 shows the sectoral breakdown for 1992-93 of large industrial users of water (ie those taking >1000 cubic metres per quarter - representing three-quarters of all industrial usage). While the manufacturing sector has continued to generate the largest demand (226 Ml/d) this is only some 75% of the demand recorded from this sector in 1991-92. A more detailed breakdown is given in the annual report[2].

Fig.5 : Large Industrial Users



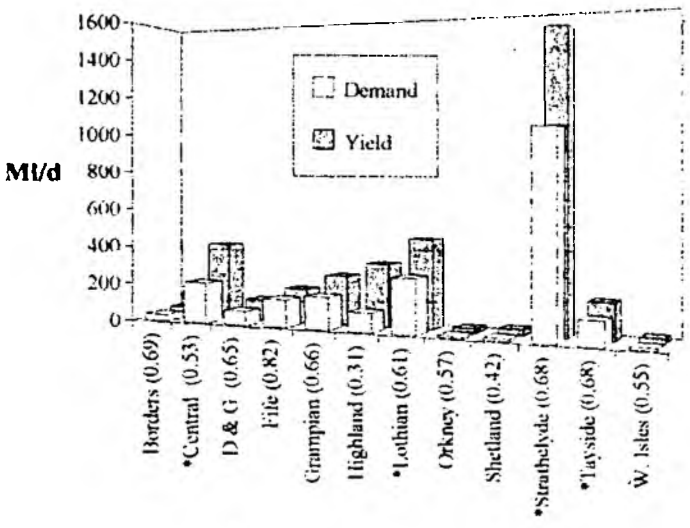
UNACCOUNTED FOR WATER

The annual water resources survey for 1991-92[6] included the most recent summary by the Department on that component of water put into supply, the use of which was not accounted for - "unaccounted for water" (UFW). Before that report, UFW, across Scotland, had been estimated to be of the order of 40 per cent of total demand. It is important to bear in mind that the terms leakage and UFW are not synonymous, even although leakage accounts for the bulk of UFW. It is also relevant to note that the leakage element of UFW includes both system leakage in mains and reservoirs and supply pipe leakage (SPL); this distinction is becoming more prominent as water undertakers throughout the UK seek to identify that fraction of leakage from apparatus for which they have a direct responsibility for repair. In the 1991-92 report a 5 per cent allowance was made for non-domestic, non-metered water used legitimately (including usage for operational purposes such as flushing mains or for public activities such as fire fighting). Lack of data prevented any distinction being drawn between system leakage and SPL. Adopting the revised allowance for domestic consumption of 148 l/head/d, UFW on an all-Scotland basis was estimated at 33% for 1991-92. If SPL were assumed at the same level as used in England and Wales, the Scottish UFW for the supply system would drop to about 28%. This position will be reviewed as part of the Department's long term review of demands and resources (see later).

DEMAND/YIELD RATIO

Combining the recorded data for total yield across Scotland for 1992-93 (3560 Ml/d) and the demand placed on developed public supply sources (2206 Ml/d), gives a demand to yield ratio of 0.62. While this ratio indicates that Scotland as a whole is in a reasonably comfortable position in terms of water resources, it is important to bear in mind that this does not necessarily reflect the situation prevailing at the local level. A slightly more local picture is revealed in Figure 6 which gives demand/yield ratios for each authority area in 1992-93. However, even this tends to mask the problems in some supply areas where, on occasion, an authority's ability to maintain an adequate supply of water has been stretched. For instance, authorities' resources were particularly severely tested during the 1984 drought[7] with only Lothian and Shetland not reporting any significant problems. A comparison of the demand/yield ratio given in Figure 6 for, for instance, Central Regional Council (0.53) with that obtained from the data for actual yield from Table I and demand from Table II (demand/yield ratio of 1.1) demonstrates the importance of the water supplied to Central and other authorities by Central Scotland Water Development Board.

Fig.6 : Demand / Yield Ratio



* Yield includes CSWDB supplies

Historically, it is of interest to note from Figure 7 the change in the demand/yield ratio from the 0.7 figure recorded during the 1970s and early 80s to the most recent ratio of 0.62, the lowest recorded in the last 20 years. While there has been an overall increase in the yield available over the period since 1977 (3222 Ml/d to 3560 Ml/d - a 10% increase) it needs to be borne in mind that this has taken place against a background of relatively small change in total demand.

River Severn Estuary.

THE NRA ROLE

The NRA is the licensing authority for water abstraction. It has a statutory duty to secure the proper use of water resources which includes:

- assessing the need for new developments,
- ensuring that the most appropriate schemes are licensed, taking into account the environmental impact of new developments and the impact on existing users.

The financing, promotion and development of new schemes will normally be the concern of the main beneficiaries. The NRA will however ensure that the needs of smaller abstractors are not overlooked.

The initiative for developing new schemes will rest with:

- a water company or consortium of water companies;
- other private sector investors.

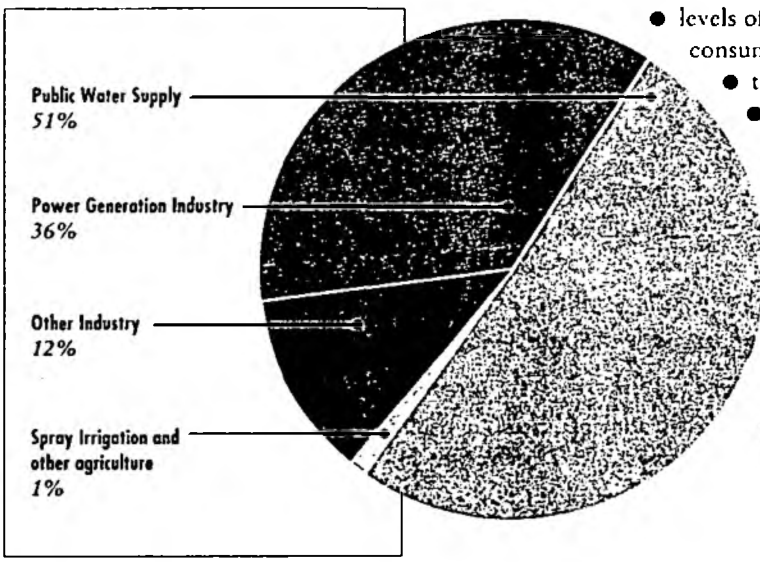
THE DEMANDS

PUBLIC WATER SUPPLY

Particular attention has been given to the identification of possible future public water supply needs since this is the largest demand of any purpose as shown in Figure 1.

Figure 1

WATER ABSTRACTION BY PURPOSE (NON-TIDAL SURFACE WATER AND GROUNDWATER ONLY)



The principal factors which have an influence on public water supply demand are:

- population growth and household size;
- consumption per person;
- levels of domestic metering;
- levels of leakage from distribution systems and consumers' plumbing;
- the level of economic activity;
- gardening habits.

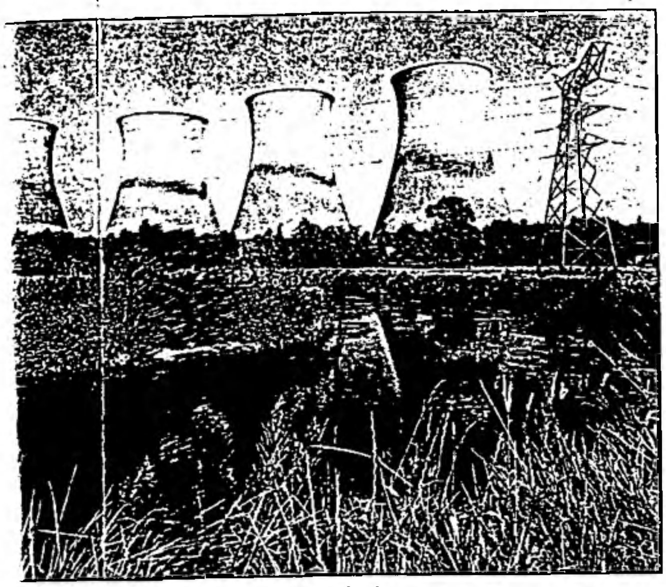
In the past, it has generally been the practice to develop new resources to keep ahead of the rise in demand. Now, however, it is considered more appropriate to identify what steps can be taken to control demand and therefore to see if new developments are really necessary.

As a result of this, three demand scenarios for public water supply have been produced.

HIGH the growth in demand assuming relatively high rates of growth in domestic and non-domestic consumption and no (or negligible) increase in current demand management activity.

MEDIUM the growth in demand assuming a moderate growth in domestic and non-domestic consumption, limited domestic metering and reduced leakage.

LOW the growth in demand assuming moderate growth in domestic consumption, no increase in non-household consumption, moderate domestic metering and further reduced leakage.

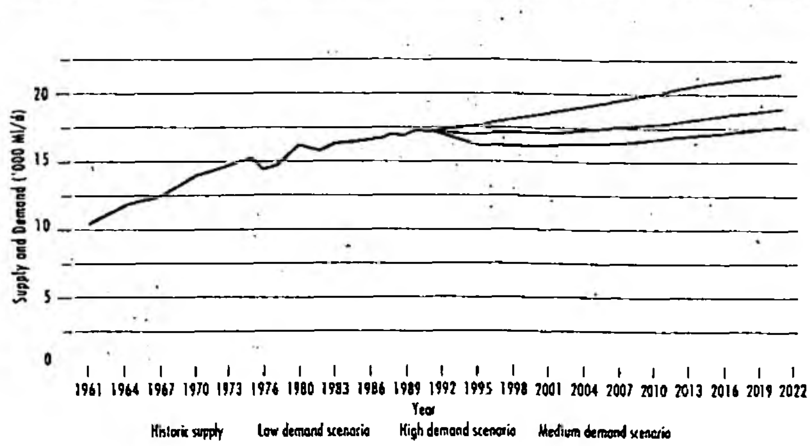


Po[illegible] station at Meaford.

Using these scenarios the possible range of demand in the next 30 years is shown in Figure 2. It is encouraging that the NRA's Low scenario is similar to the aggregated forecast made independently by the Water Companies.

Figure 2

SUPPLY AND DEMAND FOR PUBLIC WATER SUPPLY - 1961 TO 2021



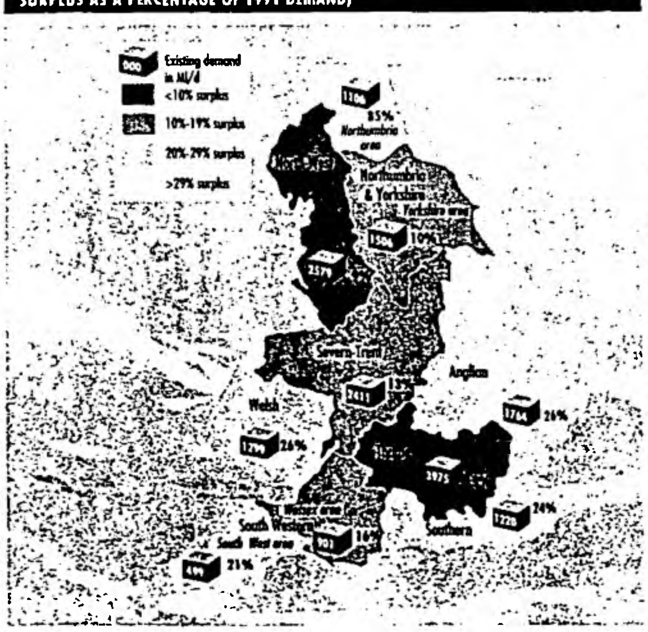
RESOURCES AND DEMAND BALANCE

Currently there is a surplus of public water supply resources as shown in Figure 3. However in future, given the possible range of increases in public water supply demand shown in Figure 4, supply deficits could occur.

The development of small water resource schemes local to specific areas of demand will go some way towards addressing these potential deficits. These so called 'local options' are numerous but will nevertheless require rigorous examination on environmental and economic grounds before they can be developed. However if all such local options were to be developed then the outstanding water resources deficits would be similar to those shown in Figure 5 and for the High and Medium scenarios would require strategic water resource developments to redress the balance before the end of the planning period (2021)

Figure 3

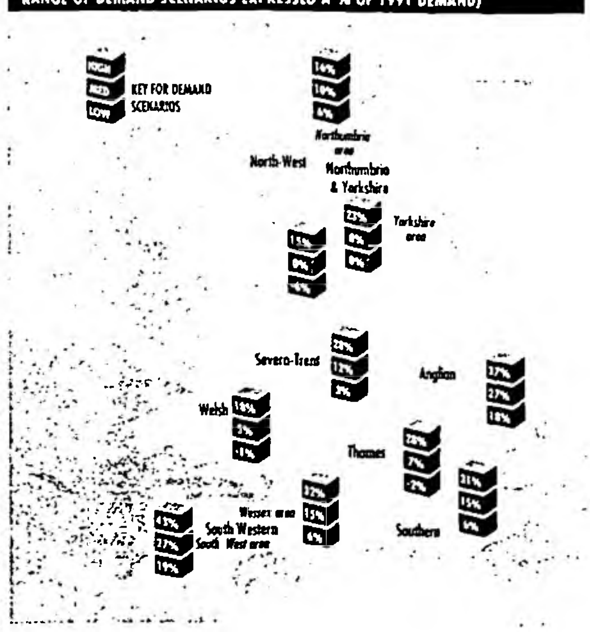
THE PRESENT SURPLUS
(PRESENT REGIONAL AVERAGE PUBLIC WATER SUPPLY SURPLUS AS A PERCENTAGE OF 1991 DEMAND)



The percentages are based upon the surplus yield over average demand within the region. However, surpluses for individual companies or districts within the region may be higher or lower than the average shown and a surplus in one part of the region may not be transferable to another.

Figure 4

THE GROWTH SCENARIOS
(INCREASE IN AVERAGE PUBLIC WATER SUPPLY DEMAND TO 2021 UNDER A RANGE OF DEMAND SCENARIOS EXPRESSED A % OF 1991 DEMAND)



The percentages are based on a summation of average demands for the companies in each region.

Footnote: Ml/d = Megalitres per day (A Megalitre is 1 million litres)

A summary of the potential growth in public water supply demand is shown below.

Table 1

Demand Scenario	Average Growth in average Public Water Supply Demand to 2021 (expressed as % of 1991 demand)	Potential Shortfall in Supply (Ml/d) assuming 'local' resource options are developed
High • No (or negligible) demand management • High growth in domestic consumption • High growth in non-domestic consumption	25%	1110
Medium • Some demand management • Moderate growth in domestic consumption • Moderate growth in non-domestic consumption	10%	142
Low • Increasing demand management • Moderate growth in domestic consumption • No growth in non-domestic consumption	2%	0

DEMAND MANAGEMENT

One of the main differences between the three demand scenarios is the extent of demand management. Modest levels of domestic metering and leakage control can have a significant effect on the requirement for new resource developments.

This effect is so marked that a proper consideration of demand management measures must be a primary element in an environmentally sustainable water resources strategy.

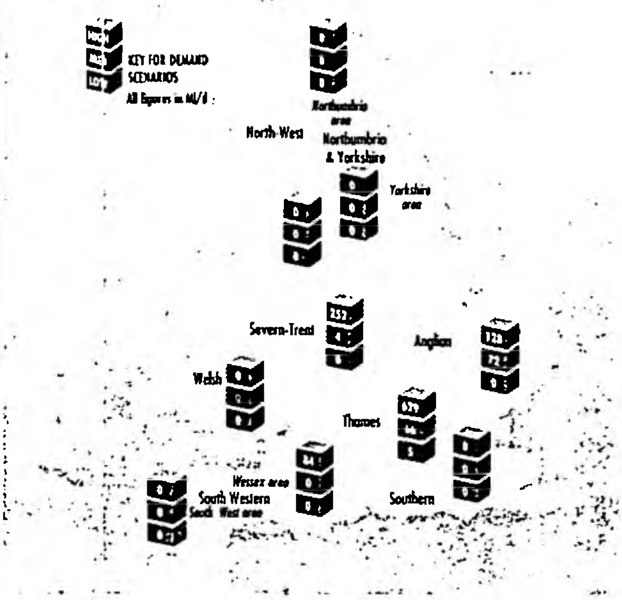
ALLEVIATION OF LOW FLOWS

The NRA is committed to alleviating the problem of low flow rivers caused by excessive abstraction. These problems were generally caused by abstractions authorised by Licences of Right granted under the Water Resources Act 1963. A total of 300 megalitres per day has been taken from the existing available resources to account for the loss of yield in varying or revoking licences to improve these problem rivers.

