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Water
NATURE'S PRECIOUS RESOURCE

An Environmentally Sustainable Water Resources Development Strategy for England and Wales

SUPPLEMENTARY REPORT

NRA

National Rivers Authority

HYDROLOGICAL MODELLING
Supplementary Report No 5
June 1994

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1 INTRODUCTION

1.1 General

This report is the fifth in a series of nine supplementary reports which provide supporting information for the National Rivers Authority Water Resources Development Strategy document:

"An Environmentally Sustainable Water Resources Development Strategy for England and Wales".

The other reports in the series are as follows:

1 Methodology and Assumptions for Demand Scenarios;
2 Review of Public Water Supply Yields;
3 Marginal Demands;
4 'Other' Options;
6 Resource Scheme Costings;
7 RESPLAN Modelling;
8 Comparative Environmental Appraisal of Strategic Options;
9 National Strategy Overview

This report describes the objectives, methods, planning and results of a series of water resource computer modelling studies undertaken by the NRA regions. The main objective of this work was to determine the resource value of major river to rivers transfers from:

- the River Severn to the River Thames;
- the River Severn to the River Trent; and
- the River Trent to the Essex rivers via the Ely-Ouse transfer system

A secondary objective was to generate data on the hydrological impact of the schemes, to assist in their environmental assessment.

A number of source developments were investigated in conjunction with these transfers, among which were:

- Lake Vyrnwy redeployment;
- South West Oxfordshire Reservoir Development (SWORD);
- Great Bradley reservoir; and
- Fenland reservoir.

The studies provided data on transfer yields and transfer volumes, the latter were used to help determine the scheme's operational costs and environmental impact.

1.2 Scope of Works

The potential for regional transfers arose from the identification, during the NRA Water Resource Planning - Strategic Options study (ref 1), of water supply deficits in NRA Anglian and Thames regions and surpluses in the North-West and Severn Trent regions. To establish if transfers between the regions, via the main river catchments and existing transfer systems, were practical the NRA commissioned a series of engineering feasibility studies (refs. 2 to 5). These investigations determined the most appropriate transfer locations and pipeline routes, and budget costs, both capital and operational.

In addition to engineering feasibility studies it was recognised that to determine transfer resource values and average transfer volumes hydrological modelling studies would be required. Three modelling study options were identified:

- to link together existing resource allocation models of the rivers Severn and Thames and the NRA Anglian region; there is no resource allocation model for the River Trent.

- to develop a single resource model by a simplistic lumping of resources and demands.

- to develop a more complex new model, with the possible incorporation of an optimisation routine based on economic criteria.

Time precluded the development of a new complex model and a simple model would have been unsuitable for the level of study being undertaken. The approach adopted was, consequently, to adapt existing models to investigate transfer resource values and use RESPLAN to assess economic viability (see Section 1.3).

The scope of work broke down conveniently into two parts, corresponding to the two main transfer systems:

- a Severn to Thames transfer (figure 1); and

- an East Anglian transfer system (figure 4).

Details of these two modelling studies are given in Section 2 and 3, respectively.

The modelling of each transfer systems required contributions from several NRA regions. North-West, Severn-Trent and Thames regions contributed to model the Severn to Thames transfer, and Severn-Trent, Anglian and Thames regions combined to model the Anglian transfer system.

As project managers of the National Water Resource Strategy Study, Halcrow had the task of co-ordinating and integrating the work of the various NRA modelling teams. Meetings chaired by Halcrow and attended by representatives from the NRA regions were held at six weekly intervals. These meetings were a forum at which discussions and decisions were made on various topics such as: project programme, report format, data transference, model compatibility and engineering criteria. Careful monitoring and clear lines of communications were required to ensure that the study remained focused.

In general, studies were undertaken in a sequential fashion, with results being passed from one study team to the next as the work was completed. Before final results were obtained, this process may have been executed several times as the results became refined.

Resulting from this work a series of internal NRA modelling reports were produced, these are listed at the back under NRA region (refs 6 to 12) and reproduced in appendix 1. This report endeavours to summarise and combine the information contained in these reports in a homogenous manner.

1.3 RESPLAN

The output from the hydrological modelling studies include:

- maximum transfer capacities;
- transfer resource values;
- transfer volumes; and
- associated source yields.

Details of data extracted from the hydrological modelling documents are given in Appendix 1 of Supplementary Report No 7. These data were input to RESPLAN to compare the various transfer schemes with other water development options. RESPLAN is a water resource planning computer model, developed by the Water Resources Board and updated and improved by the NRA. Its purpose is to analyse long-term water resource planning problems. A full description of RESPLAN is given in Supplementary Report No 7. In summary, the model is concerned with the selection and timing of long-term water resource developments to meet water demand forecasts, based upon economic criteria.

Capital and annual operating costs for all the transfers were estimated as part of transfer engineering feasibility studies undertaken in 1993 (refs 2 to 5). These costs were later adjusted by Halcrow for inclusion into RESPLAN. A description of the costing methods used are given in Supplementary Report No 6.

The transfer resource values and volumes from the hydrological modelling studies are combined with the costing data from the engineering feasibility studies, to determine unit transfer costs and net present values for transfer schemes. These costs are then used within RESPLAN to compare transfer schemes and alternative water resource options on an economic basis.

2 SEVERN TO THAMES TRANSFER

2.1 Scheme Description

2.1.1 General

The Severn to Thames transfer scheme comprises the following elements:

- the conversion and redeployment of Lake Vyrnwy from a direct supply reservoir serving NRA North West region, to a river regulation reservoir supporting abstractions on the River Severn.

- a pumped transfer of water from the River Severn to the River Thames, supported or unsupported by the development in the Severn catchment.

- regulation of the River Thames by a Severn transfer, with and without the development of a new pumped storage reservoir in South-West Oxfordshire (SWORD).

A schematic of the transfer system is shown in Figure 1. The Severn-Trent transfer, also shown on Figure 1, is part of the Anglian transfer system and is described in Section 3.

2.1.2 Lake Vyrnwy

Lake Vyrnwy is an impoundment reservoir located in the upper Severn catchment within the Severn Trent NRA Region, near Welshpool. The majority of Vyrnwy's yield is used by North West Water plc (NWW) to supply Liverpool and parts of Cheshire. NWW own the drawoff tower which feeds, via an aqueduct, a NWW water treatment works at Oswesty. Vyrnwy dam, however, is owned by Severn Trent Water plc and is operated and maintained by the company under Section 2D Reservoir Agreements.

A full description of the reservoir, its operating rules and the engineering costs of converting it from direct supply to river regulation are given in the 'Other' Options Supplementary Report No 4.

The value of the direct supply from Vyrnwy to NWW is variously defined as being:

- 212.5 Ml/d, 2% hydrological yield
- 198 Ml/d, historic minimum yield (1932-1987)
- 173 Ml/d, gravity supply limit

The normal daily compensation discharge from the reservoir is 45 Ml/d, although this may be reduced to 25 Ml/d if flows are above 20 Ml/d at the Cownwy gauge. The reservoir operates a 'water bank' which is a conceptual partitioning of the reservoir, whereby water saved from reducing compensation from 45 Ml/d to 25 Ml/d can be used for other purposes. In addition to saved compensation water, 725 Ml/d of water is allocated to the 'bank' each month from March to October. Storage in the bank is never less than zero and can be carried from one year to the next.

The water bank is used to make:

- regulation releases; and
- flood retention releases

Water from the bank can be released to augment the River Severn at periods of low flow to support downstream abstractions. Authorised abstractions have been increased by 25 Ml/d by this use of the bank. Releases may also be made to allow for flood storage in the reservoir and to prevent excessive overspill and associated wastage of water.

2.1.3 Severn to Thames Transfer

The engineering feasibility of a Severn to Thames transfer was investigated by W S Atkins, for NRA Thames Region in 1993 (ref 2). Two of the possible transfer routes identified were considered in the modelling studies:

Route 1 - a pipeline from an abstraction point on the River Severn at Deerhurst, downstream of Tewkesbury, to the east of Cheltenham, crossing the rivers Churn, Coin and Leach and discharging, via the disused Thames and Severn canal, into the River Thames at Buscot.

Route 2 - a pipeline from Deerhurst, to the north of Winchcombe, into the Windrush valley and discharging into the proposed pumped storage reservoir (SWORD), near Abingdon. The pipeline crosses the River Thames near Standlake.

The transfer would comprise the following engineering elements:

- intake on the Severn, with low lift pumping station and bankside storage;
- high lift pumping station;
- gravity pipeline to discharge point; and
- for route 1 only, restoration of the Thames & Severn canal and Thames bankside storage.

Transfers were modelled with and without support from a Severn catchment resource development - ie a redeployed Lake Vyrnwy. A flow constraint of 2500 Ml/d was assumed at Haw Bridge, with all flows above this value available for transfer. Maximum transfer capacities of 200 and 400 Ml/d were assumed.

2.1.4 Regulation of the Thames and SWORD

At times of low flow transfer flows from the River Severn would be used to support downstream abstractions on the River Thames. The hydrological characteristics of the two rivers differ; the Severn hydrograph has a sharp transition between low flows and high flows, whilst the Thames hydrograph has a smoother profile. The result being, that low flow periods in the Thames do not necessarily coincide with low flow periods in the Severn and transfers can be made without having to support the Severn. The resource values of supported and unsupported transfers were investigated by NRA Thames Region (section 2.4).

The South West Oxfordshire Reservoir Development (SWORD) is a scheme under investigation by Thames Water Utilities Ltd. It is a proposed pumped storage reservoir located near to Abingdon, which, for a storage capacity of about 100 million M^3, has an estimated resource value to Thames Region of 350 Ml/d. The resource value of the reservoir may be further increased with the augmentation of inflows by a direct transfer from the Severn.

2.2 Objectives and Planning

The objectives of the Severn to Thames transfer modelling studies were to determine the resource value and transfer volumes for:

- a transfer supported by a redeployed Vyrnwy reservoir, and
- an unsupported transfer.

The problem can be broken down into the following questions:

- for any given reduction in direct supply to NWW from Lake Vyrnwy, what size of reservoir storage, or water bank, could be made available for river regulation?

- what would be the cost to North West Water, both capital and operational, of replacing the reallocated Vyrnwy supply with alternative resources?

- what size of Severn abstraction at Deerhurst for transfer to the River Thames could be supported by the available Vyrnwy water bank?

- what would be the resource value to Thames Region of the Severn to Thames transfers?

To answer these questions modelling work was required from three NRA regions:

(a) North-West Region used North West Water's (NWW) supply optimisation model (MOSPA) to determine, for alternative reductions in Vyrnwy direct supply to NWW, the size of water bank available for river regulation and the cost of replacement sources.

(b) Severn Trent Region used their regional resource allocation model (NRAM) to determine, by routing support flows along the River Severn, the maximum transfer abstractions at Deerhurst for alternative water bank volumes; and to match these transfer sizes to the equivalent resource value (also known a 'design demand') in the Thames region.

(c) Thames Region used their water resource model (WRM) to determine the 'design demand' which can be met by a maximum transfer abstraction based upon agreed levels of service, measured at the London reservoirs.

The studies were interdependent, with the progress in one being reliant upon results from another. It was not possible in the beginning of the study to specify the problem either in terms of a single Vyrnwy resource value, or Severn-Thames transfer, or a Thames regional design demand. Therefore, to initiate the studies a range of Vyrnwy resource and Severn to Thames transfer values were selected, as input to the relevant resource models. This enabled North West and Thames study groups to proceed independently, however, Severn Trent studies were delayed until initial results were available.

2.3 North West Region Studies

North West region commissioned two separate studies: the first, to investigate the potential for reducing the direct supply to NWW from Vyrnwy and to calculate the size water of bank available for river regulation; the second, to investigate alternative water supply sources to compensate for the loss of Vyrnwy supply and to estimate the additional cost of development and operation of these alternatives.

The first study was carried out jointly for NRA-NW and NWW by Power and Water Systems Consultants (PWSC) Limited. Using North West Water's MOSPA model PWSC calculated, for a range of reductions in direct supply, the 'water bank' available for river regulation. The main results are summarised Table 2.1.

Table 2.1 Vyrnwy Water Bank Volumes available for River Severn support

Resource Option	Reductions in Direct Supply Yield Ml/d	Maintained Direct Supply Yield Ml/d	Water Bank Volumes Available Ml
NW1	0	198	5,800 (existing situation)
NW5	27	173	13,695
NW8	80	120	30,221
NW13	140	60	48,905

Note: The total volume impounding in Vyrnwy is 59,700 Ml.

For each of the alternatives given in Table 2.1, optimised control curves for Lake Vyrnwy were produced by simulation modelling, using historic reservoir inflow records from 1932 to 1987. Vyrnwy water bank volumes and the operating control curves were passed to Severn Trent region for modelling of regulation of the River Severn. The maintained direct supply yields shown in Table 2.1 are minimum assured yields. NWW assumed in their initial studies that additional non-assured yield would be available from Vyrnwy, when water was not required for regulation. This non-assured yield could be used in place of local groundwater sources to allow the latter to rest and recover level (ie conjunctive use).

The second study, into alternative resources, was carried out jointly by NWW and the consultants Binnies and Partners, working for the NRA. NWW used the MOSPA model to investigate the level of development required to meet direct supply shortfalls, taking into account the potential non-assured yield use.

The main options investigated were:

- Lancashire Conjunctive Use Scheme (LCUS)
- River Dee sources
- Rivington reservoir pumped storage scheme (River Ribble)
- Lake District sources

It was established during these studies that the maximum possible reduction in direct supply yield to NWW was 140 Ml/d. A direct supply to NWW of 60 Ml/d needed to be maintained in order to serve customers from Oswestry WTW, for whom development of new resources was impractical.

The various development alternatives were costed and compared by Binnies. It was concluded that the predicted deficits for chosen options, NW9 and NW13, would be best meet by extensions of the Lancashire Conjunctive Use Scheme.

It was later established that LCUS may in the future be subject to environmental cut-backs and full development of may not be possible. This finding undermined much of the work done by Binnies, so reappraisal of alternative schemes was required. This reappraisal was carried out by NRA NW region.

The NRA calculated the marginal demands in NWW supply region for high and medium demand forecasts, taking into account local developments and an environmental cut-back in the development of LCUS of 50 Ml/d. Full details are given in Supplementary Report No. 3. They determined that, for a high demand forecast, a maximum of 69 Ml/d could be reallocated from Vyrnwy, if both the River Dee at Huntington (74 Ml/d) and the Rivington pumped storage reservoir (40 Ml/d) were developed to their full potential. Similarly, the NRA determined that for a medium demand forecast 150 Ml/d could be reallocated from Vyrnwy, if the River Dee and Rivington were developed. The costs of these two alternatives were calculated and were adjusted by Halcrow to be compatible with other RPM costs for inclusion in RESPLAN.

The resource value of Vyrnwy has been modelled based on reallocated direct supply yields of 80 Ml/d (NW9) and 140 Ml/d (NW13), but as explained above costs included in RESPLAN were based upon reallocations of 69 Ml/d and 150 Ml/d. However, the effect of the inconsistencies on the operation and results of the RESPLAN model is not believed to be significant.

2.4 Severn Trent Region Studies

The rôle of the Severn-Trent modelling team was to match up the source, Lake Vyrnwy, with the demand, the Severn to Thames transfer, by routing flows along the River Severn without affecting existing abstractions. To achieve this task the following input data were required from the other NRA regions:

- North-West - water bank volumes and operating control curves for Vyrnwy (section 2.3)
- Thames - demand sequences for alternative sized Severn to Thames transfers (section 2.5)

The NRA's Severn Trent regional resource allocation model (NRAM) was used to simulate the operation of Lake Vyrnwy and the River Severn resource. The Severn currently supports abstractions totalling 600 Ml/d. In addition to modest volumes available from Lake Vyrnwy (25 Ml/d), under low flows the Severn is augmented by releases from Llyn Clywedog (500 Ml/d) and, in drier years, water pumped from the Shropshire groundwater scheme (currently 85 Ml/d). Releases are made to maintain a prescribed flow of 850 Ml/d at the Bewdley control point.

Adjustments were made to the model to simulate the operation of Vyrnwy in river regulation mode. However, it was discovered, early in the studies, that the model did not partition the water bank from the storage required to meet direct supply requirements. This arrangement was adequate when the water bank represented only a small proportion of total storage, but problems arose when the size of the water bank was increased to feed larger regulation releases. The unadjusted model allowed the 'water bank' to be carried over from one year to the next, and allowed the water bank to expand unchecked, until in some years it occupied nearly the full volume of the reservoir. This in turn caused double counting of the water in the bank and the water available to direct supply. To overcome this and other modelling problems the reservoir control rules in the model were changed to:

(a) prevent year-on-year carry-over of the 'water bank'

(b) reduce the water bank release season from 8 to 7 months

(c) link releases from Vyrnwy with releases from Clywedog.

Two sets of model runs were executed, Set 1 was for model change (a) only, and set 2 for changes (a) to (c) together.

Transfer demand sequences were derived by NRA Thames region by simulation modelling of transfer rates of 200, 250, 300, 350 and 400 Ml/d with and without SWORD (see Section 2.5).

Severn Trent were able to route the Thames demands along the River Severn to determine the size of water bank required to support the specified transfer rates. A summary of results is given in table 2.2.

It was noted that there was little difference in the storage requirements for transfers with and transfers without SWORD. However, the transfers with SWORD lead to higher total design demands being met in Thames Region, as shown in Table 2.3.

The above results were compared and contrasted with the Vyrnwy water bank source data generated by North-West Region (table 2.1). Initial appraisals indicated that the River Severn support afforded by a NW13 option would allow for a 315 Ml/d transfer, and the support afforded by a NW9 option would allow for a transfer of 200 Ml/d. However, these results did not take into account the impact of transfers on the existing abstractions and discharges on the Severn.

Table 2.2 Vyrnwy Water Bank requirements to support alternative maximum transfer rates from the River Severn to the R. Thames.

Max Rate of Transfer Ml/d	VYRNWY WATER BANK VOLUME Ml			
	With SWORD		Without SWORD	
	Rule Set 1	Rule Set 2	Rule Set 1	Rule Set 2
200	25790	25735	25790	25735
250	33285	33230	33245	33190
300	40850	40795	40850	40795
350	48415	48360	48415	48360
400	55980	55925	55975	55920

NRAM was used to investigate the routing of flows along the Severn. The model was run for NW13 option with alternative transfer volumes (275, 300 and 315 Ml/d) and with set 1 and set 2 control rule changes. Summaries of simulation results are given in tables 2.3 and 2.4.

The performance of the transfers was measured against the frequency with which a number drought indicators were recorded or introduced whilst maintaining transfers, over the historical period (1982-1990). The indicators included:

- Prescribed flow failures at Bewdley;
- Minimum volumes in Vyrnwy and Clywedog;
- Reservoir states of Vyrnwy and Clywedog; and
- Number of times the Shropshire groundwater scheme was used.

The results showed the levels of service at the highest transfer rate were unacceptable for control rule set 1, but acceptable for control rule set 2.

The results for Set 1 show the number of prescribed flow failures at Bewdley having increased significantly for all transfer volumes - existing number of predicted flow failures is 12. These changes would be unacceptable under the current 'standards of service'. The additional flow failures for Set 2 are considerably less, and for transfers of 275 Ml/d and 300 Ml/d no increase in frequency is predicted.

The minimum volume recorded in Clywedog reservoir is lower for all transfers, with the lowest volume predicted with a 300 Ml/d transfer rather than as expected with a 315 Ml/d transfer. This erroneous result is caused by the 315 Ml/d transfer being modelled in an inconsistent manner. The number of 'drought order' states (State 3) and 'apply for drought order' states (State 2) in Clywedog increased with all all transfers both with set 1 and set 2 control rules. However, the frequency predicted for all transfers is within the standards of service.

Table 2.3 - Summary of Transfer Simulation Runs for the River Severn using Set 1 Control Rules

System	Comparison Unit	Run						
		0	1	2	3	4	5	6
Transfer & Supply Details	SWORD	X	✓	✓	✓	X	X	X
	Transfer Rate	0	275	300	315	275	300	315
	NW option	0	13	13	13	13	13	13
	Supply State 1	225						
	Supply State 2	205						
	Supply State 3	180						
Augmentation Release Information	Clywedog	447910	485465	500135	527980	443695	457050	481105
	Vyrnwy	194360	500340	506090	528460	464410	469390	485375
	Shropshire	27580	35650	41680	46590	28215	32265	35655
	Total Release Ml	669850	1021455	1047905	1103030	936320	958705	1002135
	Excess Total Ml	81050	124475	128655	136620	113090	116805	122310
	Flow Failure	12	23	26	27	21	23	25
Clywedog Reservoir	Min Vol Ml	7625	4805	6025	5515	4805	6025	5515
	Year Min Vol	1976	1976	1976	1976	1976	1976	1976
	Pentad Min Vol	53	53	53	53	53	53	53
	State 1	4270	4254	4253	4252	4257	4256	4252
	State 2	37	49	50	50	46	47	50
	State 3	0	4	4	5	4	4	5
Vyrnwy Reservoir	Min Vol Ml	9150	20685	20645	19865	20165	20145	20105
	Year Min Ml	1934	1933	1933	1947	1933	1933	1933
	Pentad Min Vol	53	56	56	62	56	56	56
	State 1	4156	3451	3449	3444	3463	3462	3459
	State 2	76	856	858	863	844	845	848
	State 3	75	0	0	0	0	0	0
	Supply Ml/d							
Shropshire	Operated	69	87	102	114	69	78	87
Severn Thames Transfer	Cumm Transfer Ml	0	957995	1030240	1152990	1152990	155803	177149

Table 2.4 - Summary of Transfer Simulation Runs for the River Severn using Set 2 Control Rules

System	Comparison Unit	Run						
		0	1	2	3	4	5	6
Transfer & Supply Details	SWORD	X	✓	✓	✓	X	X	X
	Transfer Rate	0	275	300	315	275	300	315
	NW option	0	13	13	13	13	13	13
	Supply State 1	225						
	Supply State 2	205						
	Supply State 3	180						
Augmentation Release Information	Clywedog	447910	508825	529095	552955	465840	481355	501615
	Vyrnwy	194360	504150	514230	539020	462685	471565	491680
	Shropshire	27580	20790	24465	27785	18240	19910	22060
	Total Release Ml	669850	1033765	1067790	1119760	946765	972830	1015355
	Excess Total Ml	81050	126940	133810	139810	114755	120165	125070
	Flow Failure	12	11	12	16	9	12	17
Clywedog Reservoir	Min Vol Ml	7625	6115	4445	5970	6115	4445	5970
	Year Min Vol	1976	1976	1976	1976	1976	1976	1976
	Pentad Min Vol	53	53	53	53	53	53	53
	State 1	4270	4251	4241	4240	4254	4248	4247
	State 2	37	53	61	62	50	54	55
	State 3	0	3	5	5	3	5	5
Vyrnwy Reservoir	Min Vol Ml	9150	16610	16485	16010	17295	16570	16045
	Year Min Ml	1934	1933	1933	1933	1933	1933	1933
	Pentad Min Vol	53	56	56	56	56	56	56
	State 1	4156	3438	3435	3424	3460	3457	3446
	State 2	76	869	872	883	847	850	861
	State 3	75	0	0	0	0	0	0
	Supply Ml/d							
Shropshire	Operated	69	54	63	72	48	51	57
Severn Thames Transfer	Cumm Transfer Ml	0	957995	1030240	1152990	722715	779015	885745

The minimum volume in Vyrnwy shows no increase with any transfer, suggesting that the reservoir volume is not being fully utilised either for supply or regulation.