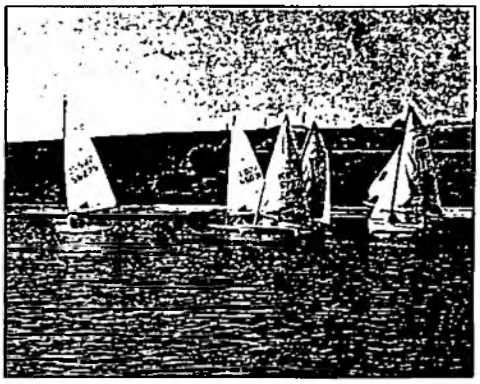
Climate change could influence the water resources development strategy. However given current uncertainties in the validity of some predictions, it is thought that there is insufficient eveidence available to allow assumptions about climate change to be incorporated within this strategy.

Figure 5

THE STRATEGIC DEFICITS
(REMAINING SHORTFALL IN AVERAGE PUBLIC WATER SUPPLY YIELD IN 2021 UNDER A RANGE OF DEMAND SCENARIOS AFTER LOCAL RESOURCE OPTIONS ARE DEVELOPED



These data are a summation of shortfalls at Demand Centre level and represent the amount of demand in the region that would need to be met from strategic sources.



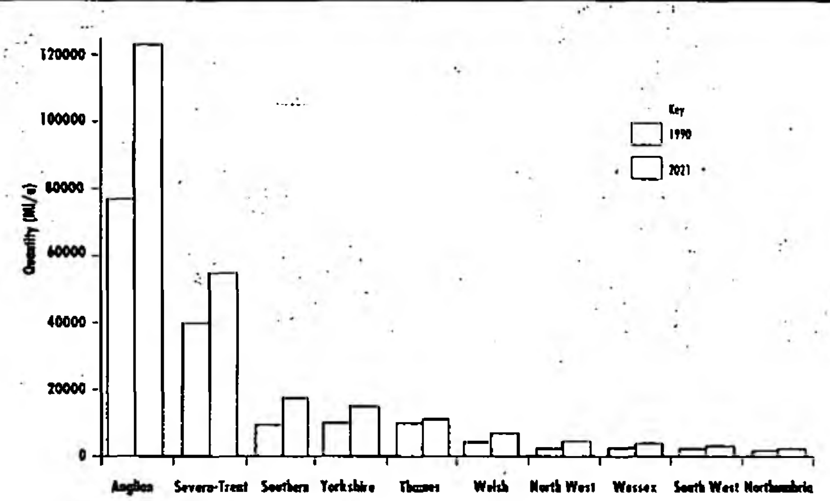
Sailing on reservoir.

INDUSTRY, AGRICULTURE AND POWER GENERATION

For the other three significant demands on water resources; namely industry, agriculture and power generation (mainly cooling), only agriculture has been forecast to show any significant increase in the next 30 years. Approximately 70% of agricultural demand in a dry year is for spray irrigation and Figure 6 shows how this is expected to rise in the next 30 years.

Figure 6

FORECAST IRRIGATION DEMAND FOR 2021 BY NRA REGION



OPTIONS FOR MEETING SPRAY IRRIGATION DEMAND

The main options for meeting future demand includes:

INVESTMENT IN NEW RESOURCES:

- on-farm winter fill storage by individual farmers;
- medium scale local development by co-operative ventures;
- shares in strategic developments;

MANAGEMENT INITIATIVES:

- cash payments between farmers to 'buy out' water rights;
- pooling licences by groups of farmers;
- improved management of resources;
- incentive charges to control demand;
- reallocation of resources through tradeable permits.

Some of these initiatives could only be introduced if there is a change in the controlling legislation.

IMPROVED EFFICIENCY:

- improved irrigation techniques in terms of time of application, and technical improvements in irrigation systems.

THE DEVELOPMENT OPTIONS AND THEIR ENVIRONMENTAL EFFECTS

DEVELOPMENT OPTIONS

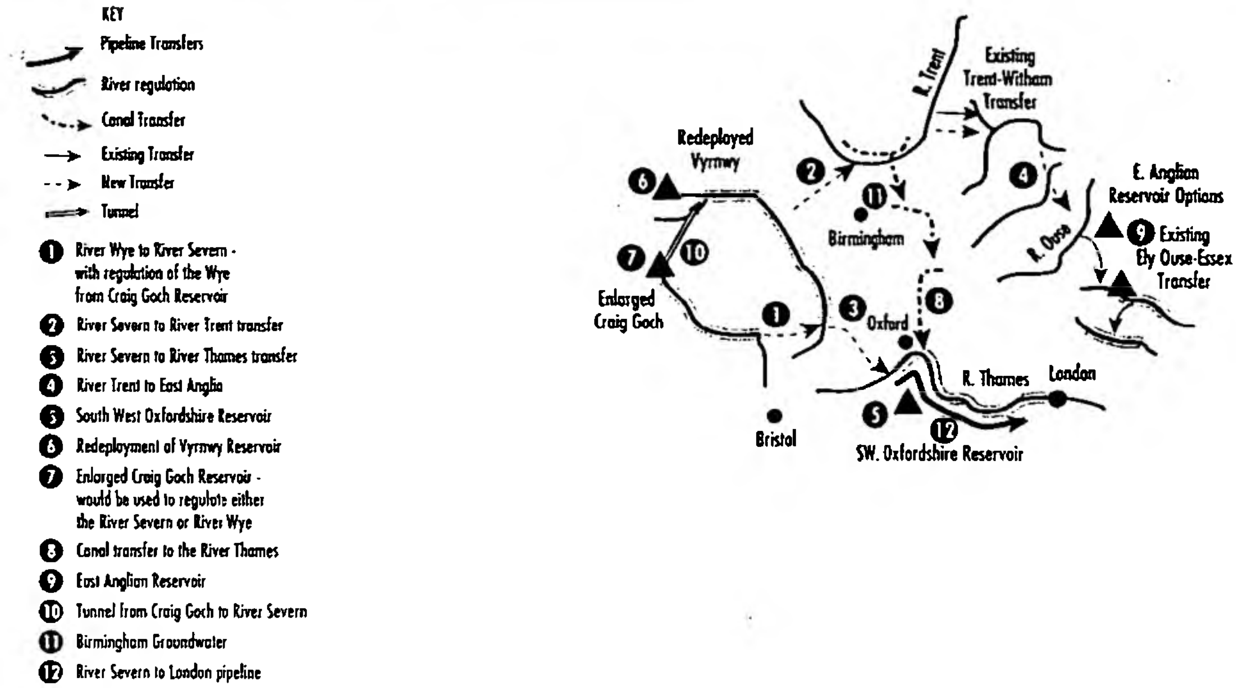
The NRA has identified a number of strategic water resource developments to meet possible deficits in supply should demand management prove ineffective. These are shown in Figure 7.

ENVIRONMENTAL APPRAISAL

A preliminary environmental overview of existing environmental assessments has been completed to enable comparisons to be made of the environmental implications for each of the possible strategic developments. The purpose of the assessment is to highlight the key environmental issues which may favour or discriminate against particular options.

Figure 7

STRATEGIC OPTIONS CONSIDERED IN THE STRATEGY



Some of the key issues arising from the preliminary assessment relate to the:

- effect on flora and fauna of mixing water of different chemistries;
- transfer of species and diseases between catchments;
- loss of terrestrial habitats due to reservoir construction;
- effect of changed river flows on fish movement;
- environmental benefits which can be obtained from specific developments.

Trent and Mersey Canal.

For a number of the strategic options, the environmental impact will be dependent upon the size of scheme required which in turn depends on the demand to be met. It is an inescapable fact however that all reservoir construction and inter-basin transfers will have some impact on the aquatic environment. If a policy of 'no change' is seriously proposed, it would mean that no development could be supported. The central issue for the NRA therefore is to question the need for the development and the scale and significance of any environmental change which may occur.

It is essential that further option specific studies are undertaken to improve the understanding of the environmental implications for the likely developments.

THE STRATEGY

The key messages emerging from the strategy are that:

- there is strong possibility that demands can be managed to avoid the need for large scale water resources developments over the next 20 years or so;
- water companies must be required to achieve economic levels of leakage and metering before new abstraction licences are granted for strategic developments;
- the NRA must take a proactive role in promoting water use efficiency in industry, commerce, agriculture and in the home;
- environmental considerations will be crucial, where in doubt a precautionary approach should be adopted;

● the attitude of companies to involvement in strategic transfer schemes with other companies as opposed to being in control of their own resources is an important factor;

● early planning of some major resource developments is necessary.

Included within the conclusions of the strategy are that:

● By far the greatest need for additional water resources, should a High or Medium demand scenario materialise, is in the Thames catchment. Although a new reservoir in the Thames Valley has been proposed, serious consideration still needs to be given to alternative ways of developing a resource to meet a future need. In cost terms a transfer from the River Severn to the River Thames is a possible alternative, but the environmental implications appear to be greater than for a reservoir. A detailed environmental impact study of this option needs to be carried out urgently.

● The partial redeployment of Vyrnwy reservoir, which is currently used as an important good quality gravity supply to the North West has been considered. However, it is not recommended that early plans are developed to redeploy this reservoir for regulation of the River Severn. However, partial Vyrnwy redeployment would appear to offer a good contingency source in that it could be brought on line relatively quickly if the need arises, provided supplies within North West region could be switched to make up any supply shortfall from Vyrnwy reservoir.

Photograph courtesy of K. Weatherhead, Silsoe College.

Agricultural spray irrigation.

● A new resource for East Anglia will be needed under the High and Medium demand scenarios. Although analysis has so far been based upon the Great Bradley reservoir location, investigations are at an advanced stage concerning an alternative site on the fens. The results of these investigations are not known at present, but early selection of a preferred option is essential.

● British Waterways (BW) have undertaken engineering studies of possible canal transfers from the Midlands to East Anglia and the Thames area. Large scale transfers via the canals are more expensive than other options mainly because of the cost of bringing spare water to the canals (eg, via a possible River Severn to River Trent transfer). Transfers via canals would not be without environmental problems but, providing these could be overcome, it is possible that they could be used for small scale transfers.

WAY FORWARD

There is much more work to be done and the strategy identifies a number of specific proposals for the next 5 years. The most important of these are:

● to give renewed impetus to the promotion of water efficiency;

● to address environmental issues in readiness for new developments should demand management prove ineffective;

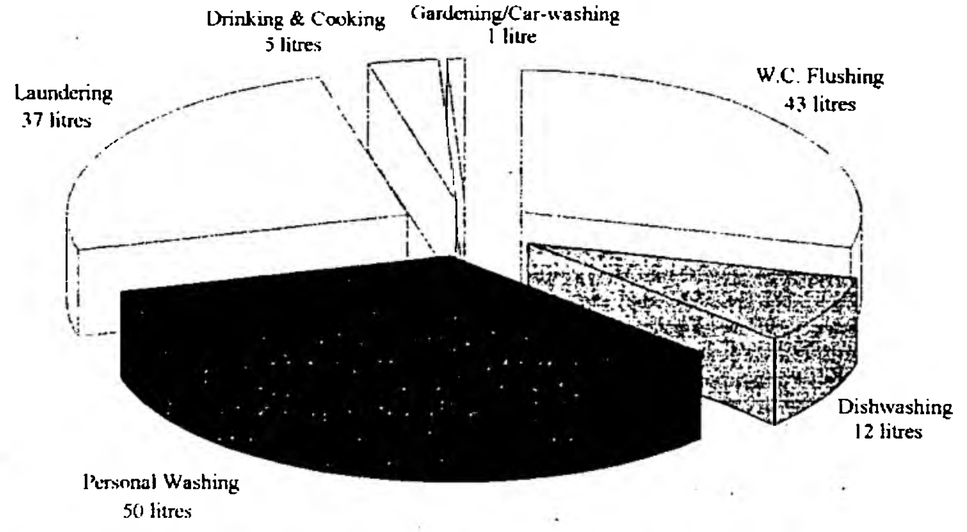
● to give particular attention to the agricultural need for water, especially spray irrigation in eastern England;

● to review the feasibility, cost and environmental impact of local schemes and to compare them with the strategic options;

● to see that this strategy can be built upon in order to help ensure secure water supplies and a better water environment.

For further copies please contact your local NRA office.

Fig.9 : Average Daily Domestic Water Usage



Total = 148 litres / person / day

FUTURE INSTITUTIONAL ARRANGEMENTS

At the time of writing (March 1994) the Local Government etc (Scotland) Bill is being considered by Parliament; this contains provisions for the formation of three new water and sewerage authorities - East, West and North Water Authorities - lying outside local government. In addition to taking on functions of the present water authorities, the new authorities will subsume the functions of the Central Scotland Water Development Board. Inevitably, the new authorities will take a strategic look at water resources to determine if any changes need to be made either to the resources themselves eg rationalisation of the number or type of sources, or to the manner in which the water supply service is delivered. It would be premature to offer a view on this aspect but the Department will certainly maintain its overview of water resources up to and beyond the restructuring date - 1 April 1996.

Concurrently with the establishment of new water and sewerage authorities the Secretary of State for Scotland has announced his intention to establish a Scottish Environment Protection Agency (SEPA). It will be responsible for those functions presently carried out by river purification authorities, Her Majesty's Industrial Pollution Inspectorate and will take over the district and islands councils' responsibilities for waste regulation and air quality.

The Department consulted last year on SEPA being given additional abstraction control powers[12]. These are modelled on the provisions for the control of abstractions for irrigation contained in the Natural Heritage (Scotland) Act 1991. The proposal is to adopt a selective approach, limiting abstraction licensing arrangements only to areas where SEPA can make out a good case that such controls are necessary.

CONCLUSIONS

The demand/yield ratio of 0.62 for Scotland for 1992-93, combined with a long term historic growth in demand hovering around zero, implies little need for action to augment resources. However, it is important for water authorities to monitor local circumstances, since the demand/yield position in some areas is not so favourable. An additional influence here is the statutory obligation to improve the quality of water put into supply; this has led to authorities reviewing raw water sources to ascertain if there are benefits to be had from changing sources either on a straight replacement basis or possibly as part of a more extensive rationalisation of resources.

Nationally, it is important for the Department to maintain its overview of demand and to be able to account for any significant changes which occur. As described in this paper this is best done on a component by component basis. Particular attention has been paid to domestic consumption, with the Department's 1991 study indicating a median figure of 148 l/head/day. Leakage is another important component of demand. In England and Wales, the UK Water Industry Leakage Initiative has led to all aspects of leakage being examined in detail. Scottish authorities, together with the Department, are keeping a close eye on developments. It is for individual water authorities to determine their response to these but it would not be unreasonable to expect them to seek to reduce leakage in their water distribution systems to the level deemed to be economic. Progress in these and other areas will be covered in the report of the present review of demands and resources.

ACKNOWLEDGEMENTS

Having drawn on the content of several Scottish Office publications the author acknowledges the contribution of colleagues - past and present - who drafted these earlier reports.

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THE EVOLUTION OF WATER RESOURCE DEVELOPMENT IN NORTHERN IRELAND

by H R F Plester, BSc, FICE, FIWEM, Director of Water Executive DOE (NI)
& C J A Binnie, MA, FICE, FIWEM, Managing Director WS Atkins Water

ABSTRACT

There is no shortage of basic resource in Northern Ireland since average rainfall across the Province varies from some 900mm to 1100mm per annum, east to west. However, as elsewhere, there is a constant need to ensure the provision of adequate water sourceworks.

In 1973 the Water Executive of the Department of the Environment for Northern Ireland took over responsibility for the water and sewerage services previously controlled by some 76 local and district authorities. Source schemes inherited, in some cases, reflected the parochial nature of the promoters rather than the wider regional approach. Upland impoundments were traditionally favoured and still account for 40% of all sources. Freshwater loughs were also used and Lough Neagh, the largest freshwater lough in the British Isles, accounts for 27% of all public supplies, with other loughs contributing a further 9%. River intakes at 13% and groundwater and springs at 11% make up the remaining sources.

The Water Executive commissioned a major study of water demand and supply in 1983 and have, with their current consultants W S Atkins, recently produced a new Water Resource Strategy for the Province. This paper outlines how water resource developments have evolved in Northern Ireland and describes the approach and recommendations of the study.

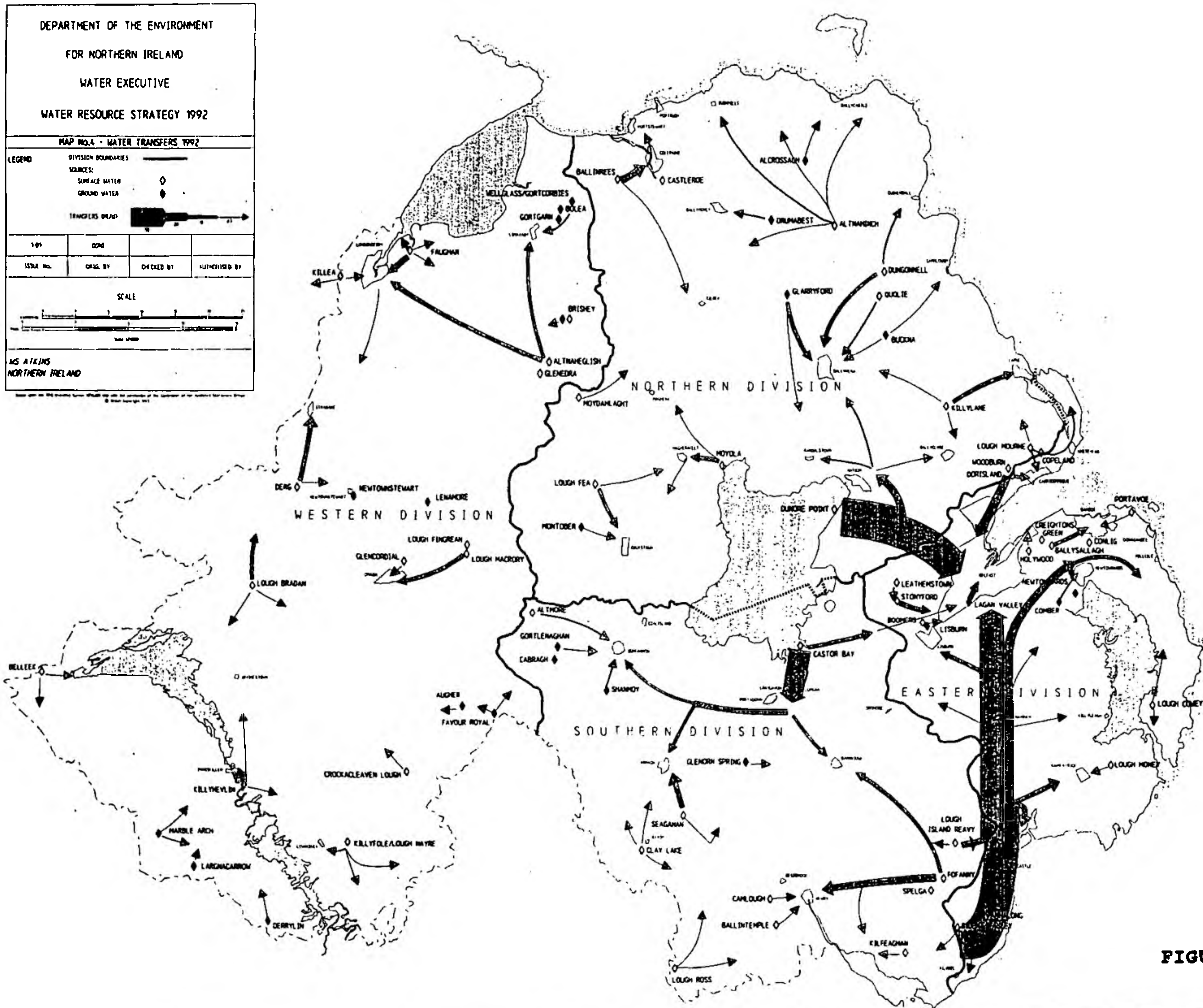
KEY WORDS: Northern Ireland; water resource; water demand; leakage; source yields; resource strategies.

INTRODUCTION

In Northern Ireland responsibility for the supply and distribution of water rests with the Water Executive of the Department of the Environment.

The total population of Northern Ireland is almost 1.6 m of whom 1.54 m are normally resident in approximately 530,000 private households. Almost 99% of these receive public water supply. In total the Water Executive currently supplies about 700 Ml of potable water every day from 67 sources (including groups of boreholes). The main sources are shown in Figure 1.

Operational management, including water supply, is the responsibility of four Divisions. Almost 50% of the population are resident in the Eastern Division and use approximately 340 Ml of the total, the bulk of this being consumed in the Greater Belfast area. Demand for water has been increasing and this trend is expected to continue. The Water Executive has therefore been planning towards augmentation of its resources particularly those which currently supply the Eastern Division.


DEPARTMENT OF THE ENVIRONMENT
FOR NORTHERN IRELAND
WATER EXECUTIVE
WATER RESOURCE STRATEGY 1992
MAP No.4 - WATER TRANSFERS 1992
LEGEND
DIVISION BOUNDARIES
SOURCES:
SURFACE WATER
GROUND WATER
TRANSFERS
ISSUE No.
ORIG. BY
CHECKED BY
AUTHORISED BY
SCALE
WS ATKINS
NORTHERN IRELAND
NORTHERN DIVISION
WESTERN DIVISION
SOUTHERN DIVISION
EASTERN DIVISION
BALLINREES
CASTLEROE
ALCROSSAGH
DRUMABEST
ALTNAHINCH
DUNGONNELL
GLARRYFORD
DUNORE POINT
KILLYLANE
LOUGH MOURNE
WOODBURN
DORISLAND
COPELAND
PORTAVOE
CREIGHTONS GREEN
CONLIG
BALLYSALLAGH
HOLYWOOD
LEATHEMSTOWN
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LAGAN VALLEY
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LOUGH MONEY
LOUGH ISLAND REAVY
FOFANNY
SPELGA
KILFEAGHAN
CAMLOUGH
BALLINTEMPLE
LOUGH ROSS
GLENORN SPRING
SEAGAHAN
CLAY LAKE
SHANMOY
ALTMORE
GORTLENAGHAN
CABRAGH
AUGHER
FAVOUR ROYAL
LOUGH FEA
MONTOBER
MOYOLA
MOYDAMLAGHT
ALTNAHEGLISH
GLENEDRA
BRISHEY
GORTGARN
BOLEA
WELLGLASS/GORTCORBIES
FAUGHAN
KILLEA
DERG
NEWTOWNSTEWART
LENAMORE
LOUGH FINGREAN
LOUGH MACRORY
GLENCORDIAL
LOUGH BRADAN
BELLEEK
KILLYHEVLIN
MARBLE ARCH
LARGNACARROW
DERRYLIN
KILLYFOLE/LOUGH MAYRE
CROCKACLEAVEN LOUGH

FIGURE 1

The promotion of a scheme for the Eastern Division was the main factor leading to the review in 1992 of the Executive's water resource strategy for Northern Ireland. This paper outlines the evolution of water resource developments in the Province and describes the strategy that has been developed.

BACKGROUND TO WATER SUPPLY IN NORTHERN IRELAND

The development of water resources in Northern Ireland reflects, in many ways, the social and industrial development of the province. The first reference to a piped public water supply dates back to 1678 when George McCartney raised the sum of £250 to lay 200 perches of wooden water pipe from the Tuck Dam to serve part of Belfast which then had a population of some 7,000 people.

During the next 100 years the development of the system was very fragmented and suffered greatly through difficulties in being able to collect charges for water supplied. The business proved so unprofitable for individuals that in 1791 the recently formed Belfast Charitable Society, realising the importance of clean water, undertook responsibility for its supply. Legislation was enacted to allow the levying of a water rate and to renovate and develop new spring sources. At that time demand forecasting was based on each person using approximately 3.5 gallons per day.

By 1830 the population of Belfast exceeded 70,000 and was growing rapidly, and in 1840 an Act of Parliament established the Belfast Water Commissioners with powers to levy rates and acquire water rights. The Commissioners were unique in that they were the only Water Board in the British Isles who were directly elected by rate payers.

Whilst the demands for clean water increased rapidly during the early eighteen hundreds, so did the demand for power to drive mills and factories throughout the Province. It is interesting to note that a number of the reservoirs, built for river and canal regulation and to provide power to the linen mills, are today used for water supply purposes.

The town of Belfast and its population continued to expand rapidly and between 1865 and 1890 the Woodburn catchment at Carrickfergus became the first source located outside the Commissioners' statutory boundary. It is also the first of the early eastern sources remaining in service today. Development at levels higher than could be supplied by the Woodburn system or other existing sources led to development of the Stoneyford and Leathemstown catchments by 1890.

Demand continued to increase sharply and the Commissioners (by then the Belfast City and District Water Commissioners) commenced development of the Mourne catchments at the turn of the century. Construction of the Silent Valley Reservoir was delayed by the Great War and was not completed until 1932. Later developments of these catchments included construction of the Bignian tunnel in 1953 to transfer water from the Annalong catchment for storage in Silent Valley, and the Ben Crom Reservoir in 1957, to increase storage capacity and yield of the system.

By that time the Commissioners were supplying water not only to their statutory area but also in bulk to areas outside such as Larne, Lisburn and most of County Down.

Parallel, smaller scale resource developments took place outside Belfast, and the eastern area, with more than 70 individual authorities being responsible for water supply. The first record of a public water supply for Londonderry, dates back to 1808 when the Corrody reservoir was constructed on the east side of the River Foyle. The supply was piped across the then wooden Foyle Bridge to the west side where most of the people lived. From 1849 to 1887, the three Creggan reservoirs were built to supply the growing west bank. These reservoirs have only very recently been taken out of commission for public water supply and now are used for recreational purposes. The Glenhordial and Altnaheglish sources were developed in 1880 and 1934 respectively.

Many of the sources are still in operation today and, in addition to those already mentioned, include the Fofanny and Spelga reservoirs (1909 and 1957) which supplied the Newry and Portadown area, the Castor Bay (1950s) abstraction from Lough Neagh serving the Craigavon area. The most rapid expansion of the distribution systems took place between 1968 and 1978 with extensive use of uPVC pipe in rural areas.

Due to the concentration of population in Belfast and its environs, the need for major source developments has generally continued to be greatest in the Eastern Division. During the 1960s industrial development played a major part in the first use of Lough Neagh for water supply to the eastern area by development at Dunore Point near Antrim.

Drought action curves are available for all of the main reservoirs. However, early in 1980, the Water Executive, working closely with the Water Research Centre (WRc), developed a conjunctive use mathematical model for the Eastern Area water supply system. Initially, the model sought to optimise demand, storage, and compensation flows. However, it was quickly developed to give information on the most economic way of using upland and lowland sources and also take account of the risk of source failures.

The combination of upland gravity sources and low level pumped supplies continues to form an important feature of the overall resource strategy. Interconnecting pipework in Belfast, Londonderry, and parts of Northern and Southern Divisions has given more robust supply systems and cost effective use of sources.

In October 1973, responsibility for all water and sewerage services in Northern Ireland passed to the Ministry of Development, later to become the Department of the Environment.

For many years demand forecasting tended to rely substantially on the extrapolation of past trends with weight also being given to movement of population and industrial growth patterns. In many instances this approach served the Water Industry well. Recently the identification of the various elements of demand and leakage have received more searching scrutiny, and much work continues to be done in more meaningfully accounting for each of the various elements of demand.

During the 1970s demand continued to increase and plans to abstract further water from Lough Neagh, at Tunny Point, were well advanced when rising electricity prices prompted the Water Executive to consider possible alternative cheaper sources.

A proposal to abstract water from the Upper Bann at Kinnahalla on the north side of the Mourne Mountains was not allowed by the Water Appeals Commission in 1980. Coincident with this decision, an economic decline led to the closure of a number of large water-using industries, notably Courtaulds and ICI at Carrickfergus. The resulting savings together with the small scale borehole development of the Lagan Valley aquifer enabled the Water Executive to continue to meet demands.

However, the underlying trend in demand was still upwards and the Water Executive was anxious to develop sufficient new resources to ensure that demand could be met. This concern led to the appointment in 1983 of engineering consultants (Sir Alexander Gibb & Partners) in association with a firm of management consultants (Deloitte Haskins and Sells) to assess and report on the water supply needs for the Province with particular reference to the Eastern Area..

Local area water supply studies had been prepared during the 1970s but the consultants' report (known as the Gibb Report) effectively became the Water Executive's first "global" water resource strategy. It concluded that preparations for introducing new source developments for the Eastern Area should be initiated taking account of the potential for leakage reduction.

LEAKAGE CONTROL

The first reference to legislation dealing with leakage control dates back to 1817, when the Belfast Charitable Society (later known as the Spring Water Commissioners) were empowered to enter private property to "prevent wastage of water". A number of the larger water authorities had "uniformed staff" whose particular duties entailed leakage control and the inspection of plumbing fittings.

In common with the water utilities in the rest of the UK, leakage has for many years been recognized as the reason for significant quantities of water being lost from the system. In the 1970s, work began in earnest to subdivide the various distribution networks into a comprehensive system of waste districts for monitoring and control of leakage. Efforts were initially concentrated in the Greater Belfast area but the system was gradually extended until it covered all of Northern Ireland in the 1980s.

The early efforts were rewarded with savings of approximately 30 megalitres per day but it was clear that success would be limited without additional resources. The Gibb Report endorsed this view and recommended additional staff resources which were provided during 1985. Their impact was marked and target leakage levels were rapidly achieved. This early success enabled lowering of the targets and has continued leading to further downward revisions.

However, the lower the rate of leakage the more difficult that leakage is to detect and the point is being approached where it may be more economic to provide additional water sources than to further increase efforts in leakage control

It is worth noting that the significant reduction in leakage from the distribution system has not always been matched by an equal reduction in total water demand. This suggests that the underlying increase in consumption levels was greater than anticipated .

NEW SOURCE PROGRESS

The preparations recommended by Gibb were source identification, outline design and the documentation required for public inquiry. These steps, together with the need for large sums to be invested to enable existing sources to comply fully with the EC Drinking Water Directive and the consequent desire to rationalise the very large number of sources, have prompted the latest water resource strategy.

Following extensive economic evaluation and a comprehensive environmental assessment of the identified source options, Water Executive has decided to develop a new source involving abstraction of water from Lough Neagh at Hog Park Point. The next step will be publication of the statutory notice of intention to abstract water. It is likely that this will be followed by a public inquiry and it will be necessary to prove to interested parties that the development is required. The expenditure will also have to be justified internally. It was recognized from an early date that these proofs would require the demand projections to be updated from those contained in the Gibb Report.

In 1973, the Water Executive inherited a large number of small sources. Within the EC compliance programme, it would be desirable to take the opportunity to phase out many of the minor, less economic sources. In 1992, W S Atkins were appointed to advise on the development of a new water resource strategy for Northern Ireland.

THE 1992 WATER RESOURCE STRATEGY

BRIEF

The brief for the study was wide ranging and included:-

1. Review of source yields and operating margins for resource planning purposes.
2. Review of capital works programme proposed for EC Drinking Water Directive compliance, including identifying sources which could be abandoned on economic grounds.
3. Audit of water demand for the demand forecasting base year including assessing:-
   a. Accuracy of the source works meters.
   b. Domestic water consumption.
   c. Industrial/commercial sector metered consumption.
   d. Under registration of consumers meters.
   e. Water Executives' leakage control programme and recommend new target levels.

4. Recommend appropriate demand management methods.

5. Propose demand forecasting methodology, review existing demand projections, and make new demand forecasts from the base year to the year 2021.

6. Identify surpluses and deficits of yield against projected demand.

7. Review the currently proposed resource schemes and identify other options as appropriate.

8. Economic appraisal of the strategy options.

9. Recommend future water demand monitoring data recording and dissemination.

10. Report on the potential effects of the introduction of an abstraction licensing and charging policy.

The Water Executive required confirmation of the programme for bringing on stream the major new source to supply the eastern area of the Province. The success of the Water Executive's leakage reduction programme, coupled with a steady decline in major water using industry in the eastern area, meant that the requirement for a major new source for the eastern area had been delayed to beyond the mid 1990's, the latest timing predicted by the Gibb Report in 1984.

CURRENT AND FUTURE WATER DEMAND

POPULATION

The publication of the 1991 Northern Ireland Census returns assisted the conclusions on the household unmeasured use element of water delivered. They were used as the basis of the population projections over the study period to 2021. The total population in 1991 was 1,577,836 and in 2021 is estimated to be 1,802,000. The 1991 population in private households was 1,540,000 people in 530,000 households, this was 51,000 fewer than the 1984 report projection. In 2021 the respective figures will be 1,759,000 in 701,000 households, and the average house occupancy rate will drop from 2.9 to 2.5 persons per household.

PER CAPITA CONSUMPTION

A zonal metering study was carried out using 73 zones and a sample size of 3,100 properties. This enabled a relationship between per capita consumption and house type, which was used as a surrogate for the socio economic groupings of the occupants, to be developed. Market research techniques were used to collect data on the houses and households in the zones and a weekly diary of water usage was completed by some 500 persons in 211 households. Components of water use were identified and compared with data from elsewhere.

The results gave an average figure for Northern Ireland per capita domestic consumption of 137.5 l/ph/d.