The number of times the Shropshire groundwater would have been operated to support abstractions increased with all transfers using set 1 control rules, but remained the same, or slightly less with transfers using set 2 control rules.

As a result of their work Severn-Trent concluded that NW option 9 would support a 200 Ml/d transfer and NW option 13 would support a 300 Ml/d. Work by NRA Thames region showed these transfers without SWORD to be worth, in terms of a design demand met in Thames, 249 Ml/d and 337 Ml/d respectively.

2.5 Thames Region Studies

The objective of NRA Thames region's modelling study was to determine the resource value or design demand which could be met by different maximum Severn to Thames transfer rates. At the beginning of the study information about the size of transfer rates was limited, with definitive answers only available once NW & ST studies were complete. In order to progress the investigations therefore, Thames Region therefore selected a range of transfer rates to investigate (200, 250, 300, 350 and 400 Ml/d).

The region's water resource model (WRM) was used to simulate the River Thames system and associated aquifers and storage elements. The model works by calculating the base-flow in each sub-catchment, noting the daily rainfall, mean monthly evaporation and aquifer parameter and then, by subtracting the base flow from archived total flow, an estimate of total surface inflow is determined. This is then divided into sub-catchment inflows.

The model was run with a naturalised historical flow record from 1920 to 1991.

The model does not directly calculate a resource yield, instead it assesses a 'design demand' which can be met by the transfer, as defined by referenced to the agreed levels of service. The levels of service are:

- Level 1 — hosepipe bans, 1 in 10 years on average
- Level 2 — pressure reduction, 1 in 20 years on average
- Level 3 — drought orders, 1 in 50 years on average
- Level 4 — rota cuts and standpipes, 1 in 100 years on average

Reductions in average demand due to the introduction of these demand restrictions have been estimated based on operational experience in 1976 - eg 27% reduction at level 4.

The storage levels in the London reservoirs provide a realistic measure of available resources in the region at any given time. The water resource model produced, as part of its output, simulated plots of the combined storage in the reservoirs for different transfer volumes and different levels of increased supply. These plots were used to determine the 'design demand' (the level of increased supply which can be maintained without failing the agreed levels of service) for varyings transfer volumes.

Simulated London reservoir storage plots for a 200 Ml/d transfer, with supply increases of +0 Ml/d, 200 Ml/d, 250 Ml/d and 300 Ml/d, are shown in Figure 2. Overlaying these plots are four control curves, which correspond to the storage levels needed to ensure maintenance of supply at differing levels of demand restriction, given estimated reductions in demand. The levels of service, as described above, determine the frequency with which the simulated storage level can drop below the corresponding control curve over the historical record (1920-1991). The storage levels described by the level 1 hose pipe ban control curve can therefore be transgressed once in ten years, whilst the level 4 standpipe control curve only once in hundred years.

To determine the design demand of a specific transfer, simulated storage levels were derived at differing levels of design demand for each year in the historic record. The plots were then inspected and a tally kept of the number of times the various control curves were crossed. The tally was then compared to the agreed levels of service to establish the if design demand could be met. The control curves should not be crossed by the simulated retention levels at a frequency greater than stated in the levels of service. A summary of results is given in Table 2.5.

Table 2.5 Design Demands met by alternative transfer capacities

Transfer Option	Transfer Capacity Ml/d	Design Demand Ml/d	Years Used	Define Mean Quantity Per Annum (Ml)*
Without SWORD	200	248.9	29	18012
	300	337.0	33	26386
	400	425.1	33	39205
+With SWORD	200	190.9	36	24641
	300	234.9	36	35085
	400	337.7	37	48748

* This figure represents the mean quantity pumped in during the years used and not over the full record.

\+ These figures exclude the design demand met by SWORD, which is estimated to be 350 Ml/d.

Thames Region investigated the potential value of transfers from the River Severn at Deerhurst without support from additional resources in the upper Severn catchment. With a flow constraint of 2500 Ml/d at Haw Bridge, it was estimated that design demands of 100 Ml/d and 146 Mi/d could be sustained by maximum transfers of 200 Ml/d and 400 Ml/d, respectively. With the presence of SWORD these design demands could be increased by relatively small increments to 103 Ml/d and 176 Ml/d.

The reduced design demand of a transfer with SWORD, as measured by available storage in London, compared with a transfer without SWORD is due to the new reservoir having prior claim to flows during critical periods. This result assumes that the full yield of SWORD is realised (350 Ml/d) before the design demand is calculated. This order of priority however is not reflected in the design demands of unsupported transfers. In this case, the design demand for a transfer with SWORD is higher than for a transfer without SWORD. For a maximum transfer capacity of 400 Ml/d the design demands are:

without SWORD	146 Mi/d
with SWORD	176 + 350 Ml/d = 526 Ml/d

The explanation given for this reversal is that the mode of operation of SWORD is no longer the critical limiting factor on transfer yield, but rather it is the timing of transfers from the Severn to the Trent that limit yield. In fact, SWORD reservoir would be beneficial in supplementing unsupported transfer yield, by releasing water periods when flows in the Severn make transfers impossible. It is assumed these additional releases would not have an impact upon SWORD's stated yield of 350 Ml/d.

In interpreting the above results for RESPLAN the NRA have assumed that a Severn to Thames transfer would be developed before SWORD, and the maximum design demand met by the transfer would be 425 Ml/d. To incorporate SWORD into a RESPLAN, following full development of a Severn to Thames transfer, the design demand of the reservoir was reduced from 350 Ml/d to 262 Ml/d, thereby avoiding double counting. [687 Ml/d (transfer + reservoir) - 425 Ml/d (transfer) = 262 Ml/d].

When NRA wished to run RESPLAN with SWORD being developed before a Severn-Thames transfer, the reservoir yield was reset to 350 Ml/d and the transfer yield reduced to 337 Ml/d accordingly.

2.6 Model Integration

The results from Thames Region's modelling work were passed to Severn-Trent Region in the form of transfer demand sequences, see section 2.4, which were matched with the required Vyrnwy water bank volumes. A graphical representation of how data from the three NRA studies relate is given in Figure 3.

Three graphs are shown in Figure 3

- Graph 1 - Vyrnwy committed direct supply V Vyrnwy water bank volume;
- Graph 2 - Vyrnwy water bank volume V maximum transfer rate; and
- Graph 3 - Maximum transfer rate V design demand met in Thames region.

The graphs are arranged in such a way that by tracing the points along the common axes from one graph to another in sequence, the reader can determine for any committed direct supply a corresponding design demand.

This information has been simplified for use in a RESPLAN analyses to linear relationships. The adjusted correlations are shown in Figure 3 as broken lines.

2.7 Hydrological Impacts

The consultants Howard Humpheys investigated the hydrological impacts of both unsupported and supported transers on the aquatic ecology, fisheries and amenity values of the donor (Severn) and recipient (Thames) rivers. Their findings are reported in Supplementary Report No 8 'Comparative Environmental Appraisal of Strategic Options'.

To help with this task the NRA provided the consultants with river flow data for the two rivers, such as:

- mean annual flow;

- mean annual flood;

- Q95 in the long term; and
- Q95 in a drought and a wet year

They were also provided with the following output data from the water resource models

- River Thames flow duration curves at Days Weir during a wet year (1985), 1 in 10 year droughts (1990 and 1929) and a design drought (1976).
- River Thames consolidated flow duration curves winter and summer periods at Days Weir for the years 1920-1991.
- Mean, maximum and minimum monthly average flows at Days Weir (1920-1991).
- Hydrographs for flow over Days Weir in 1990, 1976 and 1929.
- Flow accretion curve for the River Thames 1920-1991.
- River Severn hydrographs below Vrynwy, Clywedog and Bewdley for a design drought (1975-1976).

The above data from the water resource models were provided for the unsupported and supported transfers with maximum transfer volumes of 200, 300 and 400 Ml/d with and without a transfer to SWORD. For the readers interest, a sample of these data for the unsupported transfer is contained in Appendix A. The full data set are contained in the internal NRA modelling reports.

3 EAST ANGLIAN TRANSFER SYSTEM

3.1 Scheme Description

An East Anglian transfer scheme was first proposed in the NRA's Water Resource Planning - Strategic Options report (ref 1), as a combination of river to river transfers and new resource developments. If fully developed the proposed scheme would link the River Severn to London, via the River Trent.

A schematic of the transfer system is shown on Figure 4. The main transfer elements include:

- River Severn to River Trent transfer (shown on Figure 1);
- River Trent to River Witham transfer;
- River Witham to Ely Ouse transfer;
- Ely Ouse to Essex transfer; and
- Essex to London transfer.

Of these two already exist, the Trent to Witham and the Ely Ouse to Essex transfers.

The new resource development options associated with the East Anglian transfer system include:

- Great Bradley reservoir;
- Fenland reservoir;
- Chelmsford effluent re-use;
- Reductions in flow constraints on Bedfordshire Ouse; and
- Augmentation of inflows into Grafham and Rutland reservoirs.

These proposed transfers and new resources will meet increased public water supply demand in:

- East Anglia - as measured at Grafham and Rutland reservoirs

- Essex - as measured at the end of the Ely Ouse to Essex transfer at Abberton and Hanningfield reservoirs

- London - as measured at the London reservoirs.

Details of the main transfer and resource developments are given below.

3.1.1 Severn to Trent Transfer

An engineering feasibility study was commissioned by NRA Severn-Trent Region (Ref 3) to investigate the most economic Severn to Trent transfer route. The route chosen, shown schematically in Figure 1, was from the River Severn at Coalport, downstream of Telford, to the River Penk at Lower Drayton, thence to the River Sow at Milford and then the River Trent at Haywood. The drought characteristics of the River Severn and River Trent are similar, so when there are low flows in the Severn there are likely to be low flows in the Trent. This limits the volume of water which can be transferred to the River Trent from an unsupported River Severn. All transfers therefore need to be supported by new resource developments, such as the Vyrnwy redeployment scheme (Section 2.2). This is different from the Severn to Thames linkage where the benefits of an unsupported transfer are substantial.

Transfers between the Severn and Trent are most likely to be needed between June and October. During this period the pipelines would be kept full with a sweetening flow to avoid water quality problems developing; in winter the pipelines would be drained.

In order to minimise transfer losses and ensure a security of supply, balancing storage of 3 to days transfer volume would need to be provided.

3.1.2 River Trent to River Witham Transfer

Transfers from the River Trent to the River Ancholme via the River Witham already take place, meeting demand in Lincolnshire. Water is abstracted from the lower Trent at Torksey and transferred, via the Forsdyke Canal, to the River Witham to augment low flows: maximum transfer 138 Ml/d. Of this total, 118 Ml/d is transferred from the Witham to Toft Newton reservoir on the upper Ancholme, and 20 Ml/d remains in the River Witham to be abstracted at Boston.

Increased transfers of up to 400 Ml/d from the Trent to the River Witham are proposed as part of an East Anglian transfer system. Water would be abstracted from the Trent at Torksey and used to regulate an increased abstraction on the River Witham at Boston. Abstractions would be controlled by a flow constraint on the Trent at Colwick. Additional engineering works required would include an enlarged Torksey pumping station and a new intake at Boston.

3.1.3 River Witham to Ely Ouse Transfer

This is a proposed pipeline transfer, which will link the River Witham with the existing Ely Ouse to Essex transfer system. An engineering feasibility study (Ref 4) was commissioned to investigate alternative pipeline routes from the River Witham at Boston to the Ely Ouse at Denver. From this work two main transfer options were identified.

Option 1 - a pipeline linking Boston and Denver directly

Option 2 - a pipeline linking Boston to the Rivers Nene and Bedford Ouse and a river transfer from the Bedford Ouse to the Ely Ouse.

Links from Boston to the River Nene and Bedford Ouse, will enable water from the Trent to be transferred to Rutland and Grafham reservoirs, via the abstraction points at Wansford and Offord (see Section 3.1.8).

3.1.4 Ely Ouse to Essex Transfer

The existing Ely Ouse to transfer Essex (EOTE) is a system of pipe and river transfers, which allow the movement of water from the Ely Ouse to the main supply reservoirs in Essex: Abberton and Hanningfield. The system, see Figure 4, comprises the following elements:

- an abstraction from the Ely Ouse via the cut-off channel at Blackdyke intake;
- a gravity tunnel from Blackdyke to Kennett pumping station;
- a rising main from Kennett pumping station to the River Stour at Kirthling Green outfall; and
- a pumping station and a rising main at Wixoe on the Stour to the River Blackwater.

Water transferred to the River Stour is used to support abstractions either for direct supply or augmentation of Abberton reservoir, and transfers to the River Blackwater to support abstractions for the Hanningfield reservoir supply system. Water is abstracted from the Stour at Longham, Stratford and Cattawade and from the Blackwater at Langford Mill (direct supply) and Langford. Abberton reservoir is also augmented by abstractions from the Roman River, whilst Hanningfield reservoir is augmented additionally from the River Chelmer (Langford pumping station).

Presently, there is capacity in the system to accommodate additional transfers from the Ely Ouse, however, in order to achieve optimum yield from such transfers, pump capacities at Kennett, Wixoe and at the river intakes would need to be increased.

3.1.5 Essex to London Transfer

The Essex to London transfer is a proposed pipeline from the River Blackwater to the rivers Roding and Stort. River Roding flows directly into the Lee Valley and the River Stort flows into the Thames estuary, downstream of the Lee confluence.

The transferred water would be used to meet demand in the London area.

3.1.6 Great Bradley Reservoir

Great Bradley is a proposed impoundment reservoir in the headwaters of the River Stour. A feasibility study was commissioned by the NRA to investigate the geological, geotechnical, engineering and environmental aspects of the scheme (Ref 4). The largest reservoir considered had a storage capacity of 106 million m^3. It would be operated in conjunction with the EOTE system, with reservoir inflows being augmented by pumped flows from Ely Ouse, via Kennett pumping station and Kirthling Green outfall. Water from the reservoir would be released to regulate abstractions on the

Stour, and pumped via Wixoe pumping station to regulate abstractions on the Blackwater.

3.1.7 Fenland Reservoir

The proposed Fenland reservoir is a fully bunded pumped storage reservoir to be located in the vicinity of the Ely Ouse and is an alternative to a Great Bradley scheme. Only preliminary studies of the reservoir have, as yet, been completed. For this study, the maximum reservoir storage capacity assumed is 106 million m^3; the same as the largest Great Bradley scheme.

3.1.8 Augmentation of Grafham and Rutland Reservoirs Inflows

As described in Section 3.1.3, there is the option of transferring water from the River Witham at Boston to Rutland and Grafham reservoirs. All transfers from Boston would be pumped initially to the River Nene at Wansford, where up to 100 Ml/d could be diverted to Rutland reservoir; the water would then be pumped to the Bedford Ouse at Offord, from where up to a further 100 Ml/d could by transferred to Grafham. Finally, the remaining water, up to a maximum of 400 Ml/d, would be used to regulate the Ely Ouse abstraction at Denver.

3.1.9 Chelmsford Effluent Reuse and Reducing Flow Constraints on the Ely Ouse

The Chelmsford effluent reuse scheme involves the relocation of the effluent discharge from Chelmsford Sewage Treatment Works, so that the outfall is positioned upstream of Langford abstraction point the abstraction point for Hanningfield reservoir. The scheme is estimated to be worth 40 Ml/d.

Abstractions from the Ely Ouse at Denver are controlled by a seasonal MRF at Denver: 114 Ml/d in the summer and 318 Ml/d in the winter. A reduction of the MRF to an all year round level of 114 Ml/d is forecast to increase the yield of the EOTE transfer system by 5% to 7%. Decreasing the MRF still further, to a year round level of 50 Ml/d, is forecast to increase yields by 10%.

3.2 Objectives and Planning

The objective of the East Anglian modelling study was to determine the resource value of River Trent transfers when operated in conjunction with the Ely Ouse to Essex transfer system. The resource benefit of the Trent was determined with the existing Ely Ouse system and with the system supplemented by the addition of new resource developments, such as Great Bradley reservoir and Chelmsford Effluent Reuse scheme.

There is no single water resource model which can simulate transfers from the Severn to the Trent, to the Witham, to the Ely Ouse and then, via the Ely Ouse to Essex transfer system, to the Thames. Instead, the system had to be modelled by the linking of five existing water resource models. These were:

- Severn Trent's regional water resource allocation model (NRAM);
- Trent-Witham-Ancholme (TWA) transfer model;
- Rutland reservoir operating model;
- Grafham reservoir operating model;
- Ely Ouse to Essex (EOTE) transfer model; and
- Thames region's water resource model (WRM).

The modelling work was undertaken by NRA Severn-Trent, Anglian and Thames regions. Work was commenced simultaneously in the three regions, with initial work undertaken using input data derived from a 'best guess'. As studies progressed and results from the various studies became available so the work was refined.

The studies were carried out by each region as described below.

3.3 NRA Severn-Trent Studies

Severn-Trent calculated the maximum unsupported transfers to the Witham available from the River Trent at Torksey at different minimum residual flows (MRFs) measured at Colwick. Transfer rates were determined for MRFs of 2000, 2500 and 3000 Ml/d.

These calculations were based upon gauged flow records for the Trent rather than, as would have been preferable, naturalised flows. The assumption implicit in the use of non-naturalised flow is that the impacts of abstractions and discharges have been constant throughout the record. This is evidently not the case for the River Trent and the NRA are undertaking studies to produce naturalised flows at Colwick. However, results were not available for use in these studies. The NRA also investigating an acceptable MRF at Colwick for the fluvial river, but again, final results were not available for inclusion in the modelling studies.

In addition to calculating maximum unsupported transfers, Severn Trent region investigated maximum transfer rates from the Trent if supported from the River Severn. Using the regional water resource model NRAM, the NRA determined the storage required in the Severn catchment to support maximum transfer rates of 100 Ml/d and 300 Ml/d at different River Trent MRFs (1750, 2050 and 2400 Ml/d). The results for a design drought are shown in Table 3.1.

Table 3.1 Storage required to support Severn to Trent transfers in a drought year

Residual Flow at Colwick (Ml/d)	Installed Transfer Capacity (Ml/d)	Additional Storage for Severn (Ml)	Storage Assuming 20% Losses
1750	100	7700	9240
	300	24500	29400
2050	100	9200	11040
	300	27900	33480
2400	100	11200	13440
	300	35000	42000

The results from Severn Trent region's work were passed to Anglian region as input to the Trent-Witham-Ancholme model.

3.4 Anglian Region Studies

3.4.1 General

The studies carried out by Anglian region involved the operation and linking of four simulation models, they were:

- Trent-Witham-Ancholme model;
- Rutland reservoir model;
- Grafham reservoir model; and
- Ely Ouse to Essex transfer model.

The NRA developed a link program, which enabled data to be transferred from one model to the next. Details of how the components link together into an enlarged East Anglian Transfer System are given in Section 3.4.5. Descriptions of the individual models are given in Sections 3.4.2 to 3.4.4.

3.4.2 Trent-Witham-Ancholme Model

The Trent-Witham-Ancholme model simulates the daily transfers of water from the River Trent to the upper River Witham and from the River Witham to the upper River Ancholme. Demand for water is measured on the lower reaches of the Ancholme and the Witham.

The output of the model includes:

- daily transfers from Trent to Witham;

- daily transfers from Witham to Ancholme;

- daily times series of flows on the Witham at Boston.

The maximum transfer available for an unsupported and a supported River Trent, as calculated by Severn-Trent region, were provided as input to the TWA model (see Section 3.3). Initially the flow record for the Trent was for twenty years only, from 1972 to 1992, later NRA Severn-Trent region undertook to extend the record back to 1932, thus ensuring a common modelling period with the EOTE model.

The model was operated using a forecast of public water supply demand on the system in 2001.

The model calculated, for different MRFs on the Trent, a daily record of excess water available for transfer from the River Witham at Boston, after demand sequences on the Ancholme and Witham had been met. Losses of 5% were assumed for transfers from the Trent to the Witham.

3.4.3 Rutland and Grafham Reservoir Models

Rutland is a pumped storage reservoir located near Peterbough. It has a volume of 137 million m^3 and is filled by abstractions from the River Nene at Wansford and the River Welland at Tinwell, as well as natural inflows. Abstractions on the rivers Nene and Welland are subject to flow constraints.

Grafham is a pumped storage reservoir, located to the south of Rutland reservoir near Huntingdon with a storage volume of 56 million m^3. Natural reservoir inflows are augmented by water abstracted from the Bedfordshire Ouse at Offord. Abstractions are controlled by a MRF for the Ouse, above which 75% of all excess water maybe taken up to the licensed entitlement.

The yield of both these reservoirs is modelled by NRA Anglian region using the Operating Strategies method of Assessing Yield (OSAY). Yield is assessed in a similar way to NRA Thames Region's water resource model (see Section 2.4); it is defined in terms of the minimum supply available during a critical drought, taking account of the introduction of demand restrictions to conserve storage.

Model input data comprises monthly reservoir inflow sequences for the recorded period. For this study three inflow sequences were determined:

- natural inflows;

- pumped inflows; and

- transfer inflows from the River Witham.

Natural inflows were calculated from rainfall records, with evaporation from the reservoir surface taken into account.

Pumped inflows were calculated from naturalised river flow records on the Welland, Nene and Ely-Ouse. Firstly, daily gauged river flow records from the donor rivers were naturalised, removing the impact of past abstractions and discharges. Future abstractions and discharges were then predicted (based upon forecast demands) and added to the naturalised flow. The maximum pumped inflows were then calculated, by applying licence, operating and flow constraints to the simulated gauged river flow records, and monthly inflows were created, by aggregating daily inflows.

The transfer flows available from the Witham were provided as output data from the TWA model and were transferred to OSAY models using the linking program. The method for calculating transfer inflows is described later in Section 3.4.4, where the link program is discussed in some detail.

Initially the models were operated with a historic flow record of fifty one years (1941 - 1992). This was later extended to sixty years (1932 - 1992) to make it consistent with records used in other modelling studies.

The yield of the reservoirs are defined as the rate at which water can be abstracted such that the reservoir does not fail during a design drought. Failure is predicted by measurement of the level of water stored in the reservoir. Once storage falls below a level from which the probability of refill within the reservoir's critical period becomes unacceptable, the reservoir is deemed to have failed. The storage level which indicates failure varies depending upon the demand on the reservoir and is described by a control curve; the higher the demand the greater the storage required and the higher the control curve level.