HOUSEHOLD MEASURED AND UNMEASURED DEMAND

Households in Northern Ireland are generally unmetered, the only households where consumption is measured are those with associated non household usage and are almost exclusively farms. The demand for water in measured and unmeasured households has therefore been estimated from the population in private households and the per capita consumption figures. Double counting the agricultural household element in each demand zone was avoided. The household demand in 1992 has been estimated to be 214 Ml/day amounting to 33% of distribution input. By the year 2021 the figures will be 306 Ml/day and 37% of the distribution input.

NON HOUSEHOLD MEASURED DEMAND

There are some 72,000 water meters in Northern Ireland on non household measured supplies. Meters are read either monthly or six monthly and data held by the Water Charges Branch of the Water Executive was analyzed to ascertain the measured demand for 1992.

Four main usage categories were used for the purposes of forecasting future growth, agricultural, industrial, commercial, and public sector. For each category an analysis was made of the existing and future economic and sociological situations affecting water demand.

Commercial meter accuracy was estimated by in situ and bench testing. The results found an under registration of 4.5% and this was applied in the analysis.

NON HOUSEHOLD UNMEASURED DEMAND

Analysis of the properties that were metered show that out of approximately 72,000 meters installed 61,000 were read in 1992, of these 44,600 were agriculture meters and only 16,200 were commercial, industrial and public sector meters. There are approximately 41,500 farm holdings in the Province and 48,800 commercial, industrial and public sector properties. Thus a significant number of non household properties are not measured, because their water usage is too small, consuming less than 200 cubic meters in 12 months. Unmeasured non household demand was then estimated using a statistical approach.

DEMAND FORECASTS

The study produced water balances for each division, by comparing the water supplied, measured by source works meters, with the estimations of water used. The elements of total demand were then projected, using a componental approach where applicable, to produce the results shown in Fig. 2.

LEAKAGE

The 1984 report found leakage levels ranging from 40 - 23 litres/property/hour (l/pr/h), and recommended that these be reduced to range of 22 - 13 l/pr/h. The necessary financial and staff

Parameter	Year / Unit	1992	1996	2001	2006	2011	2016	2021
HOUSEHOLD UN-MEASURED	Ml/day	213.89	227.56	241.76	255.24	269.98	286.72	305.63
NON-HOUSEHOLD MEASURED	Ml/day	200.79	196.96	203.40	208.34	213.28	218.67	224.53
NON-HOUSEHOLD UNMEASURED	Ml/day	17.35	17.95	19.36	20.42	21.57	22.74	23.94
WATER DELIVERED – BILLED	Ml/day	432.02	442.47	464.52	484.00	504.83	528.13	554.10
Distribution Losses	Ml/day	217.44	224.86	227.21	233.95	240.39	248.00	256.42
Operational Use	Ml/day	2.59	2.65	2.79	2.90	3.03	3.17	3.32
WATER NOT DELIVERED	Ml/day	220.04	227.52	230.00	236.85	243.42	251.17	259.75
WATER TAKEN UNBILLED (Fire Service & Other)	Ml/day	11.23	11.50	12.08	12.58	13.13	13.73	14.41
DISTRIBUTION INPUT	Ml/day	663.29	681.49	706.60	733.44	761.37	793.04	828.25

DEMAND FORECASTS – NORTHERN IRELAND

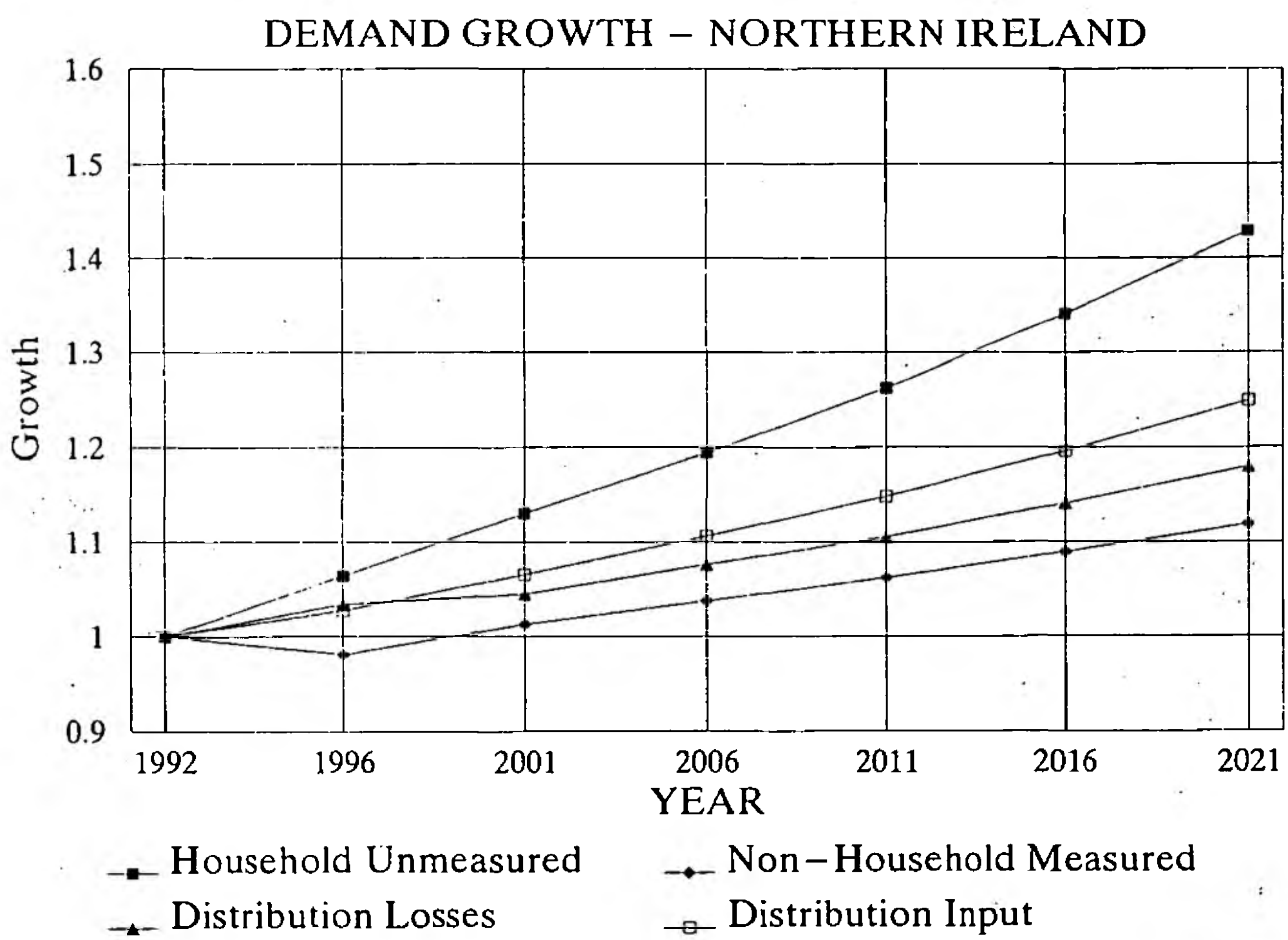

FIGURE 2

resources were made available, a leakage control programme planned and executed, and routine and effective leakage control became part of operational procedures. Significant reductions have been made in leakage levels which currently average between 11 and 8 l/pr/h.

The new study examined distribution system waste district monitoring, legitimate night flow levels, and estimated the under recording inherent in the monitoring and repair regime. Measurement factors to allow for these aspects were developed and applied to recorded leakage levels. Trunk main leakage and service reservoir leakage was also estimated. Enhanced leakage control strategies were recommended based on:-

- upgrading of monitoring equipment and methods.
- reduction in distribution system operating pressures.
- replacement and/or refurbishment of water mains in poor condition.

The different strategies vary only in their application of the recommended methods, either to all zones or concentrating on zones with known high leakage levels. The strategies propose the following guideline ranges:-

- urban areas 6 - 8 l/pr/h,
- mixed areas 7 - 9 l/pr/h,
- rural areas 8 - 10 l/pr/h.

The whole success of enhanced leakage control strategies depends as before on sufficient resources of manpower, equipment and money being provided.

SOURCE YIELDS

A review of water source yields was undertaken, noting changes in operational procedures and hydrological data availability since the 1984 report. The validity of previous yield calculations and operating margins was examined.

Useful Streamflow data throughout the Province for reservoired catchments was lacking. Some gauging stations had fallen into disrepair or gauging had been discontinued. The main hydrological/hydrometric network is managed jointly by the Environment Service of DOE (NI) and the Department of Agriculture (NI) and is mainly concerned with flooding incidents, there is little coverage of upland areas of catchments where the majority of the Water Executive's impounded reservoirs are located. A hydrometric network to serve the interests of the Water Executive is required.

Additional information was available on rainfall and evapotranspiration, including two significant drought events in the 1980's. Abstraction and storage data useful for yield recalculation was present in the case of some reservoirs.

The yields of the larger single season reservoirs was recalculated, i.e. those as having storage to annual runoff volume ratio less than 30%, and a reliable yield greater than 5 Ml/d. The recalculation used behavioural analysis techniques and a frequency based measure of failure approach. This made best use of site specific data and avoided assumptions concerning the homogeneity of hydrological conditions within Northern Ireland, and the estimation of catchment mean flows. The method depends on the availability of continuous records over a period of time and was hampered by missing data throughout the length of records in rainfall data provided by the Belfast Meteorological Office, and by differences in the rating of rainfall gauging records between the Environment Service and the Institute of Hydrology. Synthesising techniques were used to substitute for the missing data. Siltation effects were also examined.

There was an overall reduction in source yields arising from the application of available data from the past decade, and a resultant decrease in available water resources within the Province.

A database has been developed for each source to act as an inventory of all relevant information, including the policies and reasons for the mode of operation, and details of associated treatment works.

WATER QUALITY

Some 13 water sources within Northern Ireland have derogations with respect to the EC Drinking Water Directive maximum reliable concentrations (MACs) with regard to one or a combination of the following parameters :-

- aluminium
- iron
- manganese
- colour
- taste and odour.

Some 106 out of a total of 115 water supply zones are affected as a result of these exceedences at their associated source works. The MAC exceedences over a variety of quality parameters occur throughout the supply system including those for THM's, PAH's, and pesticides.

EMERGENCY PLANNING

The risk of failure of the main elements of the whole water supply system was examined for each water source and associated treatment and transfer system by identifying the risks, the likelihood of failure, and the severity of the consequence of failure. A basic level of risk matrix was developed using this approach. The margin of safety proposed consisted of either an operating margin of 5%, to cater for uncertainty in future demand forecasts, or an emergency margin to cater for sources that do not have additional treatment capacity above net storage yield, or whose supply zones cannot be supplied from an adjacent treatment works. This emergency margin varies between 0 and 20% depending on the availability of alternative sources of supply, the interconnectivity of supply areas, and the relative capacities of the sources involved. This exercise assisted in identifying interconnections required between demand zones.

FUTURE RESOURCE REQUIREMENTS

The demand forecasts were applied to each relevant demand zone and a resource versus demand model was developed and used to indicate current and future resource deficits, and provided the resource margins or deficits at five yearly intervals for each group of demand zones or sources.

Two minimalist options of 'do nothing' to provide a base line for comparison proposals in line with Treasury Guidelines, and 'do minimum' were considered. The 'do nothing' option involved not initiating any work not already underway and not closing any sources currently in use or available for use. This showed immediate resource deficits in 8 out of the 34 demand zones of which four were significant.

The 'do minimum' option involved completing works planned at treatment works to comply with the EC Drinking Water Directive and closing uneconomic sources, at 1996 there are four demand zones in deficit.

Under both the 'do nothing' and the 'do minimum' options the eastern area of the Province required a major new source either by 1999/2000 or by 2001 respectively.

RESOURCE DEVELOPMENT STRATEGIES

Three main strategy options were considered :-

1. Do minimum: Other than completing all EC Water Quality Directive Compliance Work no new developments or major enhancement of existing schemes except those already committed were included. Some minor sources closed.

2. System Rationalisation: All required new developments and major enhancements implemented together with the closure of smaller uneconomic sources.

3. System Rationalisation together with leakage reduction: All new developments and major enhancements implemented, with closure of smaller uneconomic sources together with a leakage reduction strategy.

The main sub options concern the future of the Moyola Water Treatment Works on the north side of Lough Neagh, originally using water from the Lower Bann River, and the Lough Island Reavy sourceworks in the north of the Mourne Mountains. The options for the Moyola Treatment Treatments Works range from closure to major extension, and for Lough Island Reavy there are two options to be considered, one with the source continuing to supply the Eastern Division via the Mourne Conduit and at the other with it becoming a source supplying Banbridge & Newry area of Southern Division.

Economic analyses were undertaken for each of the options. Strategy 3 was shown to be the most beneficial in both economic and technical terms and the capital cost of the recommended strategy at current prices would be £90m between 1994 and 2021. Following the economic analysis the principal resource development recommendations to be implemented include:-

1. A major new source to serve the eastern area abstracting water at Hog Park Point from Lough Neagh. The first phase of this source development and its associated infrastructure is required to be operational by the year 2000.

2. An immediate need to develop a new resource to augment the supply to the Derg demand zone which is in the northern half of County Tyrone and includes the towns of Strabane and Newtownstewart. The new source to be either a regulating dam on the Glendergan river or a river abstraction scheme on the River Mourne.

3. Depending on confirmation of the safe yield of the River Faughan due to conflicting hydrological information construction of the Glenedra Dam to secure the resource capacity required for the Derry City demand zone will be required.

4. Current plans to increase the treatment works capacity at Moyola on Lough Neagh can be cancelled and the works retained at their current capacity until the commissioning of the Hog Park Point scheme, the third major source for the eastern area. Transfer pipeline and pumping stations will be required to substitute Dunore Point (Lough Neagh) water for Moyola water once the Hog Park Point scheme is implemented. Subsequently the Moyola sourceworks can be abandoned.

5. A new pipe line is required now between Ballinrees Treatment Works, west of Coleraine, and Ballymoney, to the south east of Coleraine on the boundary of the Ballinrees demand zone, to overcome resource shortfalls and to allow the development of new capacity at Ballinrees to meet future requirements.

6. Lough Island Reavy will cease to supply raw water to the Silent Valley Mourne aqueduct except in an emergencies. The planned Silent Valley Water Works and the Mourne Conduit refurbishment capacity can exclude the yield of Lough Island Reavy. Subsequent to the commissioning of Hog Park Point Lough Island Reavy will be used in the expanded Fofannybane treatment works and used to augment supplies to the Banbridge and Newry demand zones.

7. In all cases an enhanced leakage reduction strategy will be implemented in all waste zones and not merely those with known high leakage levels.

The water transfer system forecast for the year 2021 is shown in Figure 3.

CONCLUSION

The reduced growth in forecast demand to 1992, and the lower subsequent demand forecasts have enabled rationalisation of source works to be considered as part of both the EC Water

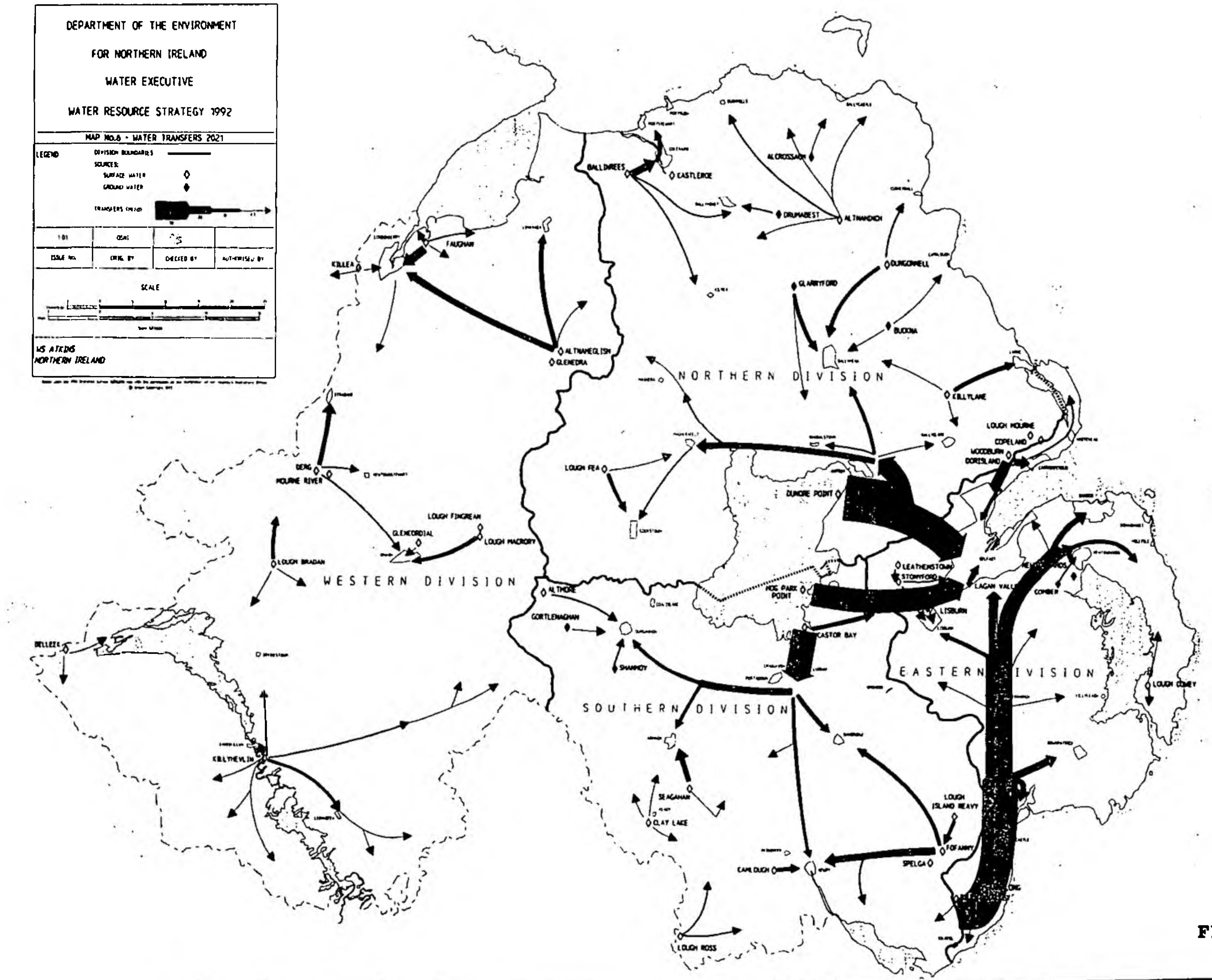
DEPARTMENT OF THE ENVIRONMENT
FOR NORTHERN IRELAND
WATER EXECUTIVE
WATER RESOURCE STRATEGY 1992
MAP No.6 - WATER TRANSFERS 2021
LEGEND
DIVISION BOUNDARIES
SOURCES:
SURFACE WATER
GROUND WATER
ISSUE No.
ORIG. BY
CHECKED BY
AUTHORISED BY
SCALE
WS ATKINS
NORTHERN IRELAND
NORTHERN DIVISION
WESTERN DIVISION
SOUTHERN DIVISION
EASTERN DIVISION
BALLINREES
CASTLEROE
ALTNAHINCH
DRUMAREST
DUNGONNELL
CLARRYFORD
KILLYLANE
FAUGHAN
KILLEA
ALTNAHEGLISH
GLENEDRA
LOUGH FEA
DUNORE POINT
DERG
MOURNE RIVER
LOUGH FINGREAN
GLENCORDIAL
LOUGH MACRORY
LOUGH BRADAN
ALTMORE
GORTLENAGHAN
MOYGANNON
LEATHEMSTOWN
STONYFORD
LISBURN
LAGAN VALLEY
COMBER
CASTOR BAY
SHANMOY
SEAGAHAN
CLAY LAKE
LOUGH ISLAND REAVY
FOFANNY
SPELGA
CAMLOUGH
LOUGH ROSS
BELLEEK
KILLYHEVLIN
LOUGH COWEY
LOUGH MOURNE
COPELAND
WOODBURN
DORISLAND

FIGURE 3

Quality compliance work, and the future strategy.

Proposed new leakage target levels depend on the commitment of adequate technical and financial resources.

The new study has provided robust evidence for justification of the need for new source works developments. It will assist the Water Executive in fulfilling its mandate in the modern environment, and into the next century.

STRATEGIC RESOURCE DEVELOPMENT OPTIONS

by

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T E A Askew BSc, CEng, MICE, MIStrutE, MIWEM⁺

ABSTRACT

This paper describes the range of options considered for new water resources as part of development of the NRA Water Resource Strategy for England and Wales. The options included inter-regional transfers by river regulation or aqueducts, strategic reservoirs, and a range of unconventional options including aquifer recharge, effluent reuse, groundwater abstraction where levels are rising, desalination, and transfer by sea. The main options are described and comparative costs are presented.

KEY WORDS: strategic planning, water resources, resource development options, water transfers, aqueducts, reservoirs, river regulation, groundwater abstraction, canal transfers.

INTRODUCTION

The NRA's strategy for development of water resources in England and Wales provides a two-pronged approach to the problem of meeting future water needs:

- firstly, restricting or eliminating the growth in water demand by measures to reduce consumption and avoid wastage;
- secondly, the classical approach to water resource planning involving a range of demand forecasts and a corresponding analysis of options to meet the future deficits.

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This paper concentrates upon the second, classical approach. The range of demand forecasts is governed to a large extent by the success of measures to control demands and avoid leakage. Although there can be no doubt that demand control is preferable to new resource development on environmental grounds, future resource deficits may still arise due to the cost or impracticality of demand control measures, or due to economic growth, population change or change in climate.

The range of forecast deficits in the year 2021 are given in Table I.

TABLE I. DEFICIT FORECASTS UNDER HIGH, MID AND LOW DEMAND SCENARIOS (BEFORE ALLOWING FOR DEVELOPING LOCAL SCHEMES) (Ml/day)

	Northumbria	North-west	Yorks	Welsh	Severn-Trent	Anglian	South-west	Wessex	Thames	Southern
High	14	164	261	133	577	195	124	201	867	152
Mid	0	0	29	38	182	100	40	58	270	57
Low	0	0	0	12	41	35	3	20	56	21

The basis of these demand forecasts is described in the NRA's strategy documentation and in an earlier paper at this Conference [1,2]. The deficits shown in Table I do not allow for the development of new resources in the locality of the demand centres. There are about 60 such schemes listed in the NRA's strategy [1] with a total resource value of 2051 Ml/d. These small-to-medium sized schemes are likely to be preferred on environmental grounds to major resource developments involving inter-regional transfer. However, even after allowing for the development of the local schemes, there would be some deficits arising as shown on Table II.

TABLE II. STRATEGIC DEFICITS AFTER ALLOWING FOR DEVELOPMENT OF LOCAL SCHEMES

	Severn-Trent	Anglian	Thames	Wessex area
High	252	128	629	84
Mid	4	72	66	0
Low	0	0	5	0

This paper concentrates upon the major strategic options for meeting the high level of deficits shown in Table II. Consideration of these large schemes provides a standard in terms of cost and environmental impact against which the smaller local options may be judged.

RANGE OF OPTIONS CONSIDERED

Table II shows that the strategic deficits are forecast to arise mainly in the central southern and eastern parts of England. The northern parts of England and the whole of Wales are shown to have no forecast deficits, reflecting their high rainfall and low population. In the drier parts of the country, there are already well publicised problems due to the environmental impact of existing resource developments, notably low flows in rivers, particularly those with a strong dependence upon groundwater-fed baseflow. Therefore, the resource availability for supplying the south-east comes down to:

- development of additional storage in the south-east to make more use of winter river flows;
- transferring water from the north of England or Wales, possibly in conjunction with development of more storage.

The range of options considered through recent pre-feasibility studies are illustrated in Figure 1 and include:

SOURCE SCHEMES	Consultant
• The Craig Goch reservoir scheme, either to regulate the River Severn or the River Wye;	Halcrow
• Redeployment of Vyrnwy Reservoir to regulate the River Severn;	Halcrow/Binnie
• use of rising groundwater under Birmingham.	Halcrow

TRANSFER SCHEMES | Consultant

•	a transfer from the River Severn to the River Thames;	Atkins
•	a transfer from the River Severn to the River Trent;	Atkins
•	a transfer from the River Trent to Anglian Region;	Atkins
•	use of the existing canal system to transfer water from the River Severn to the south and east.	Binnie

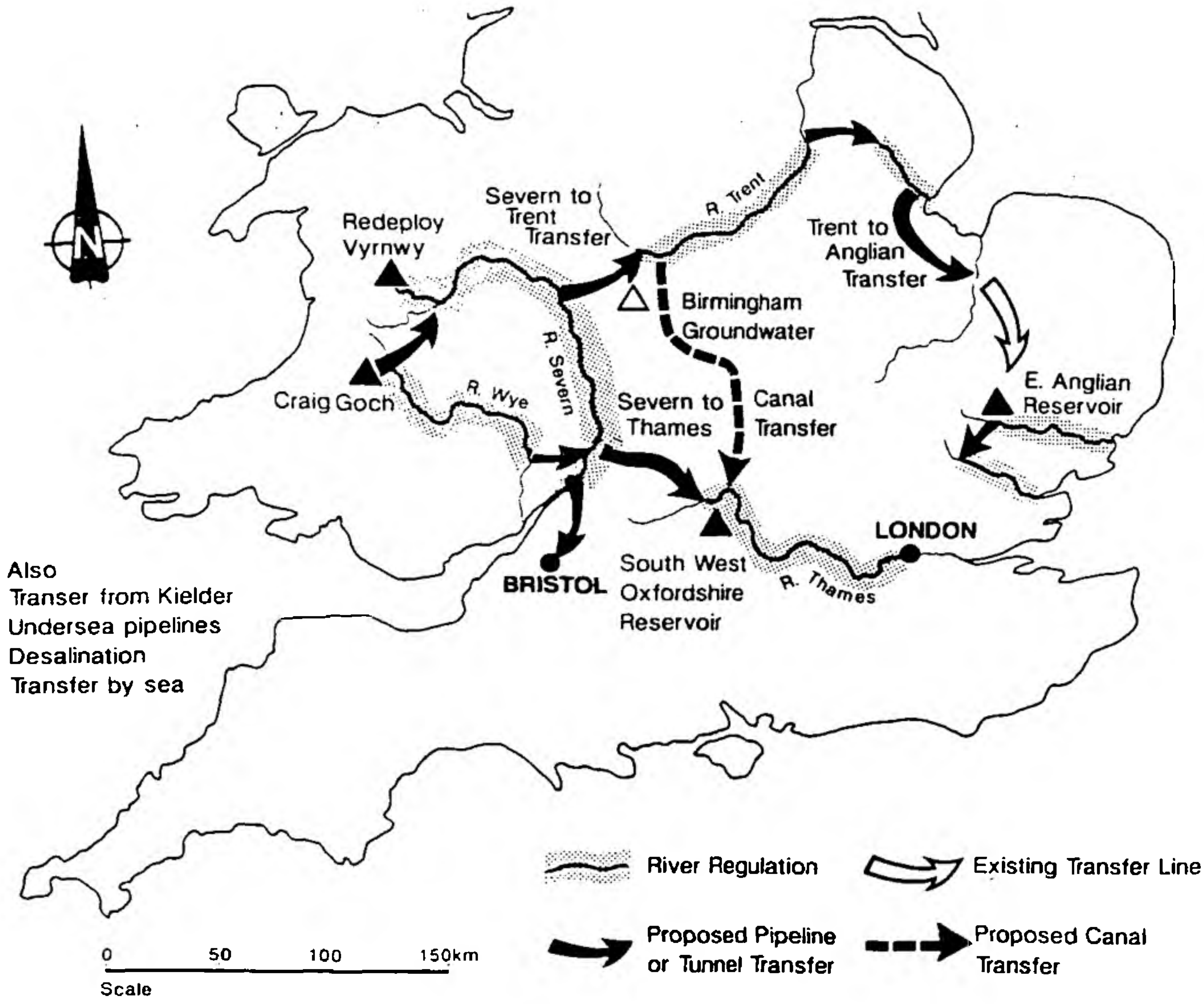

Figure 1. Strategic Options Considered

STORAGE SCHEMES	Consultant
• the South-West Oxfordshire Reservoir, either as an independent source or in conjunction with the Severn to Thames transfer;	Halcrow
• a new reservoir in East Anglia.	Atkins

In addition to these schemes, which are in essence conventional surface or ground water developments, consideration has been given to a variety of unconventional schemes. These include desalination, transfer of water through a 'national grid', transfer by undersea pipelines, and transfer by sea using tankers or water sacs.

The following sections of the paper deal with the range of options under the headings of Strategic Transfer Options, Strategic Storage Options and Unconventional Options.

STRATEGIC TRANSFER OPTIONS

In recent feasibility studies, four main transfers have been considered or reconsidered. The main features of these transfers are outlined on Table III. Potential transfer volumes range from 100 Ml/d up to 600 Ml/d, and involve distances of up to 400 km. Three studies commissioned by the NRA [3, 4, 5] looked at various transfer methods including major pipelines, tunnels, artificial and natural water courses. A study commissioned by British Waterways [6] concentrated on the use of inland waterways.

TABLE III. MAIN FEATURES OF POTENTIAL TRANSFERS

Transfer	Severn to Thames	Severn to Trent	Trent to Anglian	Canal Transfers
Donor River	Severn	Severn	Trent	Severn where applicable
Abstraction Location/ Canal input point	Deerhurst	Wroxeter or Coalport	Torksey	Salford Junction (Birmingham & Fazeley Canal)/Great Hayward Junction (Trent & Mersey Canal) Berbridge Junction (Shropshire Union Canal)
Receiving River	Thames	Penk or Trent	Fossdyke Canal/River Witham for transfer to Ouse	Trent/Thames/Nene/ Great Ouse
Discharge Location	Buscot or via South West Oxfordshire Reservoir	Lower Drayton (Penk) Sandon/Great Haywood (Trent)	Torksey (canal for onward transfer)	Nottingham/Oxford/ Northampton/Milton Keynes
Transfer rates (Ml/d)	200-400	100-300	Additional 200-600	100-300

Hydrological modelling of transfers between rivers has shown that operation of the regulation and transfer systems will only be required in the low flow period of dry years. Because the operation of a transfer system is predicted to be infrequent, running costs are not likely to be a dominant factor. As a result smaller less expensive higher pressure pipelines with greater pumping costs become more economical.

Environmental impacts associated with transfers are a key issue. The paper which follows [7] will cover overall environmental assessment and comment on specific environmental issues for individual transfers. Therefore to avoid duplication this paper concentrates on selected engineering and operational issues which are introduced and explained in the context of individual transfers.

SEVERN THAMES TRANSFER

The principal point of abstraction on the Severn would be at Deerhurst (see Figure 2). Abstractions would be linked to a prescribed flow on the Severn. An abstraction point further downstream at Gloucester could be affected by suspended solids and salinity. The main

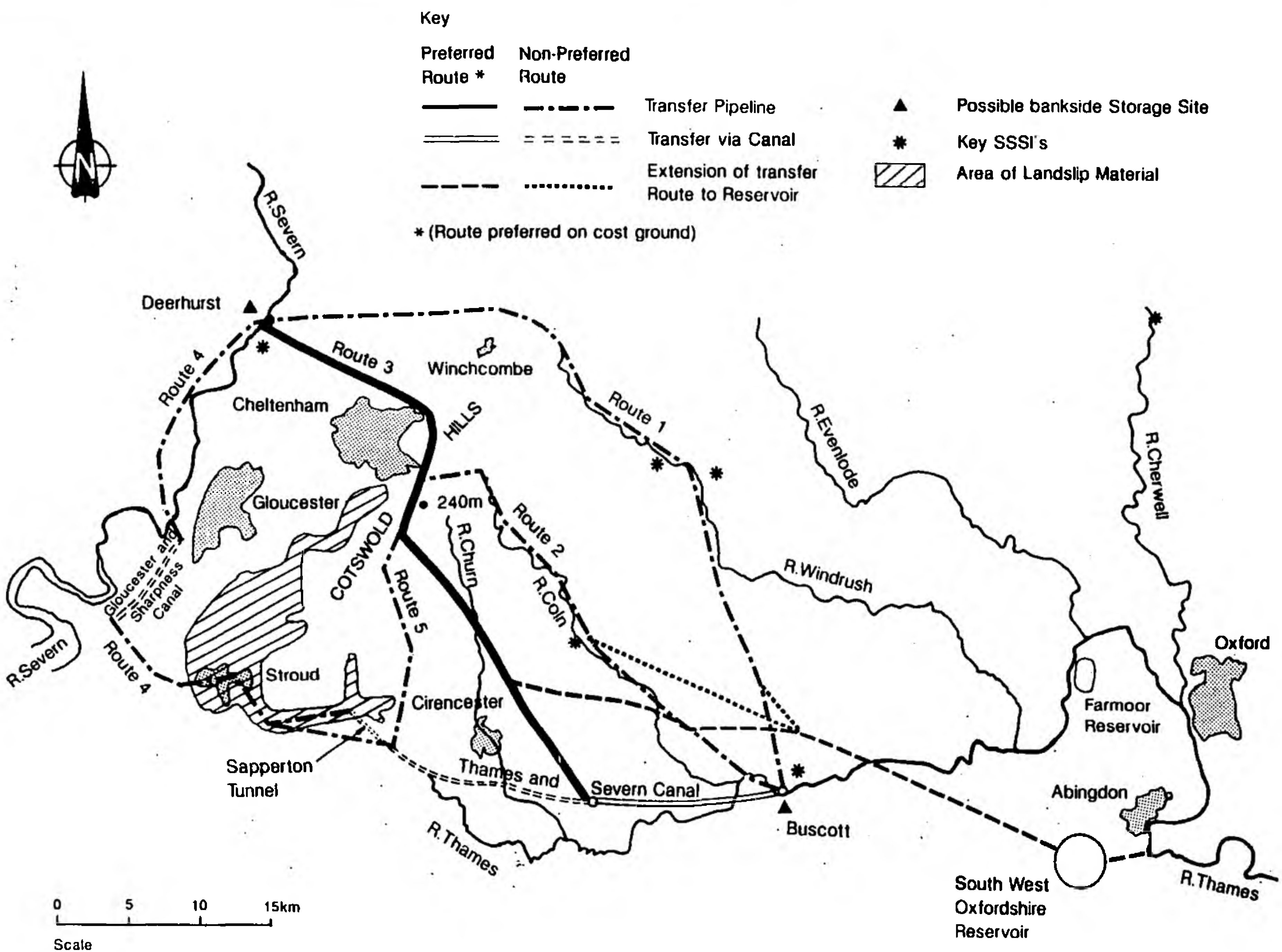

Figure 2. Severn to Thames Transfer

discharge locations considered would be on the Thames downstream of Buscot or direct to the proposed South West Oxfordshire Reservoir. The reservoir discharge would largely avoid any potential environmental risks to the aquatic ecology of the upper Thames. At the abstraction point, flood defence requirements would constrain development in the flood plain; a buried intake/low lift pump station was therefore proposed, together with bankside storage for settlement located some 2 km away outside the flood plain.