A series of control curves have been produced for Rutland and Grafham for demand loadings with the introduction of different levels of demand restrictions. These correspond to the agreed levels of service for Anglian Water pic, the owners of Rutland and Grafham:

Hosepipe bans	-	1 in 10 years, demand reduction 10 to 20%
Non-essential use	-	1 in 20 years, demand reduction 25 to 32%
Standpipes	-	1 in 100 years, demand reduction 50%

The OSAY models operate in a similar way to the NRA Thames Region's water resource model, comparing the simulated reservoir levels with the control curves for the agreed levels of service. To determine the yield of the reservoir (design demand) the supply avaialble is adjusted until the number of simulated transgressions of the control curves matches that predicted by the level of service. This match can never be exact, since the length of the data record is short in comparison with the frequency with which events are predicted to occur.

3.4.4 Ely Ouse to Essex Transfer Model

The Ely Ouse to Essex (EOTE) transfer model calculates the available yield from the Essex rivers and Abberton and Hanningfield reservoirs, when operated in conjunction with the Ely Ouse transfer system.

The reliable yield is defined as the maximum uniform demand (subject to seasonal variation) which can be met during a design drought without system failure. System failure is said to have occurred when either Abberton or Hanningfield empty. The system yield is taken to be the combined output from Abberton reservoir system (Langham and Abberton. WTWs) and Hanningfield reservoir system (Langford and Hanningfield WTWs). All yields assume 15 percent loss of water transferred from the Ely Ouse.

The yields calculated using EOTE are not strictly comparable with those calculated for Rutland and Grafham using OSAY. Since the EOTE model, unlike OSAY models, does not take account of the enhanced resource value when the impacts of resource conservation measures are considered.

Daily gauged flow data for the Ely Ouse at Denver are input to the model. Naturalised flows are believed to be unobtainable for the Ely Ouse because of the impact of legal, but unmeasured and unlicensed, abstractions to the Fens. The NRA have recommended that future modelling studies should include a sensitivity analysis to determine the impact of different Fen abstraction regimes.

As part of this study, the EOTE model was extended to incorporate:

- Trent transfers;
- Great Bradley reservoir;
- Fenland reservoir;
- Thames transfers;
- Chelmsford Effluent Reuse scheme; and
- Reductions in Ely Ouse MRFs.

The modelling of the Trent transfers is discussed in detail in section 3.4.5.

Great Bradley is modelled as an in line reservoir located between the Kennett pumping station and the River Stour (see Figure 4).

Initially the model was operated with Great Bradley supporting Abberton and Hanningfield reservoirs, with no direct supply to demand centres. The yield of the system was therefore taken to be the supply solely from Abberton and Hanningfield. Later, transfers to NRA Thames region were simulated as direct supply from Great Bradley.

There was no control curve applied to Great Bradley, so the reservoir was allowed to empty without causing system failure. Releases to support Abberton and Hanningfield had to be therefore controlled to ensure that the two reservoirs emptied at the same time, thereby preventing premature system failure.

The Fenland reservoir was represented in the model as an offstream reservoir, fed from the Ely Ouse above Blackdyke Intake. The reservoir was operated in the same manner as described above for Great Bradley.

The potential to transfer water from the Ely Ouse transfer system to NRA Thames Region was modelled by linkages between Great Bradley and the Rivers Stort and Roding. Transfers were initially simulated as a constant direct supply demand on Great Bradley, but later, following work undertaken by NRA Thames, (see Section 3.5) transfers were simulated as demand sequences on the reservoir. Maximum transfer capacities of 100 and 200 Ml/d were investigated.

Chelsmsford effluent reuse was assumed to have a yield of 40 Ml/d and the MRF on the Ely Ouse was assumed to be reduced to 114 Ml/d all year round.

The groundwater augmentation of the Great Ouse and the River Stour are not represented in the model. The yields from these two schemes are estimated to be 13 Ml/d and 25 Ml/d, respectively (combined yield 36 Ml/d).

3.4.5 Enlarged East Anglian Transfer System

The tasks involved in assessing the potential of an enlarged East Anglian transfer system were to:

- link the four Anglian water resource optimisation models together: Trent-Ancholme-Witham (TAW), Rutland, Grafham and EOTE models;
- determine the system yield transfer flows from the River Trent;
- determine the system yield with the addition of various new water resource developments;
- determine the system yield with transfers to the Thames region.

NRA Anglian developed a linking program which allowed data to be transferred from the TWA model to the EOTE model. The models were linked in two alternative options:

- Option 1 - TAW was linked to the EOTE model, by a simulated direct pumped transfer from Boston to Denver (maximum transfer 400 Ml/d). No losses were assumed in this linkage;
- Option 2 - TAW was linked to the Rutland, Grafham and EOTE models in series. The linkage was simulated by pumped transfers from Boston to Wansford (Rutland abstraction) and from Wansford to Offord (Grafham abstraction) and a river transfer down the Ely Ouse from Offord to Denver. The maximum transfer modelled from Boston to Denver was 400 Ml/d, with a further 100 Ml/d transfers to both Wansford and Offord. The maximum transfer from Boston modelled was therefore 600 Ml/d. Losses of 0% and 10% were assumed on piped and river transfers respectively.

For both arrangements the linking program calculated a daily record of additional transfer water available at Denver.

The linked TWA/EOTE model was run repeatedly, increasing the demand on the system in iterative steps until system failure - ie emptying of either Abberton or Hanningfield reservoirs. The model produced a record of the additional transfer water taken from Denver and the linking program back calculated the residual flow in the Trent.

In order to determine the reliable yield of the various new resource developments, the model was run with a number of system configurations. The main configurations (runs 0 to 8), as described in NRA Anglian Regions Stage 2 modelling report (ref 12), were as follows:

Run Number	
0	Baseline case (assumed to include Chelmsford Effluent at 40 Ml/d and Denver mrf at 114 Ml/d)
1	With Great Bradley
2	With Trent (400 Ml/d)
3	With Trent, plus increased Kennett pumps
4	With Great Bradley, plus Trent, plus increased Kennett pumps
5	With Trent, plus drop-offs at Wansford (100 Ml/d) and Offord (100 Ml/d)
6	With Great Bradley, plus Trent, plus drop-offs at Offord (100 Ml/d) and Wansford (100 Ml/d), plus increased Kennett pumps
7	With Great Bradley, but supporting a demand of 100 Ml/d in Thames Region
8	With Great Bradley, but supporting a demand of 200 Ml/d in Thames Region

Model runs were repeated for unsupported Trent transfers, constrained by MRFS of 2000, 2500 and 3000 Ml/d and supported Trent transfers.

The baseline case represents the existing EOTE transfer system, supplemented by a Chelmsford Effluent Reuse scheme and a Bedford Ouse MRF reduction. The yield of the baseline case, measured at Abberton and Haningfield reservoirs, was 398 Ml/d.

Following initial runs, it was discovered that the yield of the enlarged transfer system with a Trent transfer was limited by the existing pump capacity at Kennett pumping station (334 Ml/d). Runs 3, 4 and 6 include an enlarged, 681 Ml/d, capacity Kennett pumping station. The system yield was also restricted by the combined intake capacities on the Essex rivers. The model was re-run with increased capacities at Stratford and Cattawade on the River Stour and at Langford on the River Blackwater. Adjustments to the intake sizes were made until an optimum yield was identified. Depending upon the River Trent flow constraints increases of between 20% and 40%

in total intake capacities were necessary in order to obtain optimum yield. All model runs were operated with increased intake sizes.

Model runs 9 and 10 simulate a direct transfer from the River Trent to Rutland reservoir. The NRA commissioned W S Atkins to undertake an engineering feasibility study of this option (Ref 3).

3.4.6 Results

A full set of simulation results from the enlarged transfer model is presented in Anglian region's stage 2 modelling report (Ref 12). Table 3.7 contains the results for runs 0 to 10 with a River Trent MRF of 2500 Ml/d, these results were used for the RESPLAN analyses.

Run numbers 0, 1, 7, 8, 9 & 10 do not include a River Trent transfer. Run numbers 2, 3 & 4 include a Trent Transfer which is transferred directly to the Ely Ouse from the River Witham (option 1). Runs 5 & 6 have a Trent transfer which is diverted from the Witham to Rutland and Grafham reservoirs, before being delivered to the Ely Ouse.

Early modelling studies investigated the effect on yield of option 2 runs of alternative orders of priority for meeting demand. Transfers were modelled with two different orders of priority, these were:

- Denver - Offord - Wansford; or
- Offord - Denver - Wansford

If demand at Denver is given priority, the impact of the transfer to Wansford and Offord on the yield of the EOTE system is insignificant. However, if priority is given to Offord, before Denver, EOTE yields could be reduced, at the higher transfer rates by up to 13 Ml/d. However, these losses are more than compensated by increased reservoir yields afforded by the reservoir transfers. For example, assuming that Offord has first priority, Grafham yields could increase by 36 Ml/d and 63 Ml/d, for transfers of 50 and 100 Ml/d respectively.

TABLE 3.2 - WATER STORAGE AND TRANSFERS IN THE ANGLIAN REGION SIMULATION RESULTS - TRENT MRF 2500 Ml/d

	Trnt mrf	Wlt-Den cap	Drop offs in prior-ity order OWD	Chelm Efflt	Gt. Brad Stor	Kenn Pump Size	Wixoe pump size	Stour int. cap	Black water int. cap	Chelm int. cap	Lang Hann link cap	Denv mrf	Tran to Thames	Trnt - Rut cap	Calculated Yield			Average Transfer		
															EO-E	Graf-ham	Rutl-and	Tr-Ang	Wi-De	EO-E
	Ml/d	Ml/d	Ml/d	Ml/d	$m^{3}\cdot 10^{6}$	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d
0				40		334	227	309	205	205	280	114			398	269	199	31.5		98.7
1				40	106	334	341	309	305	205	300	114			558					.9
2	2500	400	direct	40		334	341	309	305	205	300	114			489			46.7	15.4	147.2
3	2500	400	direct	40		681	341	309	305	205	300	114			503			56.6	25.3	175.3
4	2500	400	direct	40	106	681	400	388	383	205	390	114			791			103.2	77.7	448.4
5	2500	400	100/ 100/ 400	40		334	341	309	305	205	300	114			440	338	289	109.1	90.8	127.7
6	2500	400	100/ 100/ 400	40	106	681	400	388	383	205	390	114			730	338	289	145.3	130.4	390.4
7				40	106	344	341	309	305	205	300	114	100		506					200.9
8				40	106	334	341	309	305	205	300	114	200		440					171.3
9	2500													100			295			
10	2500													200			390			

Extracted from NRA Anglian region's report

Stage 2 Modelling Water Storage and Transfer

August 1993

The simulated results in NRA Anglian Region's stage 2 report, and those inlcuded in RESPLAN, refer to only a single size Great Bradley reservoir (106 million m^3) and make no reference to a Fenland reservoir. Previous studies had been undertaken to determine the optimum reservoir options. The simulated yields for two sizes of Great Bradley reservoir given in Table 3.8 were extracted from the NRA Anglian region's Preliminary Modelling report (ref 11):

Table 3.3 - Great Bradley Reservoir Yields Ml/d

Kennett Pump size (tcmd)	Great Bradley 106 x $10^6 m^3$		Great Bradley 46 x $10^6 m^3$	
	increase Ml/d	increase %	increase Ml/d	increase %
334 (current size)	166	49	70	20
455	196	58	98	28
568	215	63	117	34
681	226	66	129	37
796	233	69	132	38

It was discovered that the yield of Great Bradley reservoirs was limited by the capacity at Kennett pumping station. A series of model runs were executed to determine an optimum size for the pumping station; a 681 Ml/d sized station was selected.

Like Great Bradley the yield of the Fenland reservoir is restricted by the pumping capacity at Kennett. The model indicated that the yield of a 106 million m^3 Fenland reservoir is, for the same size Kennett pump capacity, greater than a comparable Great Bradley scheme. The greater yield available from Fenland is attributable in part to the pump configuration assumed for the reservoir. The Fenland reservoir was not included in the RESPLAN analysis.

3.5 NRA Thames Region Studies

Large water supply deficits are forecast for the London area by the next century. Transfers from Anglian Region, via the Ely Ouse system, are believed to be a viable option to help meet these deficits.

The potential transfers from an assumed Great Bradley reservoir to the rivers Roding and Stort were investigated by NRA Thames Region, using their Water Resources Model (WRM) (ref 10). The transfers could not be modelled directly, since the rivers Roding and Stort are poorly described by WRM model. Instead, both transfers were simulated as discharges into the River Lee, upstream of Fieldes Weir.

The WRM model calculated the design demand which can be met during a design drought for various maximum transfer volumes. Three maximum transfer rates were investigated: 100 Ml/d and 200 Ml/d to the River Stort and 90.9 Ml/d to the River Roding. The WRM model calculated the average transfer volume and demand sequences for the transfers over the simulated period (1920-1991) and the demand sequences were passed to NRA Anglian Region as input to the linked TAW/EOTE transfer model. Before the NRA Thames region's modelling results had been available, the transfers had been simulated by NRA Anglian region as a constant supply from Great Bradley. This was a conservative assumption which had the effect of reducing the system yield. Using the demand sequences produced by Thames Region, NRA Anglian were able to refine the simulation results, as given in Table 3.7. Transfers to the River Roding are designed to replace the existing Chigwell bulk supply from Grafham on an equitable basis. This being the case, the transfer was used at 100% capacity, all year round.

Table 3.4 - Simulation Results for NRA Anglian to Thames Region Transfers

Max Transfer Volume Ml/d	Transfer Destination	Design Demand Ml/d
90.9	River Roding	90.9
100	River Stort	81.1
200	River Stort	176.0
100 and 90.9	Rivers Stort and Roding	172

3.6 Hydrological Impacts

The consultants Howard Humphreys undertook, as part of their environmental study, an assessment of the hydrological impacts of the East Anglian transfers, including impacts on amenity value, aquatic ecology and fisheries in the rivers Trent, Witham, Ely-Ouse, Stour, Pant and Blackwater. To help with these studies NRA Anglian Region provided with the following data:

- Simulated flow duration curves (1972-1992) on the rivers:
  - Trent at Torksey
  - Witham, downstream of Fossdyke and upstream of Boston
  - Beford Ouse at Offord
  - Stour at Langham; and
- Flow hydrographs for the existing transfer schemes and the proposed schemes on the above rivers and locations.

Samples of the data given to Howard Humphreys is given in Appendix B.

The environmental consultants did not evaluate the hydrological impacts of transfers from Essex to Thames region.

REFERENCES

1 Water Resource Planning - Strategic Options. National Rivers Authority, 1991.

<u>Transfer Engineering Feasibility Studies</u>

2 Severn-Thames Transfer - Feasibility Study. National Rivers Authority Thames Region, 1993.

3 Severn to Trent Transfer Options - Feasibility and Outline Engineering Appraisal. National Rivers Authority Severn Trent Region, 1993.

4 Options for Transfers of Water from the River Trent and Reservoir Storage at Great Bradley. Vols I and II. Components 1 to 6. National Rivers Authority Anglian Region, 1993.

5 Regional Strategic Options Study - Component 7, River Trent to Rutland Water Transfer. National Rivers Authority Anglian Region, 1993.

<u>Modelling Reports</u>

<u>National Rivers Authority North West Region</u>

6 Proforma for Reporting of Modelling Associated with Inter-regional Transfers. May 1993.

7 Notes on North West Region Marginal Demands and Vyrnwy Redeployment. National Rivers Authority North West Region and National Rivers Authority Headquarters, November 1993.

<u>National Rivers Authority Severn Trent Region</u>

8 Redeployment of Lake Vyrnwy to Support Transfers from the River Severn to the River Thames - Final Report, May 1993.

9 Regulation of the River Trent for Transfer to Anglian Region, May 1993.

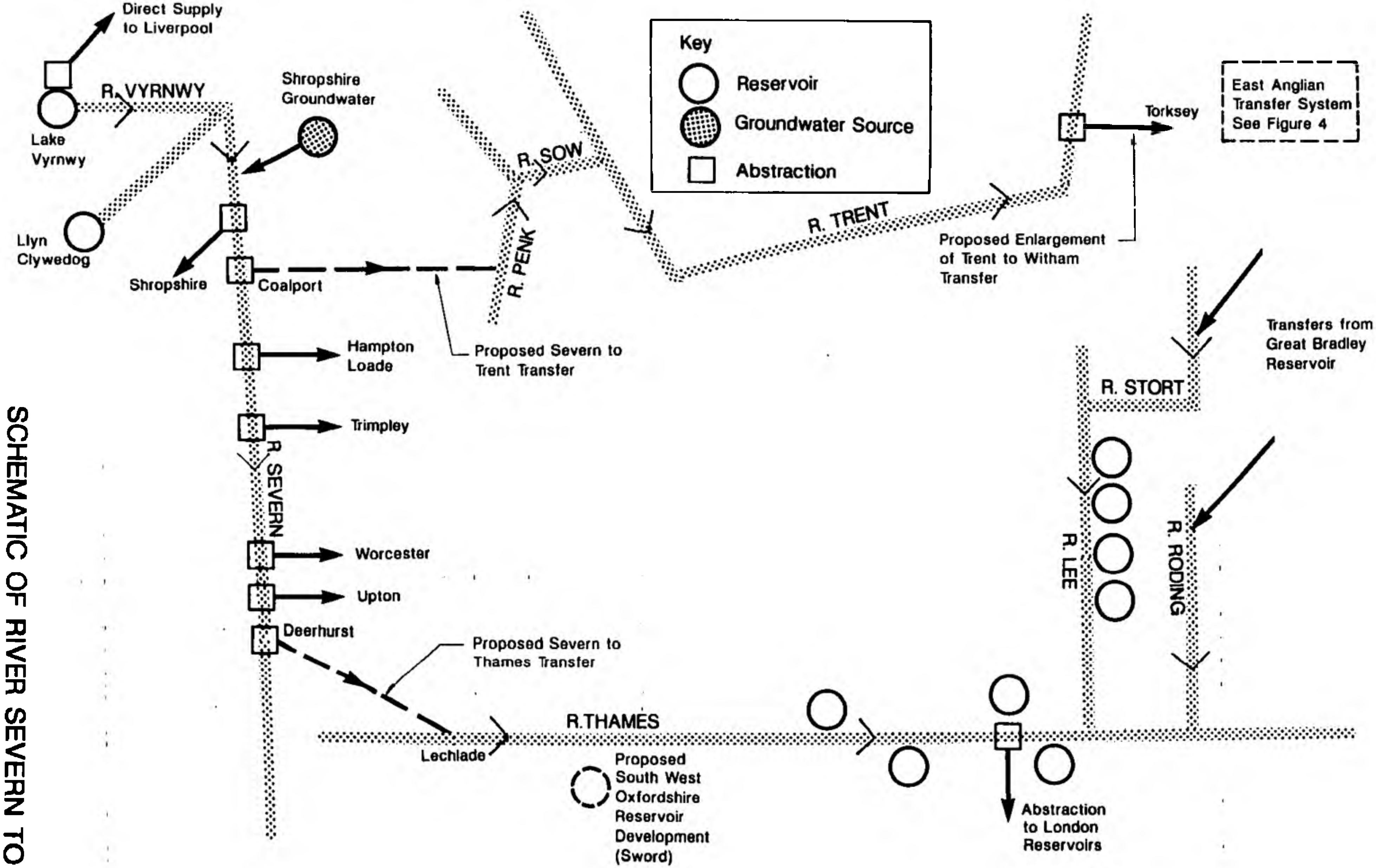
<u>National Rivers Authority Thames Region</u>

10 Inter-Regional Transfers Modelling Report, July 1993.

<u>National Rivers Authority Anglian Region</u>

11 Preliminary Modelling of Water Storage and Transfers in the Anglian Region, May 1993.

12 Stage 2 Modelling of Water Storage and Transfers in the Anglian Region, August 1993.



SCHEMATIC OF RIVER SEVERN TO RIVERS THAMES AND TRENT TRANSFERS

Figure 1

NRA THAMES REGION WATER RESOURCE MODEL
EXAMPLES OF SIMULATED LONDON RESERVOIR STORAGE PLOT

REGULATED SEVERN-THAMES TRANSFER (200 ML/D)