Routing of the transfer along a restored Thames and Severn Canal was considered, either via the Gloucester and Sharpness Ship Canal or pipeline direct to the Thames and Severn Canal summit section near the Sapperton Tunnel. The Thames and Severn Canal has been formally abandoned and the canal corridor, often overgrown or filled in, has reverted to adjacent ownership. The Cotswold Canals Trust is promoting restoration often "on the back" of other developments. The possibility of using the canal also arose for transfer via future gravel pits identified in the Gloucester Minerals Plan. The gravel pits could be used for initial blending of transfers and would improve operational flexibility.

The route via gravel pits to the Thames at Buscot was found to have the lowest cost. The route to the canal summit was relatively more expensive, in part due to a longer pipeline route to avoid potentially unstable ground along the scarp face of the Cotswolds, south of Cheltenham. Routes using the Gloucester and Sharpness Canal were expensive and pipeline or canal transfer up the Stroud Valley would be difficult, disruptive and operationally complex.

The other routes studied were predominantly pipeline routes over or around the Cotswold Hills to the Thames or its tributaries. Pipeline routes shown in Figure 2 generally follow the valleys to avoid high ground, rock excavation and unfavourable hydraulic profiles. Alternative routing over higher ground could reduce potential impacts to more sensitive habitats found in the valleys but would be at higher cost.

The transfer would involve pumping from 10 m above Ordnance Datum (mAOD) at Deerhurst to about 240 mAOD at the summit, and falling to around 60 mAOD at the discharge point on the Thames. The sizing of pipelines has a critical effect on capital cost. An increase in diameter from 1100 mm to 1200 mm increases unit pipeline costs by about 20%. It was therefore important to select an economic pipeline design. Pumping mains were optimised for minimum total costs in respect of capital and operating costs. Gravity mains were sized to maintain the hydraulic grade line above the pipeline level at local high points.

For the unsupported Severn to Thames transfer it was found uneconomic to phase construction, building a 200 Ml/d capacity pipeline and later duplicating it when required. The increased disruption and disturbance caused by later duplication would also be unwelcome particularly in the Cotswold Area of Outstanding Natural Beauty.

Change in water quality within a raw water pipeline is a particular operational and environmental issue especially for a long route such as that across the Cotswolds. When not required, the pipeline would be emptied. However, at times of intermittent transfer, because of the time taken to empty and refill a pipeline, the transfer system would be on standby with the pipeline full of water. To reduce the risk of water quality deterioration a "sweetening" flow would be required.

Settlement at the Severn end was recommended to reduce the risk of solids settling in the pipeline and developing an anaerobic slime. Discharge with aeration and buffer storage, for example at gravel pits alongside the Thames, would improve operational flexibility in dealing with an incident of poor quality water. Completely draining pipeline low points via washouts to sensitive watercourses such as pristine Cotswolds streams would be unacceptable. Therefore for complete emptying, washout discharges could be pumped along the pipeline route using small secondary pipes on the uphill sections.

SEVERN TO TRENT TRANSFER

Two abstraction locations were considered (Wroxeter and Coalport as shown on Figure 3) and three alternative discharge locations (Sandon and Great Haywood on the Trent and Lower

Drayton on the River Penk). Prescribed flows were taken as 1100 Ml/d at Buildwas and 900 Ml/d at Bewdley for abstractions at Wroxeter and Coalport, respectively. Transfer rates would range from 100 Ml/d up to 300 Ml/d. Additional water would be required in the Trent because of increasing demand for potable water within the catchment, and to support any transfer, into Anglian Region, outlined below. The key factors in aligning the pipelines were found to be:

- the Wrekin and Ironbridge Industrial Heritage Site which constrained the selection of abstraction points from the Severn;
- the capacity of the existing receiving watercourses;
- it was found economic to route pipelines over high ground close to the Severn to take advantage of opportunities to reduce the diameter of gravity mains by allowing the hydraulic grade line to follow the trend in ground levels.

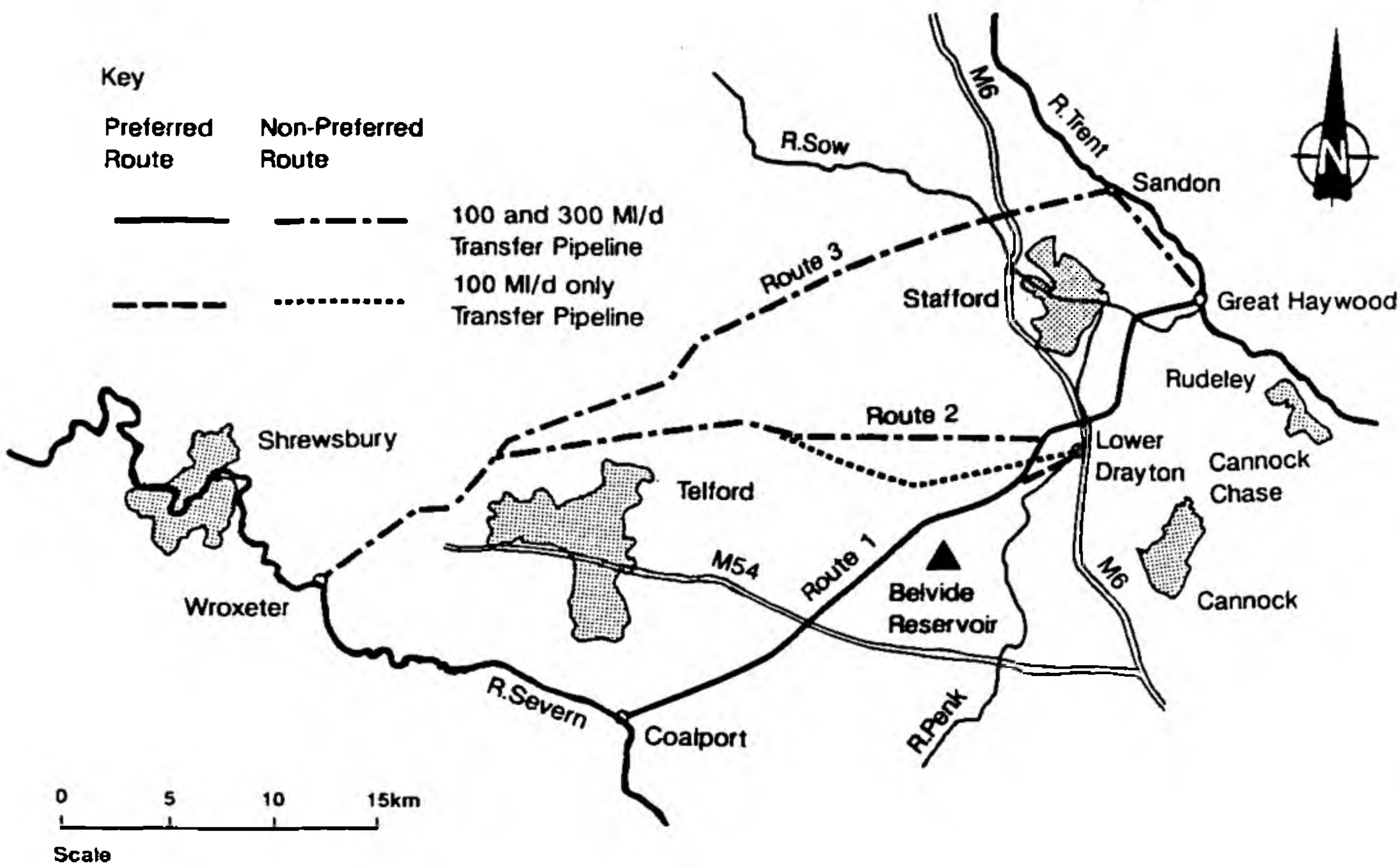

Figure 3. Severn to Trent Transfer

The efficiency of a transfer, in terms of minimising the water losses due to river regulation, may be considerably improved by the provision of balancing storage within the system. Hydrological modelling showed that most of the transfer volume to the Trent would need to be met by increased augmentation of the Severn. This has implications for in-river regulation losses since the transfer times from a source on the Severn to the abstraction point on the lower reaches of the Trent could take up to eight days excluding intermediate storage.

Table IV shows the excess volume transferred as a percentage of the required Trent augmentation for selected years. Excess volumes would primarily be transferred due to unforeseen increases in flow in the Severn and/or the Trent caused by sudden rainfall in either catchment. The table shows that excess volumes transferred might be of the order of 15-50% in drought years and that three days balancing storage could reduce these losses by about 30%. The operation of the scheme would be sensitive to flow forecasting and the effect of three days balancing storage at the mid-point of the system would be to halve the flow forecasting time.

TABLE IV. ESTIMATED EXCESS RELEASES FOR SELECTED YEARS, WITH AND WITHOUT BALANCING STORAGE ON SEVERN-TRENT TRANSFER (2400 Ml/d Prescribed Flow on river Trent at Colwick)

Scenario	Year	No of Days Transfer Required	No of Days of Excess Transfer	Excess Volume as % of the Required Volume
300 Ml/d transfer with no balancing storage	1959	137	19	15
	1975	133	50	47
	1976	132	22	18
	1981	21	21	163
300 Ml/d transfer with 3 days balancing storage	1975	133	38	36
	1976	132	15	12

Central to minimising transmission losses in the transfer would be the accurate prediction of flows in the regulated rivers. To achieve this, a system model involving real-time rainfall run-off/hydraulic models in conjunction with rain gauge telemetry, Met. Office weather radar storm tracking and telemetered river flow and level gauges could be developed and linked to an operations centre. The forecasting would need to be for at least the lag time in the system, preferably longer. This would permit operations staff to control the system to minimise losses resulting from the poor co-ordination of discharges and abstractions and changing conditions in the receiving catchments.

TRENT TO ANGLIAN TRANSFER

Availability of water in the Trent for transfer to East Anglia is dependent on the prescribed flow at the abstraction location on the Trent. Additional water could be provided by the Severn to Trent transfer or, more expensively, by using water from Kielder transferred via several rivers and pipelines.

A licence to transfer 180 Ml/d into the Fossdyke canal already exists at Torksey on the Trent (see Figure 4). A transfer of up to an additional 600 Ml/d was considered. Up to 150 Ml/d of this could be added to the existing transfer to Humberside. The principal destinations of up to 400 Ml/d of the transfer would be Essex and north-east London. The transfer corridor would use the lower River Witham to Boston, an aqueduct across the Fens into the Cut-Off Channel at Denver, and thence into the Stour, Blackwater, Chelmer, Roding or Stort, using the Ely Ouse-Essex tunnel and pipelines. An alternative, longer route using the Great Ouse system could also supply Rutland and Grafham Waters.

Transfer using the network of artificial and natural drainage channels across the Fens would be an option. However the potential cost savings through the use of existing or improved open channels would be offset by the risks of not having full operational control, water quality problems and transfer losses through sub-irrigation from drainage channels.

Transfers using the upper reaches of the rivers Chelmer, Roding and Stort would generally not be economic or environmentally attractive compared with pipeline transfer direct to the middle or lower reaches. Where there would be a need for channel enlargement it would in some

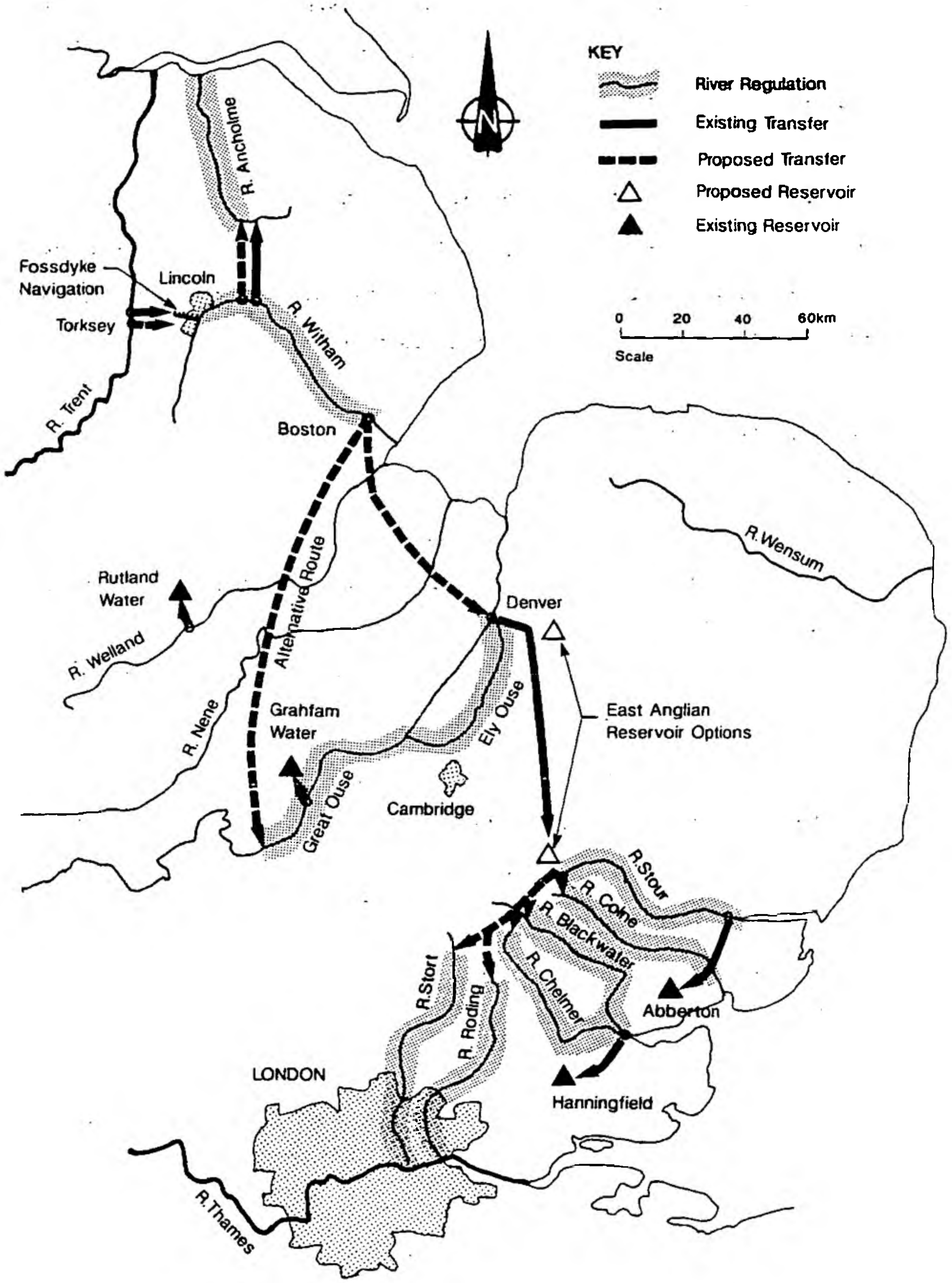

Figure 4. Trent-Anglian Transfer and/or East Anglian Reservoir

cases be possible to mitigate adverse affects of channelisation or even to use the opportunity to make environmentally sensitive improvements including the creation of low flow channels, meanders, pools and riffles.