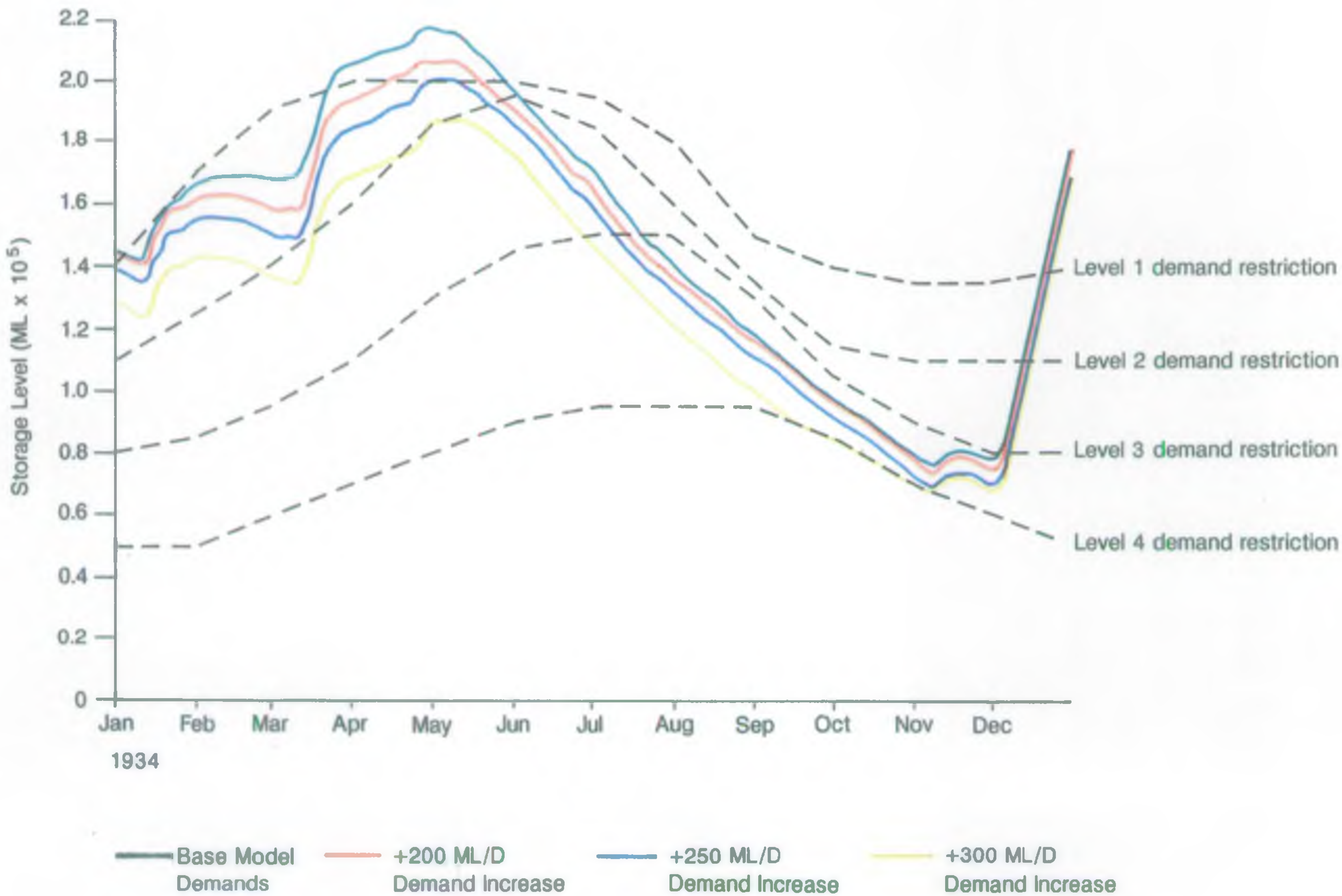
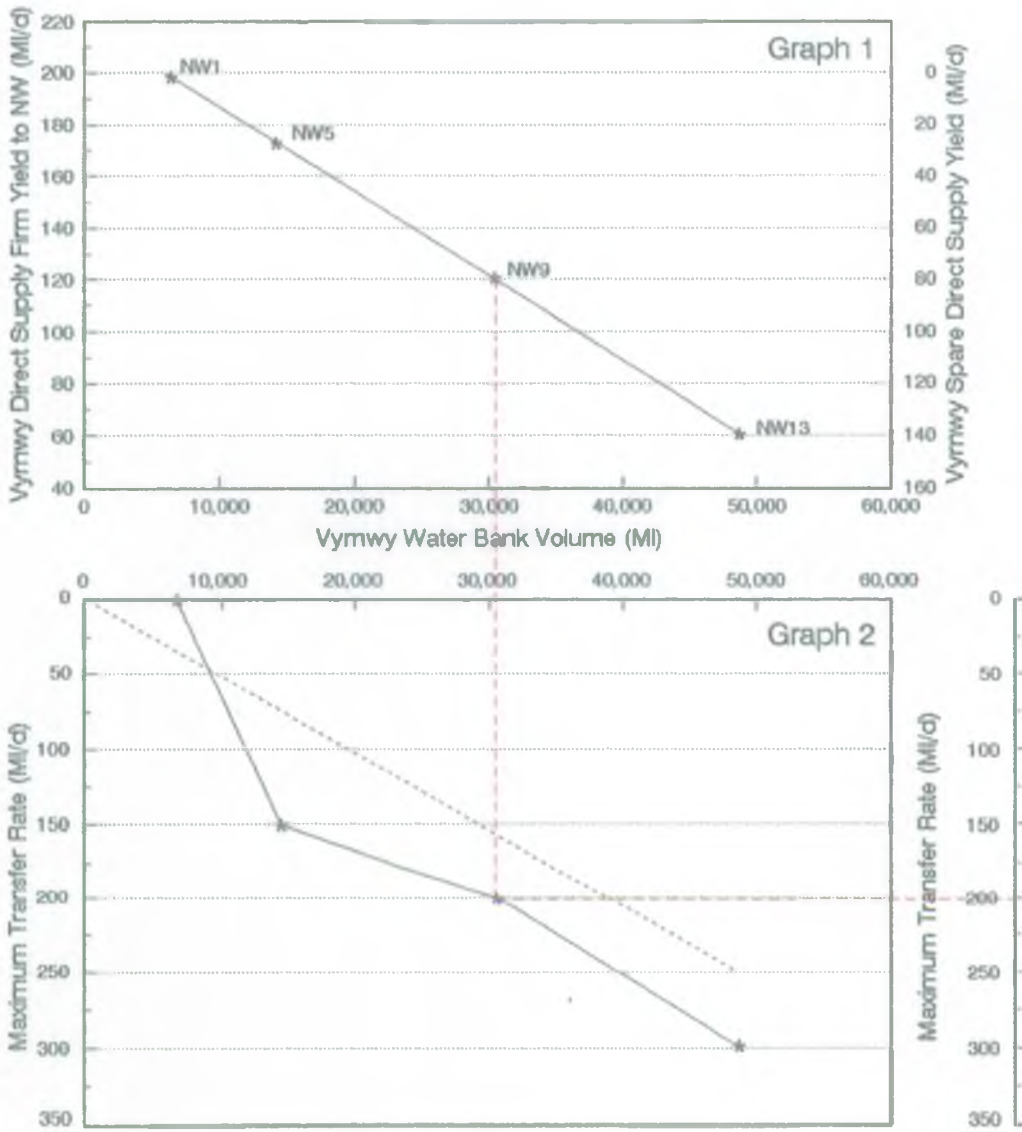


Figure 2



Based on data from G.Davies, J.Oldman & H.Smithers

The relationship between redeployed Vyrnwy yield and design demand met in the Thames Region

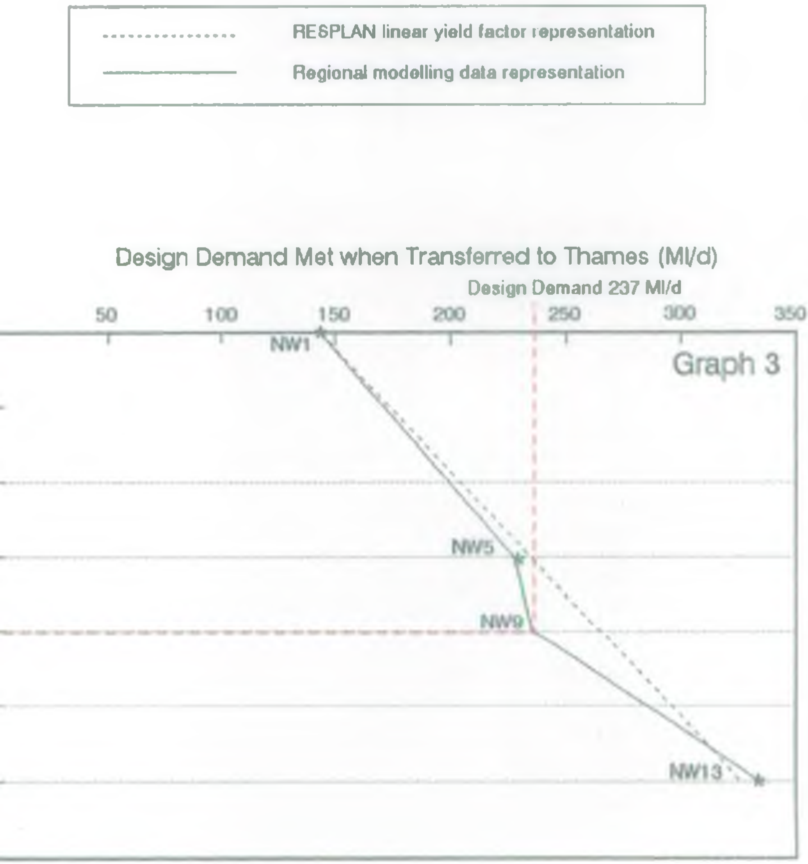
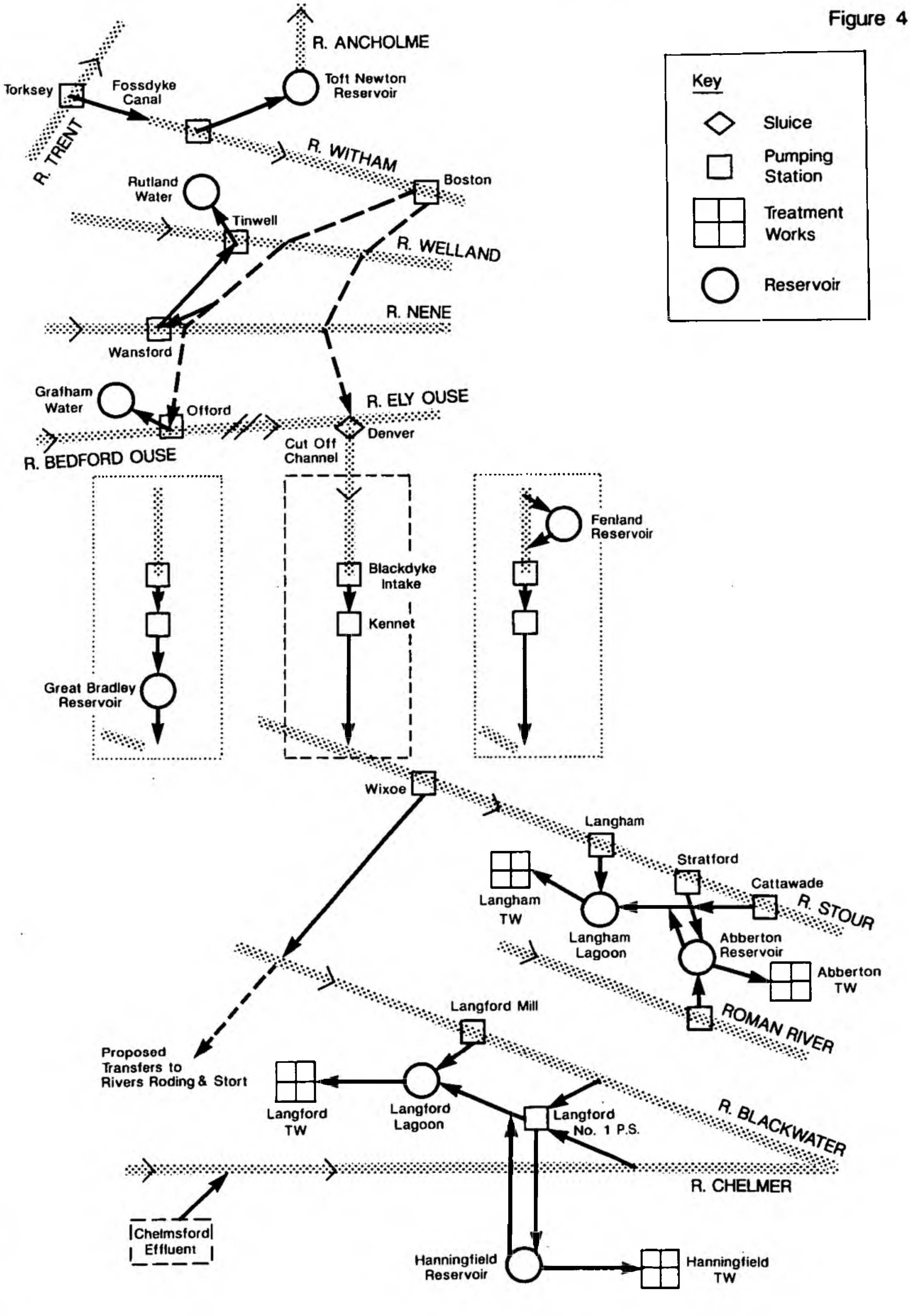


Figure 3

Figure 4



SCHEMATIC OF EAST ANGLIAN TRANSFER SYSTEM

Appendix A

INTERNAL NRA MODELLING REPORTS

Appendix A1

NRA NORTH WEST-VYRNWY REDEPLOYMENT-MAY 1993

NATIONAL WATER RESOURCES STRATEGY
Proforma for reporting of Modelling associated with inter-regional transfers.

REGION : Northwest

TRANSFER SCHEME : Vyrnwy redeployment

OPTIONS : minimum supply levels to Liverpool via Vyrnwy aqueduct of 60,120,173,200 Ml/d.
Alternative sources considered: R.Dee, Lake District, Ribble.

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1. BACKGROUND

1.1 DEPENDENCE ON VYRNWY/ CURRENT MODE OF OPERATION

1.1.1 NWW OPERATING SYSTEM. The principal strategic sources of supply for NWW are grouped for operational purposes into Northern and Southern Command Zones. These are illustrated in Fig 1. The <u>Northern Command Zone</u> (NCZ) comprises:

- Lake District sources (principally (Haweswater and Thirlmere)
- Lancashire Conjunctive Use Scheme(LCUS)-Stocks, Barnacre, Wyre-Lune, Fylde boreholes
- Longdendale reservoirs
- Numerous small sources, predominantly Pennine reservoirs

Water is supplied to Manchester and intermediate demand centres via the Thirlmere and Haweswater aqueducts (HA and TA).

The <u>Southern Command Zone</u> (SCZ) comprises:

- Lake Vyrnwy
- River Dee
- Rivington reservoirs
- Cheshire S/Lancs groundwater.

The Vyrnwy aqueduct transfers water for treatment at Oswestry and supply mainly to Liverpool. The recent NWW Asset Study identified a total cost of £104M over 20 years for works required to rehabilitate the aqueduct and increase the capacity to 250Ml/d. However this work is unlikely to all be carried out if any reduction in Vyrnwy direct supplies is agreed. Water abstracted from the Lower Dee is treated at Huntington and Sutton Hall. In addition water is transferred to the canal at Llangollen and treated at Hurleston near Nantwich.

Operating policies for both the NCZ and SCZ are derived using MOSPA, a generalised simulation/optimisation package developed by PWSC. This enables calculation of optimum policies which maintain supplies at a specified risk level while minimising costs by use of the cheapest available source and avoiding pumping. Marginal costs of increasing supply rates have also been determined.

1.1.2 SUPPLY SECURITY. Vyrnwy supplies (27% of SCZ total) are seen as extremely valuable to NWW for two main reasons. Firstly the water is high quality and easy to treat, and is supplied largely by gravity. Secondly, the source is highly reliable. This is not the case for the Dee (52% of SCZ total), which is a lowland river source with no bankside storage. Operational experience has proved the Dee to be very vulnerable to pollution from both industrial and agricultural sources in the catchment. Any further change in the proportion of Lower Dee water used would significantly increase the operating problems during such incidents.

1.2 ALTERNATIVE SOURCES

Major new potential surface resources were most recently examined between 1976 and 1979 when NWWA conducted a strategic review.
It was concluded that a Morecambe Bay scheme would have far-reaching environmental consequences, in addition to costs of the same order as the most expensive inland schemes.
Inland reservoir sites considered were Hellifield on the Ribble, Borrow Beck on the Lune, and enlargement of Haweswater. Hellifield was dismissed on the grounds that the detrimental environmental impact would outweigh the benefits. Enlargement of Haweswater would be extremely difficult politically due to its location in the Lake District National Park. Borrow Beck would prove cheaper but have more serious environmental consequences.
For the current study it was assumed that such schemes would not gain acceptability in the NW, particularly if they were to supply other parts of the UK. These have not been considered further.
The Triassic sandstone aquifer of Cheshire and S.Lancashire provides on average 163 Ml/d for potable supplies. Licences total 464Ml/d, with additional abstractions by Chester Water Co (CWC) and Wrexham & East Denbighshire Water Co.(WEDWC), and a large number of industrial abstractions. The aquifer has a history of being severely overdrawn, with increasing saline intrusion, but in recent years the balance has greatly improved under the management of North West Water Authority (NWWA) and now NWW. NRA NW regard the current level of abstraction as acceptable overall, with scope for local improvements. The maximum increase available is likely to be around 20 Ml/d.
In 1978/9 the potential for artificial recharge in the North-West was investigated. The Widnes water table depression appeared to be the most suitable. Recharge would utilise treated Vyrnwy winter flows at around 120 Ml/d, allowing a summer abstraction of around 70Ml/d. However there is no experience of artificial recharge of the Triassic sandstone so yields from such a scheme are uncertain.
The possible use of the disused Lancashire coal mines was rejected, because of doubts as to the volume available, implications for current abstractions, effects of subsidence, and poor quality. In addition a suggested use for sludge disposal is not compatible with use for public water supply.
In 1970 the Mersey and Weaver River Authority (MWRA) identified possible surface storage sites in their catchment. These have not been considered further on the grounds of environmental acceptability. NRA-NW would not wish to license further major abstractions from this area.
Enlargement of Vale House and Torside reservoirs in Longdendale was considered in 1977. Data analysis indicated that current storage volumes were close to the optimum for reservoir development. Extra storage would

therefore provide small gains in yield at great expense, in addition to environmental problems, particularly due to the location in the Peak District National Park. associated with the Peak District National Park. This scheme has not been reassessed.

1.2.1 DEE. The river Dee has been developed in stages for river regulation, beginning in the early 1950's with Llyn Tegid. This was followed by commissioning of Llyn Celyn in 1965, and Llyn Brenig in 1976. Brenig was designed to allow for subsequent enlargement and pumped refill. The yield of the Dee system was reviewed in 1980 using a 1% criterion, and it was established that 867Ml/d was available for abstraction upstream of Chester weir, with a residual flow of 363 Ml/d over the weir. These values may need amendment in the light of a current review of yields being carried out by NRA Welsh region. Taking into account existing licences, effluent returns, regulation losses, and British Waterways entitlement, estimated water available for licensing is around 38 Ml/d. However local abstractors are viewed as having priority access to this water, and anticipate taking up much of this surplus in the next 10-20 years. In addition supply shortfalls experienced during 1989 suggest that availability may have been overestimated. For this report it has been assumed that there is no unlicensed surplus. This view is supported by Welsh NRA.
The potential for increasing the maintained flow and hence licensed quantities was therefore considered.
The critical year for the Dee regulation system is 1937, when both Celyn and Brenig would have emptied. The potential for pumped refill has been examined previously, but this would aid refill rather than increasing yield.
It would be feasible to enlarge Brenig (which was designed with this in mind), and an increase in yield of between 60-75 Ml/d could then be obtained by pumping Alwen spills into Brenig.
At present Celyn is held down in winter for reservoir safety reasons. It is thought that raising of the freeboard by 1.5m would allow the removal of this restriction and an increase in yield of 25 Ml/d. Raising Brenig by 2m and Celyn by 1.5m would yield an estimated 60Ml/d.
Two options have been proposed for abstraction of increased quantities of water from the Upper and Lower Dee should additional storage be provided.
B&P have identified a route for a possible aqueduct from an intake next to the existing canal intake above Llangollen, discharging to the raw water intake to LLanforda reservoir adjacent to Oswestry treatment works. This would allow either blending of Dee and Vyrnwy water, or use of the existing reservoir bypass. Water in the Upper Dee is considered to have a low pollution risk, with a NWC classification of 1a.
Use of the canal itself for increased abstraction would lead to unacceptable velocities over several sections unless bypasses were provided.

However use of an Upper Dee abstraction point would not be supported by Welsh NRA, as it would significantly reduce regulation yields, and also dilutions in the Lower Dee.
An alternative would be extension of the existing intake and treatment works at Huntington on the Lower Dee. This has the disadvantage of increasing NWW's dependence on a river source subject to interruption by pollution incidents. The provision of bankside storage of a sufficient capacity to maintain supplies for 4 days would give increased security. Additional works would be required to increase the onward pipeline capacity to Norton, and attention paid to pumping heads to ensure security of existing aqueducts.

1.2.2 NCZ:LAKE DISTRICT. In order to determine the availability of water from the NCZ to make good any SCZ deficit, runs were carried out using the MOSPA model of the northern sources to establish the ultimate yield and the marginal cost of this water. The maximum demand which could be met from the NCZ over the historic record period (1961-90) was found to be 885 Ml/d, with a minimum storage of 31 000 Ml. The marginal cost of NCZ water at these demand levels is around £60/Ml.
An operating margin is required in order to allow for planned maintenance and remedial works. These amount to a significant programme, as much of the infrastructure has been in place for many years. This is in addition to the margin required to cope with significant seasonal and weather-related variations in demand.
The work carried out by PWSC has identified that no guaranteed supplies are available from the Lake District to replace Vyrnwy water.

1.2.3. NCZ:LCUS. The present peak output to supply from the LCUS is 80 Ml/d lower than the hydrological yield due to constraints in the bulk distribution network. It is understood that the existing Wyre/Lune transfer, the Wyre intake and Franklaw treatment works could provide 280Ml/d. Additional operating costs would be incurred, and investment would be necessary in the bulk distribution network to provide a treated water aqueduct from Franklaw via Rivington to Prescot.

1.2.4.RIBBLE/RIVINGTON. A scheme was proposed in 1970 to abstract from the Ribble at Salmesbury for additional pumped refill of Rivington, with the Ribble supported by an enlarged Stocks reservoir. Salmesbury is close to the maximum limit of saline incursion and would therefore have minimum environmental impact on the river.
This proposal has been reconsidered in the present report, without raising Stocks. In 1970 a significant problem was posed by the quality of the Calder, a principal upstream tributary. This has since improved significantly, but it was concluded that some bankside storage would still be required for monitoring purposes. In addition quality problems may arise within the Rivington reservoirs as a result of blending upland and

lowland river water, and residence times may need to be extended, thus reducing the yield.
The Ribble has important fisheries, which would be considered to be threatened by any abstraction for water supply. There is thus potential conflict even within NRA. Some preliminary modelling was carried out to assess the availability of water with a range of hands-off flows.It was concluded that pumped refill was sufficient to change the Rivington system from two-season critical to single-season critical, and that the limitation on yield was the available storage.

1.3 SUMMARY OF VIABLE OPTIONS

In summary, the availability of additional Dee water to NWW is highly uncertain, and there is little scope for redution of the operating margin in the Lake District. Development of a Ribble abstraction is certain to be protracted due to environmental considerations, and is not an ideal scheme. The first choice additional source would thus be the LCUS, after detailed reconsideration of available supplies.

2.MODELLING

2.1 MODEL

Modelling was carried out for NRA-NW and NWW jointly by PWSC Ltd, using enhancements of a previously-developed MOSPA simulation and optimisation of the SCZ. Initial runs were however carried out on Vyrnwy alone, to establish optimised control curves for direct supply at reduced rates.

2.2 DATA

Historic derived inflows for Vyrnwy 1932-87 were used for the direct supply modelling. This covers the critical drought period for the system. In the SCZ model data was also used for Rivington for the same period. It has been assumed that regulated flows in the Dee would always be sufficient to allow abstractions up to the maximum capacity of the pumping station and associated treatment works.

2.3 MODEL RUNS

Both Vyrnwy and the SCZ models were run for direct supply demands of 198 (maximum yield over record period), 173 (gravity supply limit), 120 and 60 Ml/d to provide a range of operating scenarios. NWW considered that it would be impractical to find alternative sources for a number of small supplies on the aqueduct route. The minimum throughput at Oswestry treatment works was considered to be 60 Ml/d; these factors determined the lower direct supply limit. Runs of the SCZ model also included an increased capacity at Huntington treatment works. However this option has been discounted for several reasons mentioned elsewhere in the report, so it is not considered further here. Similarly, a further option in the SCZ model runs was to increase the maximum aqueduct capacity (implying that the proposed improvement programme goes ahead). The runs presented here have been selected as representing the most likely scenarios.

2.4 ASSUMPTIONS

Vyrnwy has been modelled as a direct supply reservoir with a fixed daily compensation rate of 45.46 Ml/d. Under existing arrangements additional regulation releases can be taken from a water bank, an annual volume of water which Severn Trent may draw upon at its discretion for augmenting the flows in the Severn. The present volume of this water bank is 5818 Ml. For the current runs it has been assumed that releases are made at a constant rate for the period March-October. In order to model the impact of increased regulation this release rate has been increased.

2.5 DEMAND GROWTH TO 2021

to follow on Thursday......