Generally in all the transfer studies, the use of long distance tunnels was found to be uneconomic, especially where transfer operation would be infrequent. However tunnels of up to 4 km have been proposed for crossings including estuaries and specific SSSI washlands where buried pipelines were considered less feasible or inappropriate.

TRANSFER BY CANAL

The British Waterways feasibility study[6] looked at drawing water from the Severn via a connection to the Severn to Trent transfer pipeline or from the Vyrnwy aqueduct. Destinations considered were the Trent at Nottingham, the Thames at Oxford, the Great Ouse at Milton Keynes and the Nene at Northampton. The preferred route uses the Trent & Mersey, Coventry, Oxford and Grand Union Canals. Transfers of up to 300 Ml/d were considered, although generally it was found that transfer of up to 200 Ml/d could be considered without conflict with the canals' existing uses and heritage value[8]. The study also examined the possibility of using 50 Ml/d of groundwater near Birmingham which may be available from the rising water table.

DIRECT PIPELINES AND "NATIONAL GRID"

Pipelines transferring water directly to treatment works without using intermediate watercourses would avoid many of the perceived environmental impacts on a receiving catchment. The idea of a national water grid as a network of pipelines transferring treated water around the country has also been mooted. However desk studies [9] have shown that the "grid" would probably be two or three spine mains connecting sources in the north and west to demand centres in the south-east, via a series of spurs. Initial cost estimates show that the cost of the grid would be high, but not necessarily prohibitive. For example, a spine main from the River Severn to London, combined with the Craig Goch reservoir scheme, could meet demands in the Thames region at a comparable cost to the South West Oxfordshire Reservoir.

STRATEGIC STORAGE OPTIONS

Storage is needed to conserve winter rainfall for use during the summer when river flows are low. This storage can either be local to the demand centres in the south-east, or can be in the regions of water resource surplus, mainly the north of England and Wales. Many sites for strategic storage have been considered over the past 30 years; these have narrowed the options down to:

- the raising of the existing Craig Goch Reservoir in the Elan Valley, as the preferred site for a major new storage in Wales;
- the redeployment of the existing Vyrnwy Reservoir to regulate the River Severn instead of making a direct supply to the north-west region;
- the South West Oxfordshire Reservoir, which has been selected as the preferred site for a large pumped storage reservoir in the Thames catchment;
- a new pumped storage reservoir in East Anglia, for which various sites are at present under investigation.

The development of carefully designed and managed reservoirs can have significant environmental benefits but also adverse impacts. Established reservoirs, properly designed and managed, provide recreational and amenity facilities including walking, fishing and watersports. They also offer opportunities for habitat creation; for example, Rutland is a RAMSAR site (a wildfowl centre of international importance). On the "downside" there is the land take which can have social consequences where properties are affected. The inundation may also affect sites of environmental importance or historic interest. In most cases these impacts can be minimised through consultation and careful design.

THE CRAIG GOCH RESERVOIR SCHEME

The Craig Goch reservoir scheme would involve enlargement of the existing reservoir in the Elan Valley by the construction of a new dam at the site of the existing dam. The scheme was studied in detail in the 1970s under a joint committee comprising the former Severn-Trent and Welsh Water Authorities, and Bristol Waterworks Company. Full feasibility studies were carried out on a range of scheme sizes with the reservoir filled from its natural catchment with additional augmentation available from gravity diversions from surrounding catchments, or by pumping from the Rivers Severn or Wye (see Figure 5). A scheme designed to give a yield of over 1000 Ml/d was taken forward to the stage at which it was ready to be promoted, but was then shelved when the forecast demands in the Midlands failed to materialise in the mid-1970s. The scheme has been reviewed in the course of developing the NRA's strategy [9]. The forecast deficits could be met by a smaller scheme to that considered in the 1970s, with a 70 m high dam providing a storage of 190 million cubic metres. This could be filled by the natural catchment in the upper reaches of the Elan Valley, with the water used to regulate either the River Severn or the River Wye.

Regulation of the River Severn would probably have substantially less environmental impact than regulating the Wye and would appear to be the preferred option at this stage.

The Craig Goch reservoir would provide a large storage through the construction of a comparatively small dam at the downstream narrow neck of a wide long valley. Being located in a remote valley which has already been subject to reservoir development, there would be little impact upon agriculture, archaeology or the local population. However, a major SSSI would be affected and this could present a serious constraint to the development of the scheme.

Promotion of the Craig Goch Reservoir Scheme would be further complicated by the many water companies and NRA regions which would need to be involved. Nevertheless, it does present an opportunity for a very large reliable yield (775 Ml/d for a reservoir supplied only by the natural catchment) at a low cost.

REDEPLOYMENT OF VYRNWY

The existing Vyrnwy Reservoir was built a hundred years ago and supplies about 210 Ml/d in direct supply to Liverpool (Figure 5). If used to regulate the River Severn, instead of for direct supply, the yield via abstractions from the lower Severn could be up to 337 Ml/d. It is unlikely

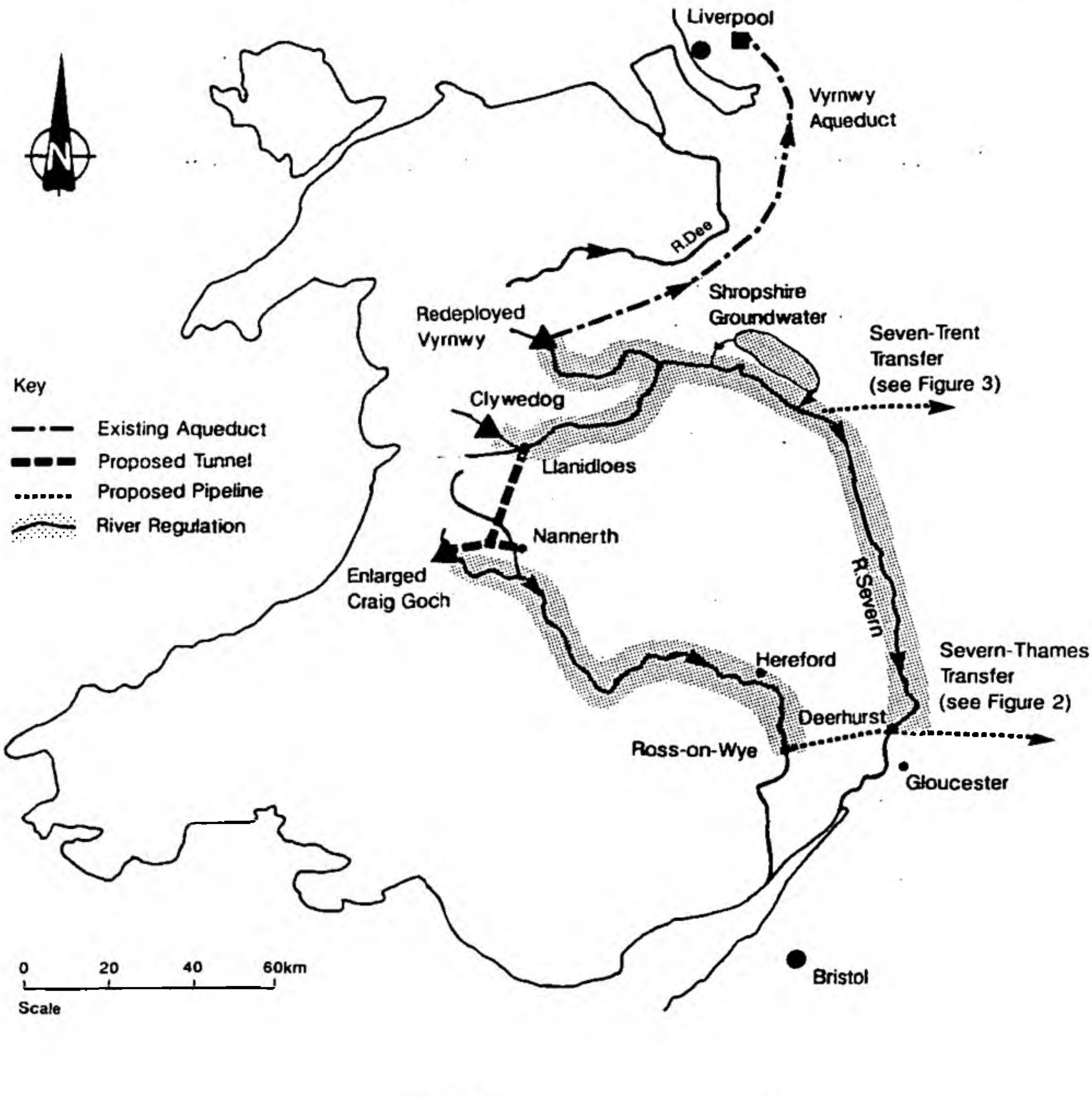

Figure 5. River Severn/Wye Regulation Sources

that Vyrnwy would be completely redeployed, although any loss of direct supply yield to Liverpool would need to be replaced by local sources in the north-west or by demand savings through leakage control. The loss of direct supply yield would incur capital and operating costs to North West Water. There would also need to be improvements to the outlet works at Vyrnwy Reservoir to allow a multi-level draw-off facility for the required volumes.

The redeployment of Vyrnwy Reservoir would have an impact on the flow regime of the River Vyrnwy and, to a lesser extent, the main River Severn. The River Vyrnwy is an important spawning and nursery area for salmon and trout, so the impact of increased regulating flows could be significant. Nevertheless, the redeployment of Vyrnwy does provide a substantial yield increase and it could be an attractive alternative to Craig Goch as a means of regulating the River Severn to meet demands in the Midlands and south-east (with a Severn to Thames transfer).

THE SOUTH WEST OXFORDSHIRE RESERVOIR

The possibility of a major reservoir in the Thames catchment has been investigated by Thames Water Utilities and its predecessor, Thames Water Authority, since the mid-1980s. A succession of studies has identified a site for a major new pumped storage reservoir to the south west of Abingdon. A storage of about 150 million cubic metres could be provided in a fully-bunded reservoir with an embankment up to 25 m high. If filled by pumping of only winter flows from the River Thames, the reservoir could supply a reliable yield of about 350 Ml/d. Alternatively, the reservoir could be used to provide a similar yield increase in conjunction with the Severn to Thames transfer. The discharge of River Severn water into the reservoir could alleviate some of the potential problems associated with discharging River Severn water direct to the Thames.

The South West Oxfordshire Reservoir presently envisaged would occupy about 1400 hectares of mainly Grade 3 agricultural land in a moderately-populated part of Oxfordshire. The impact on agriculture and local population would be significant. There would also be an unavoidable visual impact in an area which is overlooked by higher ground. However, this visual impact needs to be set in the context of the nearby Didcot Power Station which has already substantially altered the landscape. The reservoir itself would provide substantial opportunities for recreational use.

The South West Oxfordshire Reservoir would operate by regulation of the River Thames to support downstream abstraction associated with the existing large storages to the west of London. The impacts on river flows and water quality would need careful investigation, but can probably be made acceptable, subject to appropriate operating rules and other mitigating measures.

EAST ANGLIAN RESERVOIR SCHEME

There are two principal sites considered for a new reservoir in the Anglian Region. These are Great Bradley near Newmarket on the headwaters of the River Stour and a "fenland" site on the South Level Fen between Feltwell and Ely. Both sites could be supplied with winter water pumped from the Ely Ouse and would be used in conjunction with the existing Ely Ouse-Essex transfer system to augment the Stour and Essex rivers.

The Great Bradley reservoir would hold up to 106 million cubic metres, with a water area of 1200 hectares and a land take of 1500 hectares. Its yield could be 160 - 200 Ml/d depending on the size of the Ely Ouse pumps. Inflows would be treated to avoid reservoir algal blooms. It would significantly improve the quality of water transferred onwards to the Essex Rivers by reducing nitrate and phosphate levels and other pollutants. There would be significant impacts to be addressed in connection with this scheme.

The fenland site would be a fully bunded reservoir - that is it would be contained by an earth embankment on all sides. It seems likely that in terms of volume and yield it could be similar to Great Bradley. Fewer properties would be affected but amenity and recreational opportunities would be less than Great Bradley and because it is not a natural reservoir site it would probably be more expensive.

UNCONVENTIONAL OPTIONS

The range of unconventional options considered by various studies [9] in the course of developing NRA's strategy has included:

- groundwater abstraction where levels are rising;
- aquifer recharge;
- desalination;
- transfer by sea via tankers or oil sacs;
- undersea pipelines;
- effluent reuse;
- estuarial barrages.

Rising groundwater levels due to reduction in industrial abstraction over the past 20 years are a threat to building foundations, but are also a potential new water resource. In the London area, Thames Water Utilities are well advanced in the planning of a scheme to control the rise in water levels through an abstraction scheme with a resource value of 30 Ml/d as a direct supply. This has been included as a local resource development option in the NRA's strategy.

In the Birmingham area, investigations have started into abstraction of 50 Ml/d which could be used to regulate either the River Trent or the River Thames for up to 5 months per year [10]. Early indications are that such a scheme would be possible in resource terms, but that water might need treatment before discharge to rivers or canals for regulation. The location of this potential source makes it strategically important and the apparent low cost and low environmental impact adds to its attraction.

Groundwater recharge requires an aquifer unit with a synclinal structure, in which a storage deficit may be developed without significant adverse environmental impact. To be cost effective, there must be a reasonably convenient source of recharge water of suitable quality, and a reasonable proportion of it should be retained in the aquifer after recharge until it is needed. Such conditions are rare in the UK, although the confined portion of the London Basin is a good example. The usefulness of recharge here is already demonstrated by schemes in the Lee Valley and at Enfield-Haringey. Opportunities in South London are also being studied and 180 Ml/d may be available (a "local option" in the NRA strategy). Elsewhere, only the Sherwood sandstones of the Cheshire Basin have the appropriate structure on a similar scale; however more localised opportunities may exist, associated with, for example, geological folds.

Desalination has been shown to be expensive when compared to the cost of conventional storage and water transfer options. Nevertheless, there could be a role for desalination plants in meeting local deficits, and they could well be easier and faster to promote than conventional schemes.

Transfer by sea using either tankers or water sacs also appears to be much more expensive than conventional options. There would be operational risks, particularly connected with towed sacs. However, the development of new technology, for example by the oil industry, could reduce the costs and risks to an acceptable level.

Transfer by undersea pipeline would be, perhaps, double the cost of a conventional land pipeline, but could be easier and faster to promote. The transfer of water from Kielder Reservoir to the south-east via an east coast undersea pipeline is one such possibility. Although expensive, this would use established oil industry technology and could be promoted quickly in the event of demands rising faster than forecast. Such a scheme could also be suitable for private sector finance.

The reuse of sewage effluent has obvious attractions in terms of resource conservation. Reuse through treatment straight back into supply, although practised on a small scale in some parts of the world, is unlikely to be acceptable on health grounds for the foreseeable future.

However, reuse via river regulation, by discharging sewage effluents above an abstraction point, does allow dilution of the effluent and less stringent treatment requirements. Although reuse of sewage effluent is already occurring in the UK, for example through successive abstractions down the River Thames system, there are concerns about the public health implications. This applies particularly to effects which are not well researched, for example the impact on human fertility of discharges containing residues of oral contraceptives. Although effluent reuse schemes are being considered by several water companies at present, they do not seem likely to play a significant role in strategic resource planning.

Estuarial barrages were studied in detail at several sites in the 1970s. Some were found technically feasibility, if expensive, at that time, but increased environmental awareness would mean that such schemes would be very difficult to promote in the future. They are not, therefore, considered to be a serious alternative to the conventional storage options.

COMPARATIVE COSTINGS

In the course of preparing the NRA's resource strategy, cost estimates have been assembled for all the above options. This has involved collating information from many sources. In some cases, the estimates are based on recent detailed engineering feasibility studies. However, more often, the available information has been obtained from superficial preliminary studies, or from updated information from studies carried out 20 years or more ago. Nevertheless, despite the inevitable uncertainties in estimates of widely varying pedigrees, all the estimates have been carefully scrutinised and adjusted to put them, as far as possible, on a common footing. Where the costs have been based on superficial studies, increased contingencies have been allowed for factors such as the costs of environmental mitigation measures.

Table V shows the yields, capital and operating costs for a selection of schemes.

TABLE V. KEY STRATEGIC RESOURCE OPTIONS - YIELDS AND COSTS

OPTION	ADDITIONAL POTENTIAL YIELD (Ml/d)	INDICATIVE CAPITAL COST (£m)	INDICATIVE PUMPING COST (£k/Ml/d/Annum)	TIME TO PROMOTE
Severn-Thames Transfer Capacity 200 Ml/d	Supported 249	57	31.5	Medium
Severn-Thames Transfer Capacity 400 Ml/d	Supported 425	92	31.5	High
Enlarge Craig Goch Reservoir regulating River Severn	Up to 775	105.0	0	High
Partial Redeployed Vyrnwy Reservoir (74 Ml/d redeployed)	152	36.9	25.9	Low
South West Oxfordshire Reservoir	350	400.0	23.5	Medium
Severn-Trent Transfer	Capacity 100	26.0	16.3	Medium
Canal Transfer from River Severn to River Thames (initial transfer to the canal system via the Severn-Trent Transfer)	Capacity 100	49.1	20.3	Medium
Trent-Anglian transfer (to Essex Reservoirs via Fossdyke Navigation, R Witham and existing Ely Ouse-Essex transfer)	Capacity 200	108.0	26.6	Medium
East Anglian reservoir - figures only available for great Bradley Reservoir	174	69.4	0.0	High
Birmingham Groundwater	50	4.4	6	Medium

Note: Indicative times of promotion:

- high = over 20 years
- medium = 10-20 years
- low = less than 10 years.

TIMING OF DEVELOPMENTS

Experience in the promotion of new water resource schemes over the past 30 years has shown that implementation of a major new scheme involving new reservoirs or river regulation takes 20 years or more from initial studies to commissioning of the scheme. Table V gives an indication of the time which is likely to be needed for some schemes. Thus, studies need to be put in hand now to allow for the possibility of demands rising at the higher forecast rate and creating deficits in 20 years time. Although it may be five or ten years before a decision needs to be made on the promotion of schemes, initial studies should proceed on some of them:

- the Severn to Thames Transfer;
- the East Anglian Reservoir;
- Birmingham Rising Groundwater.

In addition, studies should proceed on some of the local options listed in the NRA's Strategy, so that when the need arises the choice between local schemes or strategic options can be made.

The development of the NRA strategy has pointed the way towards the most cost effective and environmentally acceptable way of meeting demands should they arise. The onus of taking the identified schemes along the next steps towards promotion is now likely to rest with the water companies or other private sector initiatives. It is inevitable that the involvement of the water companies will bring a different perspective to matters such as the operational risks of inter-regional transfers and the organisational difficulties associated with schemes requiring the cooperation of several water companies and NRA regions. This will be the challenge faced by water resource planners over the next decade.

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Environmental Assessment of the
Water Resources Development Strategy for England and Wales

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ABSTRACT

Environmental issues, objectives and constraints were taken into account throughout the formulation of the recently published NRA strategy framework for the development of water resources in England and Wales. This paper describes the environmental assessment framework used for a preliminary strategic level environmental assessment of the major potential development options. Comparison of the key issues associated with options to meet regional demands are presented, together with further research needs. It is emphasised that the assessment represents only an early stage in ensuring future water resource developments are environmentally acceptable.

Key Words: Environmental assessment, water resources planning, NRA water resources strategy, research.

INTRODUCTION

This paper describes the findings of an independent, high level environmental assessment of strategic water resource development options identified by the NRA for meeting regional water supply demands in England and Wales up to a planning horizon of 2021. The purpose of the NRA's national strategy is to indicate the sequence of likely developments, their magnitude, impacts and probable timing, and to highlight the associated environmental issues.

The aim of the assessment was to compare the main strategic options on a consistent basis in order to encourage the promotion of schemes which are both technically, environmentally and economically acceptable. In southern Britain, there is growing concern that thresholds of environmental acceptability for changes to natural hydrological regimes have been reached and in some cases exceeded. The NRA recognised the vital need to learn from past experiences by considering the environment at the earliest possible stage of project identification and planning. The assessment involved the following steps:

- A literature review of the environmental issues and known impacts associated with water resources development schemes, including the effects of river regulation, inter-basin transfer and changes to residual flows to estuaries;

- A review of the impacts of existing UK schemes to identify the lessons to be learnt for future schemes;

- The development of a framework for assessing individual schemes and objective comparison of strategic development options, taking account of EC and UK environmental assessment regulations;

- An assessment and comparison of the environmental implications of nine strategic options representative of the range of likely water resource developments, using data from existing studies and taking account of the results of hydrological modelling of specific schemes.

This paper concentrates on the assessment framework and the comparison of key issues associated with the strategically important schemes. No fieldwork was carried out for this assessment which was based on existing reports combined with simulation results of the frequency of operations and magnitude of changes to existing flow regimes from the proposed schemes. It must be emphasised that this represents an early stage in the NRA's ongoing commitment to ensure that any future water resource development schemes are environmentally acceptable.

ENVIRONMENTAL ASSESSMENT ISSUES

Environmental assessment (EA) is the process of identifying, predicting and evaluating the impact of particular activities on the environment, the conclusions of which are used as a tool in decision making. The effectiveness of EA applied at the individual project level is constrained by a number of factors, but one of the principal concerns is that project EA, such as that undertaken for the individual development schemes considered by the NRA regions, cannot in itself lead to comprehensive protection of the environment as it reacts to development proposals rather than anticipating them. In general it cannot steer developments towards environmentally resilient locations and rarely addresses alternative proposals.

There is therefore a need for a "higher level" assessment in the planning process, which enables relevant environmental issues, objectives and constraints to be more fully involved at an early planning stage and assists in implementing the concept of sustainability. The central question for this assessment was to determine an appropriate level of detail so that meaningful comparisons between the various options could be made. The aim was to determine, at a preliminary planning stage, the least environmentally acceptable schemes, the further work required to reduce the level of uncertainty over impact prediction and to identify environmental opportunities and benefits. The development of the comparison framework is described below.

ENVIRONMENTAL ASSESSMENT FRAMEWORK

A framework for preliminary environmental assessment appropriate to a higher, more strategic level than project specific environmental assessment was developed based on the literature review, review of the impacts of existing UK schemes, workshop sessions with NRA specialists and the expertise of those working on the project. The key features of the assessment framework were (see Figure 1):

- Each option component, for example, regulated river/canal reach or new reservoir/pipeline, was assessed separately;

- Categories used for assessment of components comprised;

Reservoirs/pipelines	Agriculture Community Impacts Archaeology and Cultural Heritage General Landscape Character Terrestrial Ecology Recreation/Amenity
Rivers/canals	Water Quality Fisheries Aquatic Ecology

Terrestrial Ecology
Recreation, Amenity and Navigation;

- A standard assessment was applied to pipelines due to the number of possible variants on any individual transfer route;

- River and canal reach components at this level of assessment comprised complete tributaries, individual river reaches of tens of kilometres, and estuaries; more localised issues and key sites may well emerge from detailed follow-on studies and investigation.

- The sensitivity, risk of adverse impact and benefit opportunities for each component were assessed on a matrix basis with a three point scale (low-moderate-high) for each category, using explicit guideline criteria in order to make the assessment transparent and consistent. Equal weighting is given to each category and criterion; this could be changed as appropriate in future development of the methodology;

- Options were compared using matrices presenting the advantages and disadvantages of each component, and also indicating the environmental acceptability of an overall option from the NRA's perspective as an agency with statutory environmental protection responsibilities. An option was considered difficult to accept if it had a high risk of causing unmitigable loss/damage to highly sensitive fisheries, instream ecology or terrestrial conservation sites;

The potential for adverse environmental impact depends upon: the sensitivity of the site/receptors; the risk of significant environmental change/damage; the expected magnitude and duration of change; and the potential for mitigation. A further important factor is the opportunity for environmental improvement or benefits associated with the scheme such as the restoration of a derelict canal or water quality improvements. In general, receptors of national importance or with statutory protection were deemed to be of high sensitivity, for example a NWC Class 1 river. The criteria for "high" and "moderate" sensitivities used in this assessment are given in Table 1 for rivers/canals and Table 2 for reservoirs/pipelines. Whilst these guidelines were generally followed in the assessment, expert judgement was used to uprate or downrate the sensitivity based on knowledge of particular local circumstances.

The assessment of risk was made in a similar manner. Risk is the potential for significant adverse change or impact consequent upon the scheme, and may be short term (only experienced during construction) or long term (experienced when the scheme is operational). The criteria for "high" and "moderate" risks used in this assessment are given in Table 3 for rivers/canals and Table 4 for reservoirs/pipelines.

In contrast to many environmental assessments the methodology and criteria that form the basis for assessment were deliberately made as transparent as possible. The criteria shown in Tables 3 and 4 are an attempt to be as rigorous and consistent as possible when comparing the effects of quite different components and overall schemes. The complexity of aquatic and terrestrial ecological systems is such that the effects of particular impacts on the functioning of these systems is not yet fully understood. It is therefore particularly difficult to define specific thresholds for these receptors above which impacts can be defined as significant or unsustainable, and assessment was frequently based on professional experience and judgement.

Each scheme component was assessed using data from existing reports and option studies. There are a number of variants for each pipeline transfer and so assessment of pipelines was made in general terms only, due to the disparate specific issues associated with each pipeline route variant. The results of the assessments were drawn together in summary matrices for every option component.

The component matrices for each development option were drawn into summary matrices setting out the impacts, benefits and mitigation for the option. The overall assessment for each option was taken to be the sum of its components. The breakdown between short term and long term impacts and between "high" and "moderate" was retained rather than combine the assessments in an overall index. Benefit opportunities were also retained in the option matrix. This approach inevitably meant that schemes with more components were more likely to appear to have a higher environmental risk.

COMPARATIVE ASSESSMENT OF MAIN OPTIONS

Nine strategic options representing a wide range of development types were identified by the NRA for comparative environmental assessment using the framework (see Figure 2). They were selected through iteration and elimination on the basis of engineering feasibility, cost estimates, resource value, and environmental assessment. The key issues arising from the assessment are discussed below in terms of the main options for meeting demands in Thames, Severn-Trent and Anglian regions.

THAMES REGION

The main strategic options that were considered for meeting demands in Thames Region are:

Transfers from the Severn:

- Transfer of up to 400 Mld/d to Thames at Buscot from the unregulated Severn;
- Transfer of up to 400 Ml/d to Thames at Buscot from the Severn regulated by Craig Goch;
- Transfer of up to 400 Ml/d to Thames at Buscot from the Severn regulated by Vyrnwy;
- Transfer of up to 400 Ml/d to Thames at Buscot from the Wye regulated by Craig Goch;
- Transfer of up to 100 Ml/d to Thames at Oxford from a regulated Severn via the rivers Penk and Sow and British Waterways Board (BWB) canals;

In-catchment Development:

- Construction of a new pumped storage reservoir in South West Oxfordshire drawing on the Thames at Culham; regulation of Thames below Culham for abstraction to lower Thames reservoirs.

These options are not mutually exclusive as Severn transfers could be used to fill the South West Oxfordshire reservoir. In terms of speed of development, the unsupported Severn transfer to Buscot and the BWB canal transfer to Oxford could be implemented in a relatively short time, although both of these options give rise to serious environmental concerns and require further study. The construction of a new reservoir in South West Oxfordshire or the enlargement of Craig Goch would be likely to take a number of years to promote, gain planning approval and construct, even if there were no environmental objections. Redeploying Vyrnwy could probably be implemented within a much shorter timescale, provided suitable replacement sources for North West Region are available.

The preliminary NRA figure for a possible prescribed flow constraint in the Severn at Deerhurst of 2500 Ml/d is about 1.5 times Q_{95}, which is in agreement with some salmon migration studies but is less than the 50% of mean flow suggested by other research. Provided the prescribed flow is set at a suitable value, no adverse impacts are expected in the Severn downstream. Considerable detailed studies and investigations are required to determine a suitable prescribed flow for the lower Severn and the estuary to be used as the basis for resource development.

The canal transfer option has a risk of impact through increased velocities within the canals which are themselves valuable aquatic habitats. The temporary disturbance caused by construction and improvement works along about 200 km of canals would be substantial. Set against this are potential water quality improvements to several poor quality canal reaches. There are high risks of impact on the Thames at Oxford, where significant discharges would be coming from a long canal network of generally lower quality than the Thames at the discharge point. Of particular concern are dissolved and particulate metals derived from canal bed sediments.

The Severn transfer into the Thames at Buscot carries high risks to the biochemistry of the upper Thames, which would become more than 80% lower Severn water during low flow periods. The riparian zone of the upper Thames catchment is now an Environmentally Sensitive Area. The Thames downstream of Buscot is already a highly artificial channel which is depth regulated for navigation, and there is concern that velocities should not approach the limit for boat traffic. There are significant coarse fishery interests. On the plus side, there are considerable potential benefits by renovating the Thames & Severn Canal and supporting low flows to the upper Thames. Extending the pipeline to discharge either into a South West Oxfordshire reservoir for blending or direct to the Culham reach of the Thames, where dilution would be almost 1:1 at low flows, would both appear to be far more acceptable.

Regulation of the Severn would provide a large, continuous resource for transfers to Thames and/or Trent Regions. The two potential sources considered are an enlarged Craig Goch reservoir or a redeployed Vyrnwy reservoir. Enlarging Craig Goch would risk serious damage to the internationally important SSSI at Elenydd and loss of two other SSSIs, and further studies are required to examine possible mitigation measures. The Craig Goch scheme appears likely to meet with opposition from a conservation perspective. Redeploying Vyrnwy would have a major impact on the downstream river receiving the reservoir releases which is the main spawning and juvenile reach for up to 40% of the salmon redds in the upper Severn. The risks to the Severn itself are also serious, although the river is already regulated. There are also knock-on effects of resource development in North West Region which have not yet been assessed. With different discharge arrangements, the Vyrnwy regulation could be made more acceptable.

Regulating the Wye from Craig Goch for transfer to Thames appears to be environmentally unattractive. The Wye is a unique aquatic environment in Britain, an SSSI of international importance, and the best salmon river in England and Wales. One aspect of its uniqueness is its high degree of naturalness. The revised flow regime would be likely to adversely affect the environment, particularly in the upper reaches, and the scheme would probably be strongly opposed by conservation groups. Added to which, the enlargement of Craig Goch could affect the high flow regime (no studies have yet been made), which could affect salmon migration. There appears to be little to recommend this option on environmental grounds.

The South West Oxfordshire reservoir offers the potential for considerable long term benefits, but its construction would have major short term local impacts. The scheme would develop new local resources, and obviate the need for transfers from outside the catchment with their inherent risks to the biological integrity of the Thames. The scheme would provide additional regulation and low flow support to the Thames. The reservoir itself could be planned to include a diversity of habitats and offer a valuable local amenity. On the other hand the scheme would involve major disturbance during the construction phase which is certain to generate local opposition. Sensitive reservoir design, minimising impact on the landscape, would be an important factor in determining the environmental acceptability of the scheme. Of the options for meeting deficits within Thames Region, the reservoir seems to offer most long term benefits and least risks to the aquatic environment. Care would need to be taken with respect to temperature and quality of released water, operating rules for abstraction and discharge to minimise velocity changes, and setting prescribed flows to protect downstream interests. The NRA would need to consider the extent to which the resources available in the Thames should be developed.

SEVERN-TRENT REGION

The strategic option identified for meeting regional deficits in Severn-Trent region is to transfer up to 100 Ml/d to the Trent from the Severn via pipeline and the rivers Penk and Sow to supply the East Midlands. Other sources to meet increases in regional demands are the existing surplus in Carsington reservoir and future phases of the Shropshire Groundwater Scheme, the environmental impacts of which were not covered bythe this assessment.

The Severn-Trent transfer option would be relatively quick to construct and no major environmental impacts appear likely. The transfer of higher quality Severn water into the upper Trent catchment is not the same issue as for Severn-Thames transfers, because the Trent is a lower quality river. Thus there are potential quality improvements to the Penk, the Sow and locally within the Trent. There may also be opportunities to improve the coarse fishery in the Sow through better quality and more reliable low flows. The only concern with this option is the impact on the Penk, whose low flow regime would be increased to a level where there might be long term bed and bank erosion problems and macrophyte washout, although the Penk has been the subject of recent channel changes which may mitigate this risk. The benefits of extending the transfer pipeline to discharge directly into the Sow should be investigated.

ANGLIAN REGION

Two strategic options were identified for meeting marginal deficits in Anglian Region:

- Great Bradley Reservoir with Ely Ouse-Essex scheme;
- Unsupported Trent to Essex transfer.

Both schemes are an extension to the existing Ely Ouse-Essex transfer scheme. For the unsupported Trent option the major planning hurdle is likely to be the Witham to Denver pipeline, and there are risks to water quality. With both options there are important environmental issues to be addressed relating to water quality and the magnitude of changes to existing flow regimes particularly in the Essex rivers.

The Great Bradley reservoir, at the highest top water level of 105.5m AOD, would have a substantial environmental impact because of the loss of 4 SSSIs, ancient woodland, 77 properties, 5 listed buildings, 17 archaeological sites and the short and long term disruption