3. YIELD

3.1 VYRNWY DIRECT SUPPLY YIELD
Vyrnwy yield was re-estimated in 1992 to include data up to Dec 1989, and has been reduced to ensure refill within 5 years in line with long-standing policy in the NW. Net 2% yield (5-year refill limit) is thus 212.5 Ml/d. The 198 Ml/d value is minimum historic, obtained by PWSC during this study by simulation over the period 1932-1987. By comparison with the other estimates its return period is likely to be well over 100 years.

3.2 VYRNWY AVERAGE OUTPUT

SUMMARY OF SCZ MODEL OUTPUT

PWSC				
RUN NO	1	5	9	13
MIN VYRNWY DIRECT SUPPLY ML/D	198	173	120	60
VYRNWY REGULATION RELEASE ML/D	24	56	124	200
MAX VYRNWY TAKE ML/D	200	200	200	200
MAX HUNTINGTON TAKE ML/D	382	382	382	382

AVERAGE ANNUAL TAKE FROM EACH SOURCE ML/D

RIVINGTON	64	64	64	64
VYRNWY FIRM+NONFIRM	199	184	154	120
HUNTINGTON	377	379	379	378
BOREHOLES	90	103	127	133
NCZ(DEFICIT)	0	0	6	35

NB These are average outputs only. The distribution of deficits was also investigated for 1934, the second summer in the critical sequence.

1934 TAKE ML/D

NCZ(DEFICIT)	MEAN	0	0	18	47
	MAX	0	0	77	107

3.3 AVERAGE SUPPLIES FROM ALTERNATIVE SOURCES
The deficits in 3.2 above have been taken into account in sizing capital works for replacement sources.

4. COSTS

Outline costs were derived by Binnie & Partners in consultation with NWW for viable options. These are no better than +/- 30% and reflect the preliminary nature of the assessment. There are some reductions in operating costs at lower Vyrnwy direct supply rates.

The proposals as presented here would have minimal impact on flows in the Dee. These are dominated by the maintained flow condition at Eccleston Ferry. Impact of other options will be considered by Welsh NRA in redefining the Dee operating rules, but increased abstraction from the upper catchment would reduce dilutions as well as restricting yield.

5.3 EFFECT ON LAKE DISTRICT

As no spare water is available from the Lake District effects of these schemes would be confined to slight changes resulting from a reoptimisation of the operating policy following the LCUS changes.

5.4 EFFECT ON RIBBLE

Determination of a residual flow for the Ribble abstraction would cause considerable controversy. Previously-defined levels are certain to be revised upwards. Strong concerns were expressed by NRA Fisheries over damage to the sport. In addition quality constraints dictate the need for bankside storage at the abstraction point, or careful management of residence time in the Rivington reservoirs (thus reducing the yield).

6. DATA NEEDED FROM OTHER REGIONS

6.1 SEVERN-TRENT

Severn-Trent NRA have recently included NW's Vyrnwy optimised control curve values in their resource model of the Severn NRAM. This has enabled them to supply time series demands on the water bank for the simulation period. These are currently (May 93) being used in the PWSC model to refine the previous assumptions about the operation of the water bank, and hence produce more realistic deficit sequences.

6.2 WELSH

As the model assumes that water up to the licence is always available, no time series is required for the Dee. Confirmation of the sustainable maintained flow is awaited.

7. DATA TO BE SUPPLIED TO OTHER REGIONS

7.1 WELSH

For the reasons given above in 6.2, Welsh NRA do not require time series Dee demands.

7.2 SEVERN-TRENT

If Vyrnwy reoptimised control curves are significantly altered following improved simulation of the waterbank, these values will be returned to NRA-ST. However it is hoped that iteration will not be necessary.

The relevant cost elements are given below:

Element no (B&P)	Description	Capital £m	Running £k/annum
Works at Oswestry			
13	Continue to treat 60Ml/d, max 200Ml/d.	2.0	-800
14	Continue to treat 120Ml/d max 200 Ml/d.	-	-400
15	Continue to treat 180Ml/d, max 200 Ml/d.	-	-300
Changes to licence			
24	Reduce Vyrnwy licence to 200 Ml/d (from 265)	-	-113
Treated water supply from Franklaw, LCUS			
a)20 Ml/d average, 50 Ml/d peak			
43	Supply of treated water at Franklaw S aqueduct pumping station.	-	621
44	Pumping to Hoghton	-	171
45	Treated water aqueduct Franklaw-Hoghton(700mm dia)	8.3	-
46	Extension of Hoghton PS	0.6	50
47	Treated water aqueduct Hoghton-Rivington(700mm)	6.2	-
b)80 Ml/d average, 100Ml/d peak			
53	Supply of treated water at Franklaw S aqueduct PS	-	2482
54	Pumping to Hoghton	-	780
55	Treated water aqueduct, Franklaw-Hoghton(900mm dia)	11.2	-
56	Extension of Hoghton PS	1.0	257
57	Treated water aqueduct, Hoghton-Rivington(900mm)	8.4	-
Aqueduct to carry LCUS output from Rivington- Prescot			
58	Aqueduct (50Ml/d)		
	a)gravity 900mm	17.2	-
	b)700mm with booster	13.5	226
59	Aqueduct (100 Ml/d)		
	a)gravity 1200mm	30.3	-
	b)1000mm with booster	21.6	279

Cost schedules for PWSC options 1,5,9 and 13 are attatched.

5. ENVIRONMENT

5.1 EFFECT ON VYRNWY

Impacts on Vyrnwy itself have not been assessed. However regulation use would convert the reservoir into a single season source, reducing drawdown periods.

5.2 EFFECT ON DEE

Option 180/1 PW & option 5

Description

Up to 190 Ml/d abstracted from Lake Vyrnwy, year round, to give 180 Ml/d firm output from Oswestry WTW (200 Ml/d maximum). SCZ groundwater as available/ reduced aqueduct losses to make up requirements.

Costs

Element number	Capital £million	Running £k/annum
15	-	-300
24	-	-113
62	-	723
Allow for reduced SCZ groundwater abstraction costs due to reduction in aqueduct losses following refurbishment		-100
Total	-	210

Note: Raw and treated water sections of the Vyrnwy used for max flow of 200 Ml/d

Option 120/3 PWSC Option 9

Description

Up to 130 Ml/d abstracted from Lake Vyrnwy, year round, to give 120 Ml/d firm output from Oswestry WTW (200 Ml/d maximum). 20 Ml/d average, 50 Ml/d peak supplied by new aqueduct from Franklaw WTW from the LCUS. SCZ groundwater as available/ reduced aqueduct losses assumed to make up requirements.

Costs

Element number		Capital £million	Running £k/annum
14		-	-400
24		-	-113
43		-	621
44		-	171
45		8.3	
46		0.6	50
47		6.2	
58	either	17.2 (900mm gravity main)	
	or	13.5 (700mm main with booster)	226
63		-	962
Allow for reduced SCZ groundwater abstraction costs due to reduction in aqueduct losses following refurbishment			-100
Total	either	32.3	1191
	or	28.6	1417

Note: Raw and treated water sections of the Vyrnwy used for max flow of 200 Ml/d.

Option 60/3 PWSC Option 13

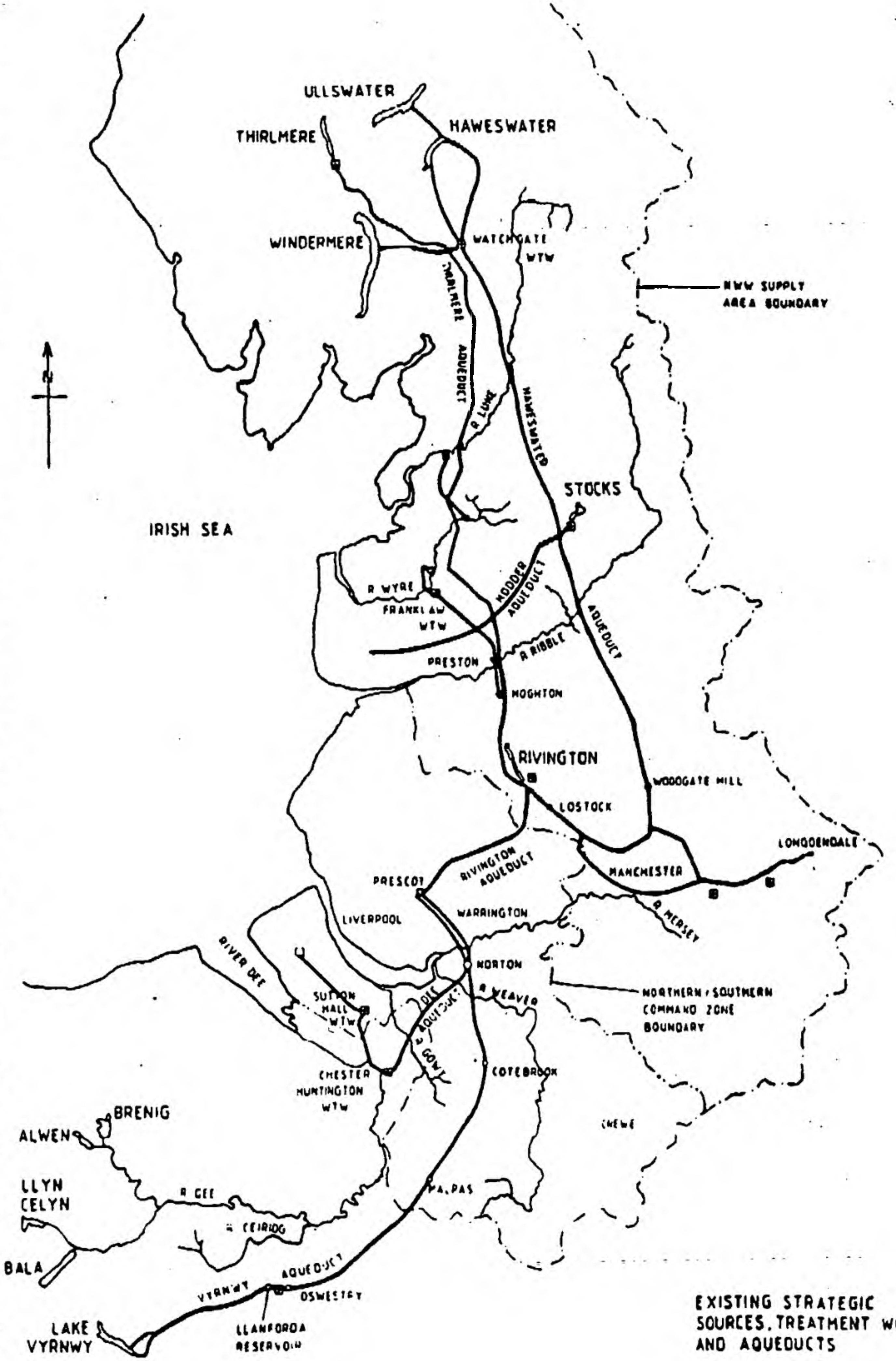
Description

Up to 70 Ml/d abstracted from Lake Vyrnwy, year round, to give 60 Ml/d firm output from Oswestry WTW (200 Ml/d maximum). 80 Ml/d average, 100 Ml/d peak supplied by new aqueduct from Franklaw WTW from the LCUS. SCZ groundwater as available/ reduced aqueduct losses assumed to make up requirements.

Costs

Element number		Capital £million	Running £k/annum
13		2.0	-800
24		-	-113
53		-	2482
54		-	780
55		11.2	
56		1.0	257
57		8.4	
60	either	30.3 (1200mm gravity main)	
	or	21.6 (1000mm main with booster)	226
63		-	962
Allow for reduced SCZ groundwater abstraction costs due to reduction in aqueduct losses following refurbishment			-100
Total	either	52.9	3468
	or	44.2	3694

Note: Raw and treated water sections of the Vyrnwy used for max flow of 200 Ml/d.



EXISTING STRATEGIC SOURCES, TREATMENT WORKS AND AQUEDUCTS

FIGURE 1

Appendix A2

NRA NORTH WEST–VYRNWY REDEPLOYMENT–NOVEMBER 1993

WATER RESOURCES DEVELOPMENT STRATEGY

NOTES ON NORTH WEST REGION MARGINAL DEMANDS AND VYRNWY REDEPLOYMENT

1. BACKGROUND

1.1 Following a liaison meeting between Halcrow, NRA Head Office, NRA Severn Trent and NRA North West in Solihull on 18 October 1993 a number of issues were raised relating to the redistribution of Vyrnwy and its representation in RESPLAN and marginal demands calculation. Work subsequent to this meeting has addressed various questions and the following note sets out what is now considered to be the correct position for the North West *vis a vis* marginal demands and Vyrnwy redeployment.

2. YIELDS AND DEMANDS

2.1 Yields

Annex 1 sets out the existing available reliable yields for North West Water. The table also indicates into which of 2 demand centres the yields can be attributed; Southern Control Zone (SCZ) and the remainder of the region (RR). Consideration of the North West region as two discrete demand centres assists the analysis of the resource implications of Vyrnwy redeployment since it corresponds with MOSPA model results. In summary the current yields available to the two demand centres and North West Water as a whole are as follows:-

2.1.1 *For the SCZ*

River Dee at Huntington	390 Ml/d
Vyrnwy	212.5 Ml/d
Rivington	43 Ml/d
Boreholes *	171 Ml/d
Total	816.5 M/ld

Reported yield of 198 Ml/d is the minimum historic yield (1934). 212.5 Ml/d is the 2% yield currently available and is the appropriate figure for marginal demand calculations. In an average year SCZ operation benefits substantially from use of casual Vyrnwy water obtained when storage is above the control curve. In the critical drought this water would not be available, and 1 Ml/d diverted to the Severn is equivalent to a 1 Ml/d reduciton in SCZ resource.

* The actual available yield of this suite of boreholes is 239 Ml/d however, 171 Ml/d is the maximum yield available before management problems result and is the figure assumed for MOSPA.

2.1.2 *For the Remainder of the Region (RR)*

River Dee at Hurleston & Heron Bridge **	245 Ml/d
Other sources	<u>1758 Ml/d</u>
Total	2003 Ml/d

** Including 80 Ml/d from the Dee at Chester Weir for industrial supply of which 29 Ml/d is bulk supply to Dwr Cymru for industrial use on Deeside.

<u>Total North West Water yield is therefore:</u>

816.5 Ml/d for SCZ
+ <u>2003 Ml/d</u> for RR
2819.5

(Without constraining the SCZ boreholes to 171 Ml/d the yield would theoretically be increased to 2887.5 Ml/d).

2.2 Demands

The MOSPA model for the SCZ assumes an existing demand at 1992 of 730 Ml/d or 29.26% of the total North West Water Distribution Input for 1991 of 2495 Ml/d. Both these figures exclude the direct supplies to industry on Deeside of 80 Ml/d from Chester Weir. The remaining 70.74% of North West Water Distribution Input is in the RR demand centre. For the purpose of marginal demands the 80 Ml/d industrial supply is included as a demand in the RR demand centre. These proportions of demand are held constant throughout the planning period.

2.3 Local Options

Local options are also identified in Annex 1 as the difference between current available yield and future maximum yield. In most cases these increases to existing yields relate to the extension of operational capacity in order to achieve the hydrological yield. Annex 2 summarises these developments and indicates to which demand centre they are allocated. Rivington pumped storage is the only all new scheme shown in Annex 2. It should be noted that NRA North West region are currently investigating whether the LCUS figure is valid in the light of environmental problems at the current level of abstraction.

2.4 Environmental Cutbacks

50 Ml/d is deducted from the RR demand centre, to account for environmental cutbacks, 20 of which results from the Lowther scheme.

2.5 Marginal Demands and Loss of Yield from Vyrnwy Redeployment

2.5.1 Basic Marginal Demands

Table 1 shows the marginal demands for the SCZ and RR demand centres based on a scenario where all local options in the RR demand centre are developed (including LCUS at 80 Ml/d) and none of the options in the SCZ are developed. No redeployment of Vyrnwy is allowed for in Table 1 therefore this situation indicates the basic marginal demands for the North West.

The RR demand centre has a deficit at 2021 of 102 Ml/d under the High scenario. This cannot be met from any additional local sources. If the High forecast were to materialise this deficit would need to be addressed by leakage control and demand management rather than by strategic options. The SCZ demand centre has a basic marginal demand at 2021 of 44 Ml/d under the High scenario.

2.5.2 Redeployed Vyrnwy

The development of the larger of the two local options (ie: Huntington at 74 Ml/d) gives a surplus in SCZ of 29 Ml/d at 2021 under the High scenario. This surplus then becomes available for redistribution from Vyrnwy if it is assumed that this spare yield could not be redirected to offset the RR deficit. Table 2 shows this scenario.

The further development of Ribble pumped storage to Rivington will yield an additional 40 Ml/d to the SCZ, thereby increasing that available for redistribution from Vyrnwy by 40 Ml/d. Table 3 shows this situation with the total reduction in direct supply from Vyrnwy at 69 Ml/d. This 69 Ml/d would be available as an increase to regulated yield on the Severn. Under a Medium scenario 68 Ml/d of Vyrnwy are available for redistribution without the development of either Huntington or Ribble. This rises to 142 Ml/d with the development of Huntington and a maximum of 150 (maintaining a direct supply of 60 Ml/d) can be achieved with the additional development of Ribble.

2.5.3 RESPLAN Inputs

The drought yield available from redeployed component of Vyrnwy will need to be estimated for RESPLAN. The figure to be used in the High demand scenario is the river regulation yield equivalent to a direct supply from Vyrnwy of 71 Ml/d. The RR demand centre can be discounted for the purpose of RESPLAN modelling.

Table 1

MARGINAL DEMANDS CALCULATION

REGION: North West

DEMAND CENTRE	YIELDS OF EXISTING AND PLANNED SOURCES (Ml/d)							TOTAL DEMANDS (Ml/d)							MARGINAL DEMANDS (Ml/d)						
	1991	1996	2001	2006	2011	2016	2021	1991	1996	2001	2006	2011	2016	2021	1991	1996	2001	2006	2011	2016	2021
NWW (RR)																					
High	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1818.8	1875.4	1933.4	1990.0	2049.4	2111.0	0	0	0	0	0	40	102
Low	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1668.1	1629.2	1653.3	1674.5	1700.7	1727.6	0	0	0	0	0	0	0
Med	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1781.3	1716.3	1730.4	1764.4	1803.3	1843.6	0	0	0	0	0	0	0
NWW (SCZ)																					
High	796.1	796.1	796.1	796.1	796.1	796.1	796.1	730.0	719.2	742.6	766.6	790.0	814.6	840.0	0	0	0	0	0	18	44
Low	796.1	796.1	796.1	796.1	796.1	796.1	796.1	730.0	656.9	640.8	650.7	659.5	670.3	681.4	0	0	0	0	0	0	0
Med	796.1	796.1	796.1	796.1	796.1	796.1	796.1	730.0	703.7	676.7	682.6	696.6	712.7	729.4	0	0	0	0	0	0	0

SUPPORTING INFORMATION

Local Schemes included in existing sources

Scheme		Ml/d
Ribble	SCZ	0
Huntington	SCZ	0
Lake District	RR	10
LCUS	RR	80
Improvement to existing schemes	RR	-17.5
TOTAL		107.5

Proportion of Distribution Input into Command Zones

SCZ	730	0.293
RR	1765	0.707
	2495	

Environmental cutbacks (Ml/d)

Lowther & LCUS 50

Other Cutbacks (Ml/d)

Volume of Vyrnwy redistributed 0

Bulk supply and other commitments (Ml/d)

Industrial from Dee yield 80

	Existing yields (Ml/d)	Total planned yield (Ml/d)	Yield less contingency Factor: 0.975
RR	2003	2060.5	2009
SCZ	816.5	816.5	796.09

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Table 2

MARGINAL DEMANDS CALCULATION

REGION: **North West**

DEMAND CENTRE	YIELDS OF EXISTING AND PLANNED SOURCES (Ml/d)							TOTAL DEMANDS (Ml/d)							MARGINAL DEMANDS (Ml/d)						
	1991	1996	2001	2006	2011	2016	2021	1991	1996	2001	2006	2011	2016	2021	1991	1996	2001	2006	2011	2016	2021
NWW (RR)																					
High	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1818.8	1875.4	1933.4	1990.0	2049.4	2111.0	0	0	0	0	0	40	102
Low	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1668.1	1629.2	1653.3	1674.5	1700.7	1727.6	0	0	0	0	0	0	0
Med	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1781.3	1716.3	1730.4	1764.4	1803.3	1843.6	0	0	0	0	0	0	0
NWW (SCZ)																					
High	840.0	840.0	840.0	840.0	840.0	840.0	840.0	730.0	719.2	742.6	766.6	790.0	814.6	840.0	0	0	0	0	0	0	0
Low	840.0	840.0	840.0	840.0	840.0	840.0	840.0	730.0	656.9	640.8	650.7	659.5	670.3	681.4	0	0	0	0	0	0	0
Med	840.0	840.0	840.0	840.0	840.0	840.0	840.0	730.0	703.7	676.7	682.6	696.6	712.7	729.4	0	0	0	0	0	0	0

SUPPORTING INFORMATION

Local Schemes included in existing sources

Scheme		Ml/d
Ribble	SCZ	0
Huntington	SCZ	74
Lake District	RR	10
LCUS	RR	80
Improvement to existing schemes	RR	-17.5
TOTAL		181.5

Proportion of Distribution Input into Command Zones

SCZ	730	0.293
RR	1765	0.707
	2495	

Environmental cutbacks (Ml/d)

Lowther & LCUS 50

Other Cutbacks (Ml/d)

Volume of Vyrnwy redistributed 29

Bulk supply and other commitments (Ml/d)

Industrial from Dee yield 80

	Existing yields (Ml/d)	Total planned yield (Ml/d)	Yield less contingency Factor: 0.975
RR	2003	2060.5	2009
SCZ	816.5	861.5	839.96

Date: 08/11/93 Time: 12 08 Originator: M H S

Table 3 MARGINAL DEMANDS CALCULATION

REGION: **North West**

DEMAND CENTRE	YIELDS OF EXISTING AND PLANNED SOURCES (Ml/d)							TOTAL DEMANDS (Ml/d)							MARGINAL DEMANDS (Ml/d)						
	1991	1996	2001	2006	2011	2016	2021	1991	1996	2001	2006	2011	2016	2021	1991	1996	2001	2006	2011	2016	2021
NWW (RR)																					
High	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1818.8	1875.4	1933.4	1990.0	2049.4	2111.0	0	0	0	0	0	40	102
Low	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1668.1	1629.2	1653.3	1674.5	1700.7	1727.6	0	0	0	0	0	0	0
Med	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1781.3	1716.3	1730.4	1764.4	1803.3	1843.6	0	0	0	0	0	0	0
NWW (SCZ)																					
High	840.0	840.0	840.0	840.0	840.0	840.0	840.0	730.0	719.2	742.6	766.6	790.0	814.6	840.0	0	0	0	0	0	0	0
Low	840.0	840.0	840.0	840.0	840.0	840.0	840.0	730.0	656.9	640.8	650.7	659.5	670.3	681.4	0	0	0	0	0	0	0
Med	840.0	840.0	840.0	840.0	840.0	840.0	840.0	730.0	703.7	676.7	682.6	696.6	712.7	729.4	0	0	0	0	0	0	0

SUPPORTING INFORMATION

Local Schemes included in existing sources

Scheme		Ml/d
Ribble	SCZ	40
Huntington	SCZ	74
Lake District	RR	10
LCUS	RR	80
Improvement to existing schemes	RR	17.5
TOTAL		221.5

Proportion of Distribution Input into Command Zones

SCZ	730	0.293
RR	1765	0.707
	2495	

Environmental cutbacks (Ml/d)

Lowther & LCUS 50

Other Cutbacks (Ml/d)

Volume of Vyrnwy redistributed 69

Bulk supply and other commitments (Ml/d)

Industrial from Dee yield 80

	Existing yields (Ml/d)	Total planned yield (Ml/d)	Yield less contingency Factor: 0.975
RR	2003	2060.5	2009
SCZ	816.5	861.5	839.96

3. COSTS

An important consideration is that of the cost of Vyrnwy redeployment to North West Water (or NRA) if Vyrnwy direct supply is reduced by 69 Ml/d under the High scenario. As noted above, in order to achieve this level of redeployment, both Huntington and Ribble would require development. Moreover, part of the Huntington yield would need to be developed anyway to meet the increased basic marginal demand of the SCZ under the High demand scenario.

3.1 Capital Cost

The accounting for the capital costs to Vyrnwy redeployment is as follows:-

		£M
a)	Cost of Huntington extension at 74 Ml/d (to bring the abstraction up to licence limit)	x
	Cost of Ribble pumped storage at 40 Ml/d (new scheme)	y

b) Yield available for Vyrnwy redeployment with Huntington developed = 29 Ml/d (See Section 2.5.2 - assumes that Huntington would be developed before Ribble).

c) Yield available for Vyrnwy redeployment with Huntington and Ribble developed = 69 Ml/d (See Section 2.5.2)

d) Therefore under the High demand scenario the additional costs to be met for a Vyrnwy redeployment of 69 Ml/d would be

$$(29/74 \times x) + y$$

e) However, under a medium demand scenario the costs change.

For example for a 150 Ml/d reduction in direct supply from Vyrnwy, the maximum redeployment possible whilst maintaining a direct supply of 60 Ml/d, (see Section 2.5.2 and Table 4) the additional costs to be met would be:

$$(8/40 \times y) + x$$

This assumes that the Huntington licence would be fully used before developing Ribble.

The correct representation of the Vyrnwy redeployment cost is clearly dependent on the regional demand for water and the demand for river regulation water.

Table 4 MARGINAL DEMANDS CALCULATION

REGION: **North West**

DEMAND CENTRE	YIELDS OF EXISTING AND PLANNED SOURCES (Ml/d)							TOTAL DEMANDS (Ml/d)							MARGINAL DEMANDS (Ml/d)						
	1991	1996	2001	2006	2011	2016	2021	1991	1996	2001	2006	2011	2016	2021	1991	1996	2001	2006	2011	2016	2021
NWW (RR)																					
High	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1818.8	1875.4	1933.4	1990.0	2049.4	2111.0	0	0	0	0	0	40	102
Low	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1668.1	1629.2	1653.3	1674.5	1700.7	1727.6	0	0	0	0	0	0	0
Med	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	2009.0	1845.0	1781.3	1716.3	1730.4	1764.4	1803.3	1843.6	0	0	0	0	0	0	0
NWW (SCZ)																					
High	761.0	761.0	761.0	761.0	761.0	761.0	761.0	730.0	719.2	742.6	766.6	790.0	814.6	840.0	0	0	0	6	29	54	79
Low	761.0	761.0	761.0	761.0	761.0	761.0	761.0	730.0	656.9	640.8	650.7	659.5	670.3	681.4	0	0	0	0	0	0	0
Med	761.0	761.0	761.0	761.0	761.0	761.0	761.0	730.0	703.7	676.7	682.6	696.6	712.7	729.4	0	0	0	0	0	0	0

SUPPORTING INFORMATION

Local Schemes included in existing sources

Scheme		Ml/d
Ribble	SCZ	40
Huntington	SCZ	74
Lake District	RR	10
LCUS	RR	80
Improvement to existing schemes	RR	17.5
TOTAL		221.5

Proportion of Distribution Input into Command Zones

SCZ	730	0.293
RR	1765	0.707
	2495	

Environmental cutbacks (Ml/d)

Lowther & LCUS 50

Other Cutbacks (Ml/d)

Volume of Vyrnwy redistributed 150

Bulk supply and other commitments (Ml/d)

Industrial from Dee yield 80

	Existing yields (Ml/d)	Total planned yield (Ml/d)	Yield less contingency Factor: 0.975
RR	2003	2060.5	2009
SCZ	816.5	780.5	760.99

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Clearly reliable costings for the Huntington extension and Ribble pumped storage are also required. Costs are available from the Binnie and Partners Vyrnwy Resource Study Report (February 1993). However, it would be advisable to audit these costings before use in RESPLAN. (Annex 3).

3.2 **Revenue Costs of Vyrnwy Redeployment**

3.2.1 Operating Options for High & Medium Demand Scenarios

	High	Medium
Regulation Direct Supply Total	69 <u>143.5</u> 212.5 Ml/d	150 <u>62.5</u> 212.5 Ml/d

3.2.2 Demands in SCZ

	High	Medium
Present 2021 Additional Required	730 <u>840</u> 110 Ml/d	730 <u>729</u> -1 Ml/d

3.2.3 SCZ Operating Costs and Deficits to Supply 730 Ml/d

	High	Medium
New Operating Costs Normal SCZ Additional Operating Costs	4.721 * 4.543 £0.178 mpa	4.666 ** 4.543 £0.123 mpa
SCZ Supply Deficit ***	6 Ml/d	35 Ml/d

* Approximated by run 9 (Annex 4)
** Approximated by run 13 (Annex 4)
*** Approximated from runs 5 & 13 (Annex 4)

Operating costs are <u>average</u> for 32 to 87 simulation period and relate to average demands.

3.2.4 Additional Revenue Costs to meet 2021 Demands (in excess of present demand of 730 Ml/d)

	High	Medium
Demand from 3.2.2 above Demand from 3.2.3 above Total Additional demands	110 6 116 Ml/d	- 1 35 34
Sources to meet total additional demand (to be costed by Halcrow using Annex 3 data based on average running costs).	Huntington Ribble	Huntington Ribble

3.2.5 Total Revenue Costs of Vyrnwy Redeployment

	High	Medium
Licensed SCZ Costs Additional Source Costs	£0.178 mpa (see 3.2.4 above)	£0.123 mpa (see 3.2.4 above)
Total	N/A	N/A

4. CONCLUSIONS

4.1 The above calculations are considered to provide a satisfactory representation of the effect of Vyrnwy redeployment on North West marginal demands. In order to represent the region in the National Strategy, appropriate cost data for the Huntington and Ribble schemes are required.

Mark Sitton
Richard Streeter
Hilary Smithers

9 November 1993

ANNEX 1 : EXISTING SOURCE YIELD ESTIMATES

Source Name /Location	Source Type	Demand Centre	Current Available Yield (agreed with NWW) Ml/d	Future Maximum Yield (Ml/d)
River Dee	SW	SCZ	390	464
River Dee	SW	RR	245	245
Windermere Group	SW	RR	690	700
LCUS	SW & GW	RR	180	260
Vyrnwy	SW	SCZ	212.5	212.5
Longendale Reservoirs	SW	RR	102	102
Ennerdale	SW	RR	53	53
Langthwaite Group	SW	RR	46.7	46.7
Entwhistle	SW	RR	44.5	44.5
Rivington	SW	SCZ	43	43
Dunsop Valley	SW & GW	RR	38.8	38.8
River Derwent	SW	RR	35	35
Buckton Castle	SW	RR	33	33
Goyt Valley	SW	RR	32.8	32.8
Geltsdale	SW	RR	29.7	29.7
Crummock Water	SW	RR	27.3	27.3
Ulpha	SW	RR	22	22
Greenbooth	SW	RR	18.4	18.4
Poaka Beck	SW	RR	15	15
Kinder	SW	RR	14.1	14.1
Haslingden Grane	SW	RR	14	14
Schneider Road	GW	RR	13.1	13.1
Cant Clough	SW	RR	10.3	10.3
Prenton	GW	RR	10	10
Watergrove	SW	RR	10	10
Lymm	GW	RR	9.1	9.1
Woodford	GW	RR	9.1	9.1
Primrose Hill	GW	RR	4.5	4.5
Chapel House Group	SW	RR	9	9

Source Name /Location	Source Type	Demand Centre	Current Available Yield (agreed with NWW) Ml/d	Future Maximum Yield (Ml/d)
Piethorne	SW	RR	8.1	8.1
Delph	SW	RR	8.1	8.1
Denshaw Valley	SW	RR	7.4	7.4
Barley Ogdens	SW	RR	6.9	6.9
Worsthorne	GW	RR	6.7	6.7
Worthington	SW	RR	3.6	3.6
Castleshaw	SW	RR	5	5
Levers Water	SW	RR	3.3	3.3
Lower House	GW	RR	6	6
Adlington	GW	RR	5.9	5.9
Wilmslow	GW	RR	5.9	9.1
Park Road South	GW	RR	5.7	6.8
Butterworth Hall	GW	RR	5.3	13.6
Bearstone	GW	RR	5	5
Lyme Park	SW	RR	4.9	4.9
Langley	SW	RR	4.9	4.9
Lamaload	SW	RR	4.8	4.8
Clitheroe	GW	RR	4.5	4.5
Springs/Dingle	SW	RR	4.6	4.6
The High Group	GW	RR	4.6	4.6
Clowbridge	SW	RR	4.5	4.5
Hug Bridge	GW	RR	4.5	4.5
Thorncliffe Road	GW	RR	4.5	4.5
Clough Bottom	SW	RR	4.4	4.4
Langden Group	SW & GW	RR	44.9	44.9
Corn Close 1	GW	RR	3.7	3.7
Tytherington	GW	RR	3.5	3.5
Fernilee	GW	RR	3.1	3.1
Neston	GW	RR	3.1	3.1
Hooton	GW	RR	3	3
Spring Hill	GW	RR	3	3

Source Name /Location	Source Type	Demand Centre	Current Available Yield (agreed with NWW) Ml/d	Future Maximum Yield (Ml/d)
Haze Water	SW	RR	3	3
Cowpe	SW	RR	3	3
Boulsworth Hill	GW	RR	2.7	2.7
Mitchells 1 & 2	SW	RR	2.7	2.7
Churn Clough	SW	RR	2.5	2.5
Dark Lane	GW	RR	2.5	2.5
Rushton Spencer	GW	RR	2.5	2.5
Ramsden	GW	RR	2.4	2.4
Green Lane	GW	RR	2.9	2.9
Worm Gill	SW	RR	2.3	2.3
Halsall	GW	RR	2.5	2.5
Spring Mill	SW	RR	2.3	2.3
Sunnyhurst	SW	RR	2.3	2.3
Haydock Park	GW	RR	2.3	2.3
Simpson Ground	SW	RR	2.2	2.2
Baystone Bank	SW	RR	2.2	2.2
Corn Close 2	GW	RR	2.2	2.2
Eden Hall	GW	RR	2.2	2.3
Dean Clough	SW	RR	2	2
Forge Lane	GW	RR	2	2
Millbrook	GW	RR	2	2
Waddington Fell	GW	RR	2	2
Hurst	SW	RR	1.9	1.9
Cliburn	GW	RR	1.8	1.8
Coldwell	SW	RR	1.7	1.7
Lane Shaw	SW	RR	1.7	1.7
Altham	GW	RR	1.6	4.5
Swineshaw	SW	RR	1.6	1.6
Bowscar	GW	RR	1.5	3.4
Tarnbeck	SW	RR	2	2
Roughton Gill	SW	RR	1.9	1.9

Source Name /Location	Source Type	Demand Centre	Current Available Yield (agreed with NWW) Ml/d	Future Maximum Yield (Ml/d)
Aira Beck	SW	RR	1.8	1.8
Grindleton	SW	RR	1.6	1.6
Bull Fell	GW	RR	1.5	1.5
Blackmoss	SW	RR	10.5	10.5
Dubbs	SW	RR	1.4	1.4
Longworth Clough	GW	RR	1.4	1.4
Mow Cop	GW	RR	1.4	1.4
Swindens	SW	RR	1.3	1.3
Broomedge	GW	RR	1.1	1.1
London Road	GW	RR	1.1	1.1
Bankwood	GW	RR	1	1
Ghyll Head	SW	RR	1	1
Boreholes SCZ	GW	SCZ	171	171
TOTAL SCZ			816.5	890
TOTAL RR			2003	2110

ANNEX 2 : LOCAL OPTIONS FOR NORTH WEST REGION

Scheme	Demand Centre	Yield Ml/d
Ribble	SCZ	40
Huntington *	SCZ	74
Lake District	RR	10
LCUS	RR	80
Improvement to existing GW Schemes	RR	17.5

* To bring available supplies from the River Dee up to full licence quantity.

ANNEX 3

8 COSTING OF OPTIONS

Basis of costing

8.1 As required by the terms of reference costings are pre-feasibility outline estimates for the provision of the replacement supplies.

8.2 Costings for major items of infrastructure such as pipelines, treatment works and pumping stations have been provided by NWW Engineering. Estimates are not better than +/- 30%.

8.3 All costings are adjusted to Q4 1992 using values of the Producer Price Index - Construction Output Price provided by NWW Engineering for the period 1985 to 1992. Q4 1992 is provisionally 132 over the base of 100 in 1985. Where earlier estimates have been updated, output price indices for new construction have been used pre-1985.

8.4 Costings other than for pipelines, treatment works and pumping stations have been prepared by Binnie & Partners. Wherever possible such costings have been taken from recently constructed works. The WRc Technical Report TR61 of 1977 has been used to assess how costs are likely to vary with size of works. The level of accuracy will be similar to the estimates produced by NWW Engineering.

8.5 Costs include design, supervision, planning, overheads and where appropriate land costs.

8.6 Capital cost elements provided by NWW do not include contingencies, largely because they are derived from outturn costs of recent projects. Capital cost estimates for raising of dams and for bankside and covered storage provision have 10% contingencies added. No contingencies have been added to running costs.

8.7 Plant replacement costs have not been calculated but would need to be included if economic analysis is carried out as plant replacement for all electrical, mechanical and control equipment is likely to needed at least every 20 years. For a pumping station plant replacement cost would be about half initial capital cost.

8.8 Running costs for treatment works are total costs and include power, chemicals, labour and maintenance as provided by NWW Engineering. Running costs for pumping stations are prepared by Binnie & Partners.

8.9 For the costing of transfer of surplus (spill) water from Alwen to Brenig reservoirs it has been assumed that the pipeline planned by Welsh Water, to draw water from Brenig to their new WTW at Alwen, will have been completed and can be used. Only the cost of the booster pumping station is therefore included.

Options for costing

8.10 A schedule of all the options costed is included as Table 8.1. The cost elements used are scheduled in Appendix B. Detailed calculation sheets for each option are in Appendix C.

18	Modify to treat 120 Ml/d Vyrnwy (max 200 Ml/d) and 120 Ml/d from Dee below Llangollen	18.0	+300
19	Modify to treat 60 Ml/d Vyrnwy (max 200 Ml/d) and 60 Ml/d from Dee below Llangollen	9.0	-400
20	Modify to treat 60 Ml/d Vyrnwy (max 200 Ml/d) and 120 Ml/d from Dee below Llangollen	18.0	-100
21	Modify to treat 60 Ml/d from Dee below Llangollen, no firm Vyrnwy flow but occasional abstraction up to 200 Ml/d	9.0	-500
22	Modify to treat 120 Ml/d from Dee below Llangollen, no firm Vyrnwy flow but occasional abstraction up to 200 Ml/d	18.0	-300
23	Modify to treat 120 Ml/d from Dee below Llangollen. No flow from Vyrnwy. Remainder of works decommissioned.	19.9	-500

Note that quoted WTW running costs are the difference between the estimated running costs of the new arrangements and the running costs for the existing Oswestry works taken as £1500k. (£1000k in 1992/1993 increased by £500k for ozone if plant output 250 Ml/d)

Changes in Vyrnwy and Dee licences

Element No	Description	Capital £million	Running £k/annum
24	Reduce Vyrnwy licence to 200 Ml/d (from 265 Ml/d)	-	-113
25	Cancel Vyrnwy licence	-	-461
26	Abstraction of further 60 Ml/d from the Dee (above existing NWW licences)	-	+281

Extension of intake from Dee at Huntington

Element No	Description	Capital £million	Running £k/annum
60 Ml/d			
27	Extension of intake at Huntington	0.1	
28	Extension of low lift pumping station at Huntington and raw water main to WTW	0.9	146
29	Provision of bankside raw water storage for 240 Ml with suitable connecting pipelines and pumping facilities	3.7	
30	Extension of Huntington WTW and high lift pumping station	26.6	912
31	Increase in capacity of Dee aqueduct between Huntington and Norton	11.0	
32	240Ml additional covered storage at Prescot	19.0	

COST ELEMENTS

1 All annual running costs quoted for all the WTW and pumping stations are for continuous working at full output, unless peak and average flows are stated when running costs are calculated on average output.

2 Works by Welsh NRA or Welsh Water to increase yield of the Dee by 60 Ml/d

Element No	Description	Capital £million	Running £k/annum
1	Raise Llyn Celyn reservoir by 1.5m to prevent need for flood storage	0.7	-
2	Raise Brenig reservoir by 3.5m	3.0	
3	Raise Brenig reservoir by 2.0m	1.6	
4	Transfer spill water from Alwen to Brenig reservoirs	0.9	137

3 New intake from Dee below Llangollen and aqueduct to Oswestry

Element No	Description	Capital £million	Running £k/annum
60 Ml/d			
5	Intake on R Dee	0.2	
6	Pumping station at intake	1.2	790
7	Aqueduct from R Dee to Oswestry WTW	5.6	
8	Inlet works to Llanforda raw water reservoir at Oswestry	0.1	
120 Ml/d			
9	Intake on R Dee	0.4	
10	Pumping station at intake	2.0	1444
11	Aqueduct from R Dee to Oswestry WTW	8.4	
12	Inlet works to Llanforda raw water reservoir at Oswestry	0.1	

4 Works at Oswestry WTW

Element No	Description	Capital £million	Running £k/annum
13	Continue to treat 60 Ml/d from Vyrnwy, maximum 200 Ml/d	2.0	-800
14	Continue to treat 120 Ml/d from Vyrnwy, maximum 200 Ml/d	-	-400
15	Continue to treat 180 Ml/d from Vyrnwy, maximum 200 Ml/d	-	-300
16	Modify to treat 180 Ml/d Vyrnwy (max 200 Ml/d) and 60 Ml/d from Dee below Llangollen	9.0	+200
17	Modify to treat 120 Ml/d Vyrnwy (max 200 Ml/d) and 60 Ml/d from Dee below Llangollen	9.0	-200

60 Ml/d			
48	Supply of treated water at Franklaw south aqueduct pumping station	-	1862
49	Pumping to Hoghton	-	597
50	Treated water aqueduct from Franklaw to Hoghton (800mm dia)	10.1	
51	Extension of Hoghton PS	0.8	191
52	Treated water aqueduct from Hoghton to Rivington (800mm dia)	7.5	
80 Ml/d average, 100 Ml/d peak			
53	Supply of treated water at Franklaw south aqueduct pumping station	-	2482
54	Pumping to Hoghton	-	780
55	Treated water aqueduct from Franklaw to Hoghton (900mm dia)	11.2	
56	Extension of Hoghton PS	1.0	257
57	Treated water aqueduct from Hoghton to Rivington (900mm dia)	8.4	

10 Aqueduct to carry LCUS and increased Rivington output from Rivington to Prescot

Element No	Description		Capital £million	Running £k/annum
50 Ml/d				
58	Aqueduct from Rivington to Prescot	- either	17.2	-
		(900mm gravity)		
		- or	13.5	226
		(700mm with booster station)		
60 Ml/d				
59	Aqueduct from Rivington to Prescot	- either	20.3	-
		(1000mm gravity)		
		- or	16.2	195
		(800mm with booster station)		
100 Ml/d				
60	Aqueduct from Rivington to Prescot	- either	30.3	-
		(1200mm gravity)		
		- or	21.6	279
		(1000mm with booster station)		
120 Ml/d				
61	Aqueduct from Rivington to Prescot	- either	43.0	-
		(1400mm gravity)		
		- or	21.6	510
		(1000mm with booster station)		

7 Intake, pumping stations, bankside storage and aqueduct from Samlesbury to Rivington reservoirs for increased Rivington output of 20 Ml/d average, 50 Ml/d peak. (For case with 40 Ml/d increased steady output from Rivington the costs are taken as similar).

Element No	Description	Capital £million	Running £k/annum
33	Construction of intake at Samlesbury	0.3	
34	Construction of pumping stations at Samlesbury	5.2	1600
35	Raw water aqueduct from Samlesbury to Upper Rivington reservoir	17.4	
36	240 Ml bankside storage at Samlesbury	3.7	
37	Inlet works at Upper Rivington reservoir	0.1	
38	Abstraction licence for 150 Ml/d from Ribble	-	245

8 Outlet from Rivington, and treatment works

Element No	Description	Capital £million	Running £k/annum
Increase of 20 Ml/d average, 50 Ml/d peak			
39	Outlet works from Lower Rivington reservoir and pipeline to treatment works with provision for booster pumps	1.0	
40	Extension or new treatment works at Rivington	22.6	200
Increase of 40 Ml/d steady			
41	Outlet works from Lower Rivington reservoir and pipeline to treatment works with provision for booster pumps	1.0	
42	Extension or new treatment works at Rivington.	18.3	333

9 Treated water supply from Franklaw WTW, LCUS

Element No	Description	Capital £million	Running £k/annum
20 Ml/d average, 50 Ml/d peak			
43	Supply of treated water at Franklaw south aqueduct pumping station	-	621
44	Pumping to Hoghton	-	171
45	Treated water aqueduct from Franklaw to Hoghton (700mm dia)	8.3	
46	Extension of Hoghton PS	0.6	50
47	Treated water aqueduct from Hoghton to Rivington (700mm dia)	6.2	

11 Additional SCZ groundwater costs (from MOSPA studies)

Element No	Description	Capital £million	Running £k/annum
62	Variable abstraction from existing groundwater sources as available for Vyrnwy 180 Ml/d cases	-	723
63	Variable abstraction from existing groundwater sources as available for Vyrnwy 120 Ml/d cases	-	962
64	Variable abstraction from existing groundwater sources as available for Vyrnwy 60 Ml/d cases	-	1028

ANNEX 4

Combination Number	Vyrnwy Firm Direct Supply (Mld)	Water Bank Release* (Mld)	Maximum Vyrnwy Take (Mld)	Maximum Huntington Take (Mld)	Minimum Vyrnwy Storage (Ml)	Additional NCZ Supplies Required: Average (Ml/a)	Additional NCZ Supplies Required: Average (Mld)	Additional NCZ Supplies Required: Maximum (Mld)	Average SCZ Op. Cost (£/a)	NCZ Supplies : 25 £/Ml: Total Op. Cost (£/a)	NCZ Supplies : 25 £/Ml: Cost Variation (£/a)	NCZ Supplies : 60 £/Ml: Total Op. Cost (£/a)	NCZ Supplies : 60 £/Ml: Cost Variation (£/a)
1	198.367	23.750	200	382	6,502	0	0	0	4,543,034	4,543,034	0	4,543,034	0
2	198.367	23.750	200	462	6,502	0	0	0	4,591,966	4,591,966	0	4,591,966	0
3	198.367	23.750	253	382	6,415	0	0	0	4,506,465	4,506,465	0	4,506,465	0
4	198.367	23.750	253	462	6,415	0	0	0	4,543,765	4,543,765	0	4,543,765	0
5	173.000	56.125	200	382	6,541	0	0	0	4,578,531	4,578,531	35,497	4,578,531	35,497
6	173.000	56.125	200	462	6,541	0	0	0	4,616,832	4,616,832	24,866	4,616,832	24,866
7	173.000	56.125	253	382	6,541	0	0	0	4,539,175	4,539,175	32,710	4,539,175	32,710
8	173.000	56.125	253	462	6,541	0	0	0	4,564,037	4,564,037	20,272	4,564,037	20,272
9	120.000	123.855	200	382	6,501	2,181	6	47	4,721,136	4,775,661	232,627	4,851,996	308,962
10	120.000	123.855	200	462	6,501	0	0	0	4,738,147	4,738,147	146,181	4,738,147	146,181
11	120.000	123.855	253	382	6,448	2,252	6	47	4,688,775	4,745,075	238,610	4,823,895	317,430
12	120.000	123.855	253	462	6,448	0	0	0	4,685,012	4,685,012	141,247	4,685,012	141,247
13	60.000	200.431	200	382	6,653	12,801	35	107	4,666,176	4,986,201	443,167	5,434,236	891,202
14	60.000	200.431	200	462	6,653	431	1	27	4,927,165	4,937,940	345,974	4,953,025	361,059
15	60.000	200.431	253	382	6,653	13,726	38	107	4,632,661	4,975,811	469,346	5,456,221	949,756
16	60.000	200.431	253	462	6,653	449	1	27	4,890,730	4,901,955	358,190	4,917,670	373,905
17	0.000	277.458	200	382	6,532	24,528	67	167	4,544,283	5,157,483	614,449	6,015,963	1,472,929
18	0.000	277.458	200	462	6,532	8,450	23	87	4,928,408	5,139,658	547,692	5,435,408	843,442
19	0.000	277.458	253	382	6,532	26,606	73	167	4,497,761	5,162,911	656,446	6,094,121	1,587,656
20	0.000	277.458	253	462	6,532	9,020	25	87	4,896,560	5,122,060	578,295	5,437,760	893,995
21	0.000	277.458	0	382	6,532	41,219	113	167	4,594,612	5,625,087	1,082,053	7,067,752	2,524,718
22	0.000	277.458	0	462	6,532	12,208	34	87	5,250,157	5,555,357	963,391	5,982,637	1,390,671

* March - October inclusive

File : RESULTS.WK1/18. 1.93/tw

TABLE 1 : SIMULATED OPERATION OF THE SCZ SYSTEM 1932 - 1987 : AVERAGE ANNUAL OPERATING COSTS

Appendix A3

NRA SEVERN TRENT-VYRNWY REDEPLOYMENT-FINAL REPORT SEPTEMBER 1993

NATIONAL RIVERS AUTHORITY
SEVERN-TRENT REGION

REDEPLOYMENT OF LAKE VYRNWY TO SUPPORT TRANSFERS FROM THE RIVER SEVERN TO THE RIVER THAMES - FINAL REPORT

NRA

National Rivers Authority
Severn-Trent Region
Water Resources

REDEPLOYMENT OF LAKE VYRNWY TO SUPPORT TRANSFERS FROM THE RIVER SEVERN TO THE RIVER THAMES - FINAL REPORT

CONTENTS

Summary

As part of the National Water Resources Strategy, a number of potential water resources options are being investigated. One of these identified options is the redeployment of Lake Vyrnwy to increase the regulation of the River Severn to support a transfer from the River Severn to the River Thames. This report provides a summary of the work undertaken by NRA Severn-Trent as part of this investigation.

From the simulation results undertaken during the study it would seem that NW option 9 would support a maximum transfer rate of 200 Ml/d and NW option 13 will support a maximum transfer of 300 Ml/d. These are initial estimates and involved changes to the regulation release control rules and further work is recommended.

The impact of the flow regime downstream of Lake Vyrnwy would be significant with a significant increase in flow rates, particularly in dry summers. The environmental impact of the proposed changes in the flow regime will be investigated further by Howard Humpries as part of a national contract. The costs associated with the redeployment of Vyrnwy and the Severn to Thames transfer have been estimated by NRA North West and NRA Thames respectively.

The cross-regional nature of the study has caused problems due to the different models and modelling strategies used in each region. If this options is to be progress further more detailed work will be required, notably on the regulation and supply control rules for Vyrnwy, the acceptable 'standards of service' for the River Severn regulation and the actual transfer requirements for the Severn to Thames Transfer.

1. Introduction

This study has been carried out to assess the benefits of reallocating a proportion of the existing Lake Vyrnwy direct supply yield for low flow augmentation of the River Severn. At present the bulk of Vyrnwy storage is used by North West Water Ltd to supply Liverpool and a proportion is used to supplement River Severn flows. Reallocated water could be used to resource increased licensed abstractions from the River Severn and/or support inter-basin transfers as part of the national water resources strategy.

The Severn resource system currently supports net abstractions totalling around 600 Ml/d. In addition to the modest quantities available from Lake Vyrnwy the Severn is augmented under low flows largely by releases from Llyn Clywedog (500 Ml/d max) plus water pumped from the Shropshire Groundwater Scheme in drier years (currently 85 Ml/d max). Releases are made to maintain flows at the Bewdley control point above a prescribed flow of 850 Ml/d. Figure 1 shows the key features of the resource system.

Under the present Lake Vyrnwy operating rules a fixed allocation of 725 Ml is allocated to a "water bank" on the first of each month from March to October, which is then available for regulation releases to support River Severn flows. Water is also discharged from the bank as a result of flood drawdown and reservoir spillage during the autumn and winter which will often completely deplete the bank before the following regulation season. Details of the current operating rules are included in Appendix 1.

1.1 Project Objectives

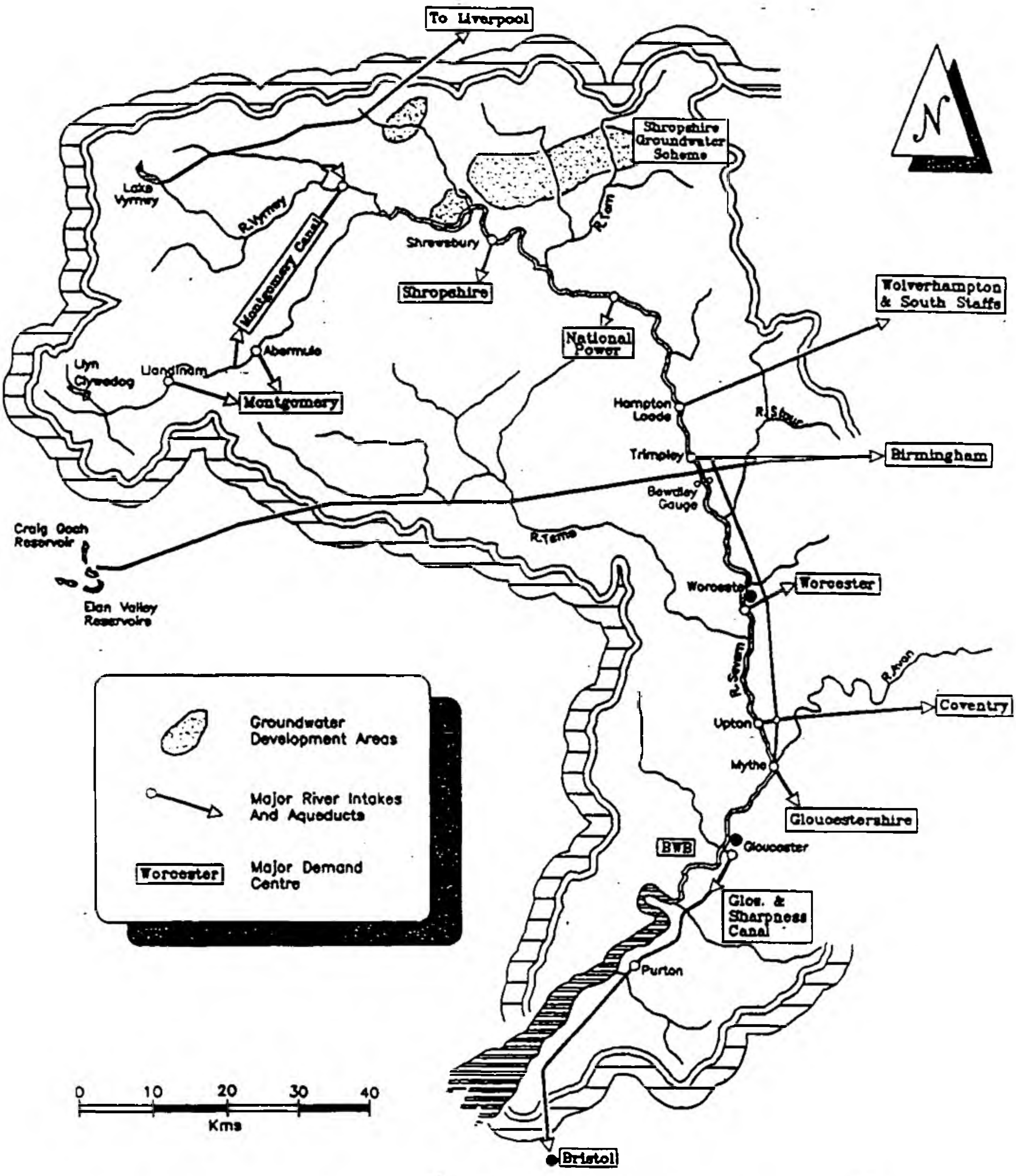
The objective of the study was to provide the necessary information for the Water Resources Economic Planning Model RESPLAN. In order to simulate a resource option RESPLAN requires the; capital cost, average operating cost and yield for any resource option.

For this study the 'resource system' involved was spread over three NRA regions. The source (Lake Vyrnwy) is a major water resources source for the area cover by NRA North West. the transfer involves increased augmentation of the River Severn , and the demand centre was in NRA Thames.

Any changes in operation of Lake Vyrnwy would have widespread implications. The cost of new operating rules have been calculated by NRA North West. The redeployment strategies were investigated using the MOSPA model run by independent consultants for NRA North West and North West Water. This study looked at the implications and costs associated with changing the size of the 'water bank' within Lake Vyrnwy.

The expected demand centre for any increased yield due to the augmentation of the River Severn was within NRA Thames. The sequence of abstractions from the River Severn had to be provided by NRA Thames. The costs of the actual transfer scheme has already been costed as part of a separate consultancy study. The actual yield of the resource system would be a function of the maximum transfer rate. The conversion of the maximum transfer rate to a resource yield is a responsibility of NRA Thames.

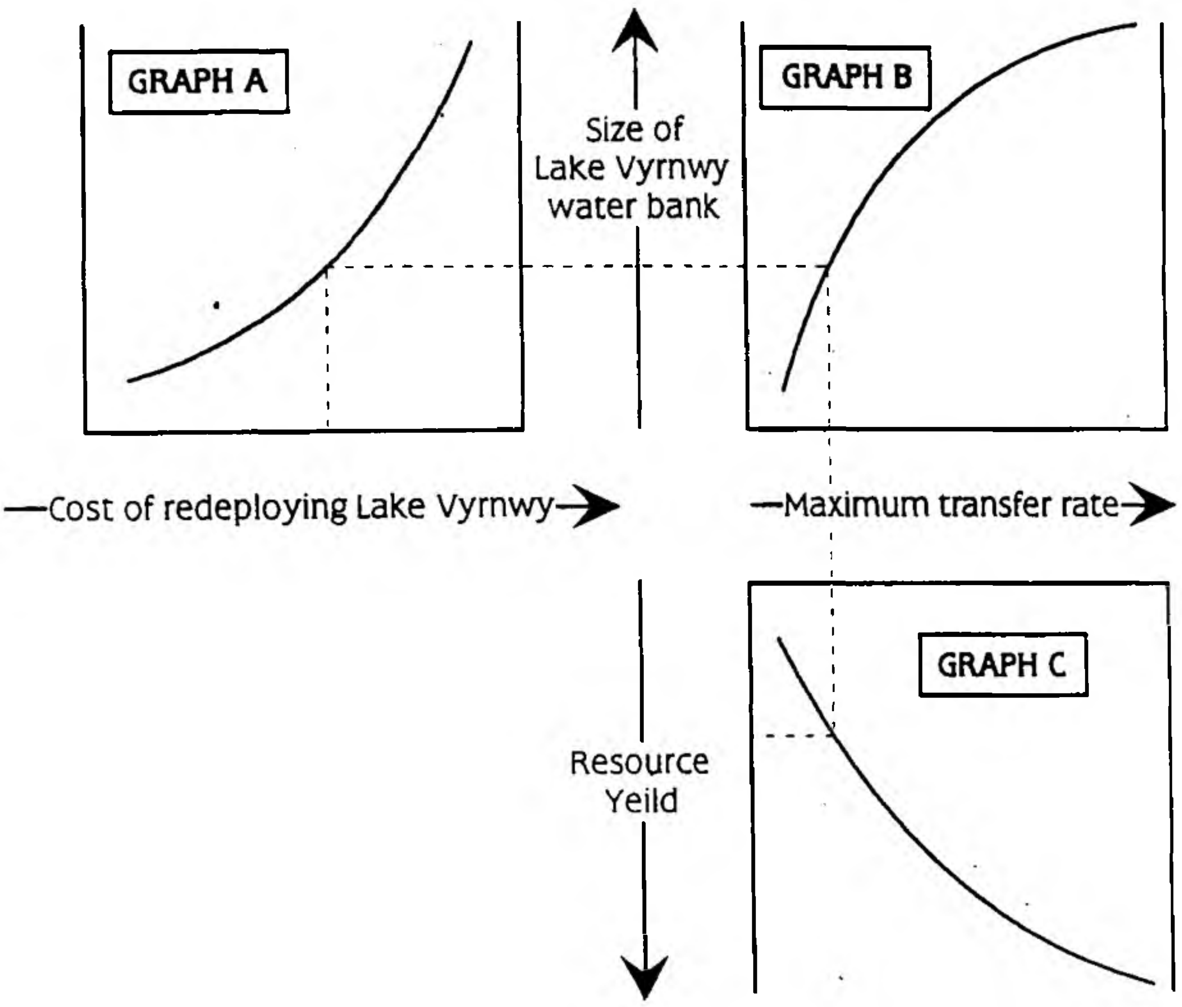
Figure 1 - The River Severn Water Resources/Supply System



The role of NRA Severn-Trent was to match up the source and demands by routing them along the River Severn without affecting the existing abstractors. The costs of the flow routing through the River Severn was considered minimal and the work within this region concentrated on estimated the maximum transfer rate that could be supported.

The methodology for estimating the relationship between the cost of redeploying Lake Vyrnwy and the resultant yield to within Thames Region is given in Figure 2. NRA North West, NRA Severn-Trent and NRA Thames respectively provide the information required for graph A, B and C. Given these graphs it is possible to estimate the redeployment costs and resources yield from the size of the Lake Vyrnwy 'water bank'. This report summaries how the information for graph B was estimated.

Figure 2 - Diagrammatic representation of the relationship between the cost of redeploying Lake Vyrnwy and the resources yield of the supported Severn to Thames transfer



1.3 Interim Reports

Four interim reports have been produced as part of this study during the different phases of the study. A summary of the contents of these reports are given in Table 1. The results included within reports replace those of the previous reports as more information became available from NRA North West and Thames.

Table 1 - Summary of Interim Reports produced during Study

Phase	Report	Date	Comments
I	Interim Report	3/93	Investigated the potential benefit of modifying the supply control rules of Lake Vyrnwy in order to provide additional resources for River Severn regulation while still maintaining the average supply rate to North West Water.
2	Phase 2 Report	5/93	Investigated the ability of different operating rules provided by NRA North West to support increased abstractions from the River Severn
3	Phase 3 Report	5/93	Investigated the ability of the different operating rules provided by NRA North West to support to transfer requirements identified by NRA Thames for the River Severn to River Thames transfer
4	Progress Report	7/93	Investigated the maximum supportable transfer rate for the Severn to Thames transfer for the different operating rules provided.

2. Modelling Method

2.1 Computer Model

The NRA Severn Trent regional resource allocation model (NRAM) was used for this study to simulate operation of Lake Vyrnwy and the River Severn resource system over the period 1932 to 1990. NRAM is written in FORTRAN 77 for use on the Regions DEC VAX 3100 computer. The model simulates the allocation of water supply to the major supply zones within the region from the major and local water resources sources on a five day time step (PENTAD).

The NRAM model also takes into account potential regulation losses. The level of loss depends upon;

- travel time to the regulation point,
- level of regulation, and
- whether rain storm conditions have occurred.

2.2 Model Enhancements

The basic model NRAM model which represented the existing water resources system within the region was modified in order to enable the proposed redeployment. These enhancements included;

- Ability for user to vary the monthly Lake Vyrnwy 'water bank' allocation,
- Incorporate new control rules for releases from Lake Vyrnwy,
- Changed the control curves for Lake Vyrnwy supply rates to relate to costed options
- Read in transfer requirements provided by NRA Thames,
- Incorporate Severn to Thames abstraction within the regulation requirement algorithm,
- New output data file for transfer to graphical and data analysis packages, and
- Run-time screen output displaying simulation results and summary statistics.

In March results became available from studies commissioned by NRA North West Region and North West Water Limited which to model Vyrnwy supplies. A total of over 20 combinations were evaluated in the North West studies of which four were chosen for use for simulation of the Severn resource system, NW1, NW5, NW9 and NW13. Of these NW1 represented baseline conditions. The control curves for each of these options are given in Appendix 2.

2.2.1 Lake Vyrnwy Releases - Adjustments to Control Rules

During the study a number of difficulties relating to the operating rules of the Lake Vyrnwy 'water bank' were identified. These related to the carry-over of the 'water-bank' from one year to the next and the rules controlling the release volume from the reservoir.

The existing operating rules for Lake Vyrnwy enable the 'water bank' volume in Vyrnwy to be carried over from one regulation period to another as long as Vyrnwy does not spill. When the size of the 'water bank' was increased these 'rules' caused the size of the bank to expand to nearly the full volume of the reservoir during the critical years (eg 1975-76). In turn this cause a potential double accounting of the reservoir volume available for the 'water bank' and for supply to North West Water. NRAM was changed to enable the user to define that the 'water bank' was set to zero outside the regulation period (ie November to February). The results from these simulation are comparable with the results from the NRA North West simulations which had assumed no carry-over of the 'water-bank'.

The critical period for low reservoir volumes in Vyrnwy and Clywedog is approximately late September. However, the 'water-bank' extends to the end of October. If the 'water-bank' is not being carried over from year to year this October water would be lost. As a consequence the model was enhanced so that the monthly distribution of the 'water-bank' could be varied, for example, spread over seven rather than eight months.

The existing regulation releases from Clywedog and Vyrnwy are controlled by different rules. A new 'test' regulation rule was developed which added the available 'water bank' volume to the volume in Clywedog and split the required release between them without the need for the 'water bank' to last to the end of October.

During the model simulation runs various combinations of the above rules for controlling the 'water-bank' releases were used. The simulations rules are summarised in Table 2. Rule 0 reflects the existing control rules, while run number 1 represents that assumed by NRA North-West when simulating the water supply rates from Lake Vyrnwy under the different redeployment options.

Table 2 - Summary of 'Water-Bank' release rules used in simulation runs

Rule No	Carry-over allowed	'water bank' period (months)	Extend to end of October	Link release with Clywedog
0	✓	8	✓	x
1	x	8	✓	x
2	x	8	✓	✓
3	x	7	x	✓

2.2.3 Additional Augmentation Volume Calculation

Another development of NRAM was undertaken to provided an estimate of the additional volume of augmentation that would be required to support different transfer sequences provided by NRA Thames. A base run version of NRAM was adapted to estimate the additional volume required to support the transfer for each calendar year.

2.3. Model Procedure

The Phase 1 looked at the yields that might be available without changing the average supply rate from Lake Vyrnwy. During Phase 2 the operating rule for the different NRA North West options were used to estimate the maximum continuous abstraction rate that could be supported. The dummy abstraction was placed upstream of Bewdley. The actual abstraction sequences simulated by NRA Thames were matched up with the NRA North West control rules in Phase 3. A more detailed investigation of the supportable transfer rates was undertaken during Phase 4. The results of these investigations are given in Section 3.

2.4 Standards of Service

A fundamental aspect of the study was the need to define what was the 'level of service' that would be used to ensure that existing abstractors were not affected by the changes being simulated. The 'levels of service' chosen related to the number of prescribed flow failures at Bewdley and the occurrence of a drought order states in Clywedog. These measures were taken as primary indicators of changes in the existing resources system performance.

The different return periods of naturalised flow sequence at Bewdley (1932-1990) were given in the Phase 2 report. In all cases the return period of the 1976 drought was greater than 1 in 50 years. Consequently, for the purpose of this study the occurrence of a drought order (reservoir level 3 occurrence in Clywedog) was deemed acceptable in 1976. The number of prescribed flow failures was not allowed to increase by more than 1 (that is not greater than 14).

3) Yields

3.1 Status of Results

The maximum transfer rate results reported in previous reports are replaced by those report in this section. The results report here are derived from the latest abstraction sequences provided by NRA Thames. Ten pentad flow sequences for the period 1932-1991 were provided. These were for maximum transfer rates of 200, 250, 300, 350 and 400 Ml/d with and without the South West Oxfordshire Reservoir (SWOR).

3.2 Initial Estimate of Additional Storage

Using the enhanced version of NRAM discussed in section 2.2.3 it was possible to estimate the additional volume required to support the Severn to Thames transfer for the different transfer sequences provide by NRA Thames Region using the different 'water-bank' release rules. The results for the different simulations are given in Table 3.

Table 3 - Estimated Additional Storage Volume (Ml) Required for Severn to Thames Transfer

Max Rate	With SWOR		Without SWOR	
	Rule 1	Rule 3	Rule 1	Rule 3
200	25790	25735	25790	25735
250	33285	33230	33245	33190
300	40850	40795	40850	40795
350	48415	48360	48415	48360
400	55980	55925	55975	55920

There is not a great deal of difference between the additional storage requirement with or without the South West Oxfordshire Reservoir. In all cases the critical year was 1976 and the transfer requirements are similar.

Table 4 Volume (Ml) of 'Water Bank' in North West Scenario

NRA North West Option	'Water Bank' Ml
NW1	5,800
NW5	13,695
NW9	30,221
NW13	48,905

The 'water bank'. volumes for the different North West options are given in Table 4. Combined with the results from Table 3 it would seem that NRA North West option 13 would potentially support a maximum transfer rate of around 315 Ml/d. The 'water bank' volume required a 200 Ml/d maximum transfer is only slightly greater than that provided by NW9.

The maximum 'water bank' volume (Ml) required by the 400 Ml/d transfer is significantly greater than that available from the NW13 scenario and greater than the volume of Vyrnwy. However, the estimated volume for the 200 Ml/d transfer is available from NW9.

This methodology assumes that when the reservoirs are supporting the transfer to Thames Region that the reservoir volumes will recover to a similar level. This is unlikely to be the case when tha abstractions are occurring. Another assumption is that operation constraints, such as maximum release rates, will not affect the ability to met the regulation requirement. To investigate the impact of these assumptions a number of full simulation runs had to be undertaken.

3.3 Simulation Results

A series of simulation runs were undertaken to investigate the impact of, the changes in the 'water bank', as defined by North West option 13, and the increased river augmentation requirement, on the existing 'levels of service'. These simulation runs had different maximum transfer rates (275, 300 and 215 Ml/d), used the with and without SWOR transfer sequences and used either rule 1 or rule 3.

The summary simulation results from these model runs for NW13 option using rule 1 and rule 3 are given in Table 5 and 6.

System	Comparison Unit	Run						
		0	1	2	3	4	5	6
Transfer & Supply Details								
	SWOR	X	✓	✓	✓	X	X	X
	Transfer Rate	0	275	300	315	275	300	315
	NW option	0	13	13	13	13	13	13
	Supply State 1	225						
	Supply State 2	205						
	Supply State 3	180						
Augmentation Release Information								
	Clywedog	447910	485465	500135	527980	443695	457050	481105
	Vyrnwy	194360	500340	506090	528460	464410	469390	485375
	Shropshire	27580	35650	41680	46590	28215	32265	35655
	Total Release Ml	669850	1021455	1047905	1103030	936320	958705	1002135
	Excess Total Ml	81050	124475	128655	136620	113090	116805	122310
	Flow Failure	12	23	26	27	21	23	25
Clywedog Reservoir								
	Min Vol Ml	7625	4805	6025	5515	4805	6025	5515
	Year Min Vol	1976	1976	1976	1976	1976	1976	1976
	Pentad Min Vol	53	53	53	53	53	53	53
	State 1	4270	4254	4253	4252	4257	4256	4252
	State 2	37	49	50	50	46	47	50
	State 3	0	4	4	5	4	4	5
Vyrnwy Reservoir								
	Min Vol Ml	9150	20685	20645	19865	20165	20145	20105
	Year Min Vol	1934	1933	1933	1947	1933	1933	1933
	Pentad Min Vol	53	56	56	62	56	56	56
	State 1	4156	3451	3449	3444	3463	3462	3459
	State 2	76	856	858	863	844	845	848
	State 3	75	0	0	0	0	0	0
	Supply Ml/d							
Shropshire								
	Operated	69	87	102	114	69	78	87
SevernThames Transfer								
	Cumm Transfer Ml	0	957995	1030240	1152990	1152990	155803	177149

Table 5 - Summary Simulation Results for different transfer rate using test control rule 1

System	Comparison Unit	Run						
		0	1	2	3	4	5	6
Transfer & Supply Details								
	SWOR	X	✓	✓	✓	X	X	X
	Transfer Rate	0	275	300	315	275	300	315
	NW option	0	13	13	13	13	13	13
	Supply State 1	225						
	Supply State 2	205						
	Supply State 3	180						
Augmentation Release Information								
	Clywedog	447910	508825	529095	552955	465840	481355	501615
	Vyrnwy	194360	504150	514230	539020	462685	471565	491680
	Shropshire	27580	20790	24465	27785	18240	19910	22060
	Total Release Ml	669850	1033765	1067790	1119760	946765	972830	1015355
	Excess Total Ml	81050	126940	133810	139810	114755	120165	125070
	Flow Failure	12	11	12	16	9	12	17
Clywedog Reservoir								
	Min Vol Ml	7625	6115	4445	5970	6115	4445	5970
	Year Min Vol	1976	1976	1976	1976	1976	1976	1976
	Pentad Min Vol	53	53	53	53	53	53	53
	State 1	4270	4251	4241	4240	4254	4248	4247
	State 2	37	53	61	62	50	54	55
	State 3	0	3	5	5	3	5	5
Vyrnwy Reservoir								
	Min Vol Ml	9150	16610	16485	16010	17295	16570	16045
	Year Min Vol	1934	1933	1933	1933	1933	1933	1933
	Pentad Min Vol	53	56	56	56	56	56	56
	State 1	4156	3438	3435	3424	3460	3457	3446
	State 2	76	869	872	883	847	850	861
	State 3	75	0	0	0	0	0	0
	Supply Ml/d							
Shropshire								
	Operated	69	54	63	72	48	51	57
SevernThames Transfer								
	Cumm Transfer ML	0	957995	1030240	1152990	722715	779015	885745

Table 6 - Summary Simulation Results for different transfer rate using test control rule 3

3.3.1 Prescribed Flow Failures

The results for Rule 1 (Table 5) shows that the number of prescribed flow failures has increased significantly for all the simulation runs. This increase in the number of failures would be unacceptable under the 'standards of service' given in section 2.4. The results for Rule 3 (Table 6) are more acceptable. particularly for the 275 and 300 Ml/d maximum transfer rates.

3.3.2 Clywedog Reservoir Volume

For all the simulation the minimum volume in Clywedog was lower. The lowest volume came in the 300 Ml/d simulation rather than the 315 Ml/d transfer. The 315 Ml/d transfer sequence was a chopped version of the 350 Ml/d transfer as consequently did not fully represent transfer requirements for a maximum 315 Ml/d transfer rate, particular during the extreme year of 1976.

The number of 'drought order' states in Clywedog increased in all the simulations. These all occurred in 1976 and could be acceptable under the 'standards of service' given in section 2.4. The number of 'apply for drought order' states (State 2) also increased.

3.3.3 Vyrnwy Reservoir Volume.

The minimum Vyrnwy volumes increase in all the simulations. This indicates that the reservoir volume is not being fully utilised either for supply or for augmentation Further work is required to investigate this aspect of the resource system.

3.3.4 Shropshire Groundwater Abstractions

Under Rule 1 (Table 5) more regulation is provided from the Shropshire Groundwater scheme than the base run (column 1 of Table 5 and 6). The results from the rule 3 simulations (Table 6) show that the level of augmentation from the Shropshire Groundwater scheme was less or similar to the base run.

3.3.5 Summary of Simulation Results

The results show the impact of the assumptions made in section 3.2. The 'theoretical' maximum transfer rates indicated in section 2.4 are greater than those actually supportable. If rule 1 is used the maximum supportable transfer rate is significantly less than 275 Ml/d. If the new 'test' operational rule is used then the maximum transfer rate is approximately 300 Ml/d. Further investigations are required to look at the operation of Vyrnwy reservoir and the acceptability of the proposed new operating rule (rule 3).

The NW option 13 should support a maximum transfer rate of 300 Ml/d with only a slight impact on the existing 'standards of service'. More work is required to confirm this initial estimate, particularly on the control rules for Vyrnwy and the regulation releases.

4) Costs

The costs associated with the increased regulation of the River Severn are minimal. The cost of the modifications required to Lake Vyrnwy have been estimated by Halcrow. The costs associated with the building and operation of the Severn to Thames transfer have been estimated by NRA Thames.

5) Environmental

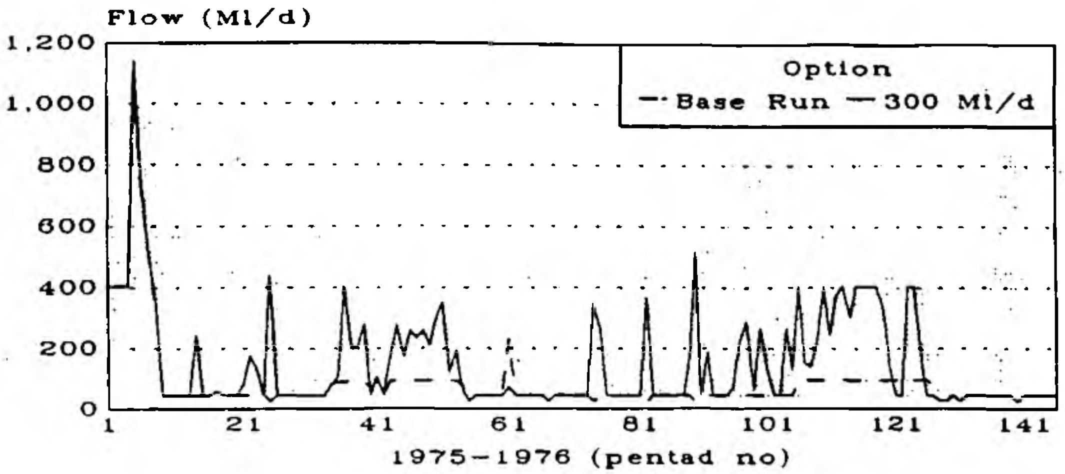
The redeployment of Lake Vyrnwy will have an impact on the flow regime of the Afon Vyrnwy and to a lesser extent on the Afon Clywedog and the River Severn at Bewdley. The flow series for these three locations for 1975 and 1976 are given in Figure 3. The diagrams illustrate the difference between the current situation simulation and the flows for the rule 3, 300 Ml/d transfer with SWOR. In addition the difference between the base run and the 300 Ml/d transfer is shown in the Bewdley diagram.

The large impact on the flow regime below Vyrnwy can clearly be seen. There is a lesser impact on the flows below Clywedog, and very little impact, relatively, at Bewdley

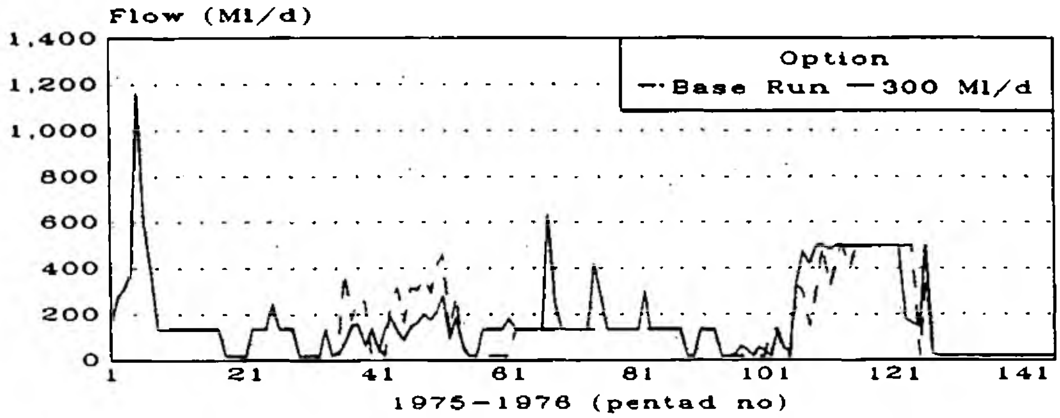
The environmental impact of the increased flows, particularly in the Afon Vyrnwy will need to be investigated more closely during the Environmental Impact Study being undertaken by Howard Humpries.

Figure 3 - Flow changes below Vyrnwy and Clywedog and at Bewdley for 300 Ml/d Severn to Thames Transfer with SWOR as compared to NRAM 1990 Base Run

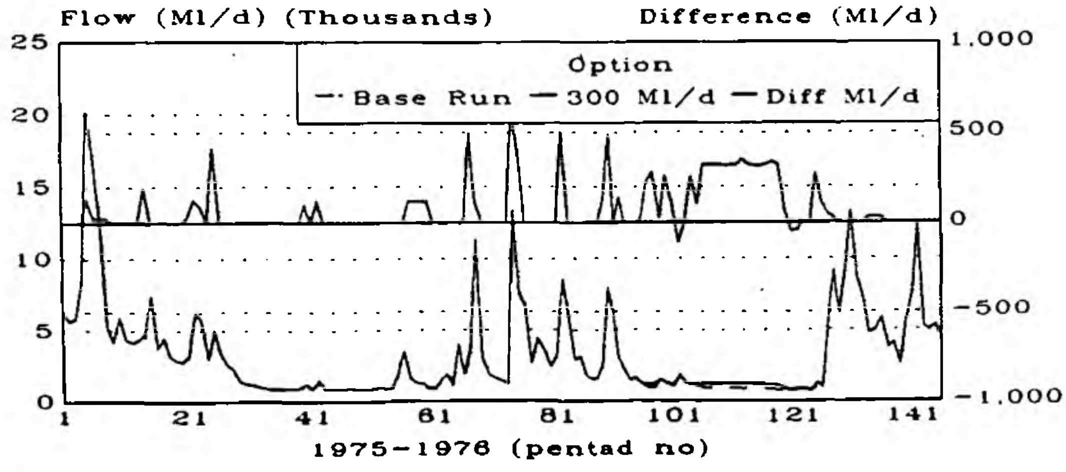
Flow below Vyrnwy



Flow below Clywedog



Flow at Bewdley



6) Conclusions

The main objective of this study was to provide an estimate of the maximum transfer rate supportable by different Vyrnwy redeployment options. The cross-regional nature of the study has caused problems due to the different models and modelling strategies used in each region. If this options is to be progress further more detailed work will be required, notably on the regulation and supply control rules for Vyrnwy, the acceptable 'standards of service' for the River Severn regulation and the actual transfer requirements for the Severn to Thames Transfer.

From the simulation results undertaken during the study it would seem that NW option 9 would support a maximum transfer rate of 200 Ml/d and NW option 13 will support a maximum transfer of 300 Ml/d. These are however initial estimates.

The impact of the flow regime downstream of Lake Vyrnwy would be significant with an increase in flow rates, particularly in dry summers.

Appendix I - Current Control Rules for Lake Vyrnwy

SECTION 3 - LAKE VYRNWY

3.1 Introduction

These Guidelines define where responsibility rests for various aspects of the Lake Vyrnwy Compensation Variation Scheme and they should be read in conjunction with a report which describes the scheme. In particular, the Guidelines set a framework for achieving a balance between the potentially conflicting interests of:-

Direct supplies to North West Water
Discharges for flood retention to minimise the frequency of overflows
Discharges for river augmentation to support water supply abstractions from the River Severn
Discharges for fisheries management in the River Vyrnwy downstream of the Lake
Maintenance

The STWA (Lake Vyrnwy Discharge) Order 1979 authorises discharges not exceeding 405 Ml/d by virtue of the provisions of Section 37 of the Liverpool Corporation Waterworks Act 1880 (Amended 1979) as follows:-

(a) A normal daily compensation discharge of 45 Ml/d.

(b) A reduced daily compensation discharge of 25 Ml/d on any day when at 9.00 am the flow at the Cownwy Gauge is above 20 Ml/d.

The requirement to discharge the monthly compensation water in accordance with previous provisions of the 1880 Act has been removed.

The water retained in the reservoir as a result of these provisions is discharged during times of natural low flows to augment the flow in the River Vyrnwy and the River Severn. Authorised abstractions from the River Severn have been increased by 25 Ml/d by this conjunctive use of Lake Vyrnwy and Llyn Clywedog.

3.2 Operating Staff

At Lake Vyrnwy the Resident Agent is responsible for the physical control of the discharge valves to the River Vyrnwy. These may be adjusted during normal office hours by staff reporting to the Resident Agent. Out of office hours special arrangements are made.

North West Water Staff deal with direct supplies taken from the Straining tower or the Aber Conduit and these operations are not described in these guidelines.

The Lake Vyrnwy Management Committee, comprising officers from Severn-Trent and North West Water, meets several times each year and has particular responsibility for management of the reservoir and the dam itself.

At Regional HQ, the Resources Section is responsible for ensuring that correct amounts of water are discharged to the River Vyrnwy and that the quantity of water in storage is sufficient to meet the statutory requirements and other interests defined in the Introduction. The Principal may delegate his responsibilities defined in these guidelines to the Flow Forecasting Duty Officer.

3.3 **The BANK Statement**

a) Severn-Trent Water may release water at its discretion from a 'BANK' accumulated by storing compensation water. The attached banking statement (Table 3.1) shows relevant information day by day. The Resident Agent is responsible for keeping the statement and at the end of each month he sends a copy to Resources, District Fisheries Officer, and to the Managers of the Upper Severn (STWA) and Western (NWWA) Divisions.

b) The BANK will never be less than zero. Water may be held in the BANK from one year to the next.

Resources Section is responsible for calculating the daily volume of water passing the Vyrnwy Dam Gauge. Each Thursday staff at Lake Vyrnwy Estate and Resources exchange information and agree the balances of the BANK.

3.4 **Daily Compensation Water Discharges**

a) The Resident Agent at Lake Vyrnwy is responsible for ascertaining the flow at the Vyrnwy Dam Gauge, Cownwy Gauge and reservoir level at 9.00 am clock time each working day. Daily compensation water discharges are set by the Resident Agent according to the flow in the Afon Cownwy, and do not require confirmation from Resources. The Cownwy trigger applies on working days only. On all other days the daily compensation discharge will be a minimum of 45 Ml/d.

b) If the Cownwy flow is less than or equal to 20 Ml/d (at 9.00am on working days), the Resident Agent will discharge a minimum of 45 Ml/d from Lake Vyrnwy as measured at the Vyrnwy Dam Gauge.

c) If the Cownwy flow exceeds 20 Ml/d (at 9.00am on working days) the Resident Agent will discharge a minimum of 25 Ml/d from Lake Vyrnwy unless the reservoir drawdown is less than 0.5 metres. At these times the discharge will be 45 Ml/d. This is to reduce the chance of overspill at a later date.

d) If the Afon Cownwy is diverted away from Lake Vyrnwy for STWA engineering purposes at Cownwy Gauge appropriate deductions will be made from the STWA BANK, by Resources. If the BANK is zero and Lake Level is below the flood drawdown line, the Resident Agent will consult with North-West Water prior to any diversion of the Afon Cownwy away from Lake Vyrnwy.

LAKE VYRNWY WATER BANK STATEMENT

TABLE 3.1

MAY 1988

DATE	RESERVOIR LEVEL AT 09.00 HRS (m)	CONWWY FLOW (Ml/d)	DAILY COMP. RELEASE (Ml/d)	VYRNWY WEIR FLOW (Ml)	ADDITION TO BANK (Ml)	TOTAL DEDUC-TIONS (Ml)	DETAILS OF DEDUCTIONS FROM BANK: FLOOD DRAW DOWN (Ml)	RIVER REGUL ATION (Ml)	FISHERY PURPOSES (Ml)	DISCHARGE OF BANK (Ml)	OVERFLOW LESS RELEASES (Ml)		BALANCE IN BANK (Ml)
												B/FWD	725
												ADD	725
1	-0.66	0.0	45	51	0	0	0	0	0	0	0		1450
2	-0.67	0.0	45	51	0	0	0	0	0	0	0		1450
3	-0.66	21.3	25	[illegible]	20	0	0	0	0	0	0		1470
4	-0.62	21.3	25	27	20	0	0	0	0	0	0		1490
5	-0.58	20.9	25	27	20	0	0	0	0	0	0		1510
6	-0.59	16.9	45	48	0	0	0	0	0	0	0		1510
7	-0.62	12.6	45	49	0	0	0	0	0	0	0		1510
8	-0.66	10.9	45	48	0	0	0	0	0	0	0		1510
9	-0.71	10.0	45	49	0	0	0	0	0	0	0		1510
10	-0.73	9.7	45	48	0	0	0	0	0	0	0		1510
11	-0.76	0.0	45	48	0	0	0	0	0	0	0		1510
12	-0.81	0.0	45	47	0	0	0	0	0	0	0		1510
13	-0.86	9.7	45	47	0	0	0	0	0	0	0		1510
14	-0.90	0.0	45	46	0	0	0	0	0	0	0		1510
15	-0.94	0.0	45	46	0	0	0	0	0	0	0		1510
16	-0.99	7.2	45	46	0	0	0	0	0	0	0		1510
17	-1.05	6.6	45	47	0	0	0	0	0	0	0		1510
18	-1.10	6.1	45	47	0	0	0	0	0	0	0		1510
19	-1.14	6.6	45	47	0	0	0	0	0	0	0		1510
20	-1.18	6.8	45	47	0	0	0	0	0	0	0		1510
21	-1.23	0.0	45	47	0	0	0	0	0	0	0		1510
22	-1.28	0.0	45	47	0	0	0	0	0	0	0		1510
23	-1.34	5.0	45	47	0	0	0	0	0	0	0		1510
24	-1.54	14.5	45	47	0	0	0	0	0	0	0		1510
25	-1.35	28.5	25	25	20	0	0	0	0	0	0		1530
26	-1.35	30.7	25	25	20	0	0	0	0	0	0		1550
27	-1.30	28.8	45	45	0	0	0	0	0	0	0		1550
28	-1.33	0.0	45	47	0	0	0	0	0	0	0		1550
29	-1.35	0.0	45	49	0	0	0	0	0	0	0		1550
30	-1.27	0.0	45	48	0	0	0	0	0	0	0		1550
31	-1.21	0.0	45	46	0	0	0	0	0	0	0		1550
		TOTALS	1295		100		0	0	0	0	0		
		MEAN	1295										

0011R

e) The Resident Agent will enter the reservoir level, Cownwy flow, and daily compensation water on the banking statement and add 20 Ml to the STWA BANK on days when the daily compensation is 25 Ml/d.

3.5 Monthly Compensation Water

On the 1st of each month from March to October inclusive, the Resident Agent will add 725 Ml to the STWA BANK.

3.6 Discharges for Flood Retention

a) A flood drawdown line has been approved by the Lake Vyrnwy Management Committee (Figure 3.1) for the period 15 September to 1 March each winter.

b) When storage is above this line discharges will be made from Lake Vyrnwy subject to:-

(i) A maximum flow at the Vyrnwy Dam Gauge of 405 Ml/d.

(ii) The Resident Agent being satisfied that the river level at the Meifod Gauge is less than 1.5 metres above a local datum of 81.0m AOD at the time.

(iii) The Resident Agent deeming in the light of local circumstances that a full discharge should not be made.

(iv) A request from the Flood Duty Officer of Upper Severn Division or Resources to withhold flood drawdown discharges in view of current or anticipated river conditions some distance downstream of Lake Vyrnwy.

c) If there is a possibility of flooding from snowmelt and the current level at Lake Vyrnwy is such that rapid melting of snow could cause considerable overflow then Resources will consult with the District Manager, NWWA to agree the amount of drawdown which should be made to accommodate meltwater. It is likely that two-thirds of the lying snow would run into the reservoir; the remaining one-third being lost to the atmosphere.

In these circumstances storage will be temporarily below the flood drawdown line.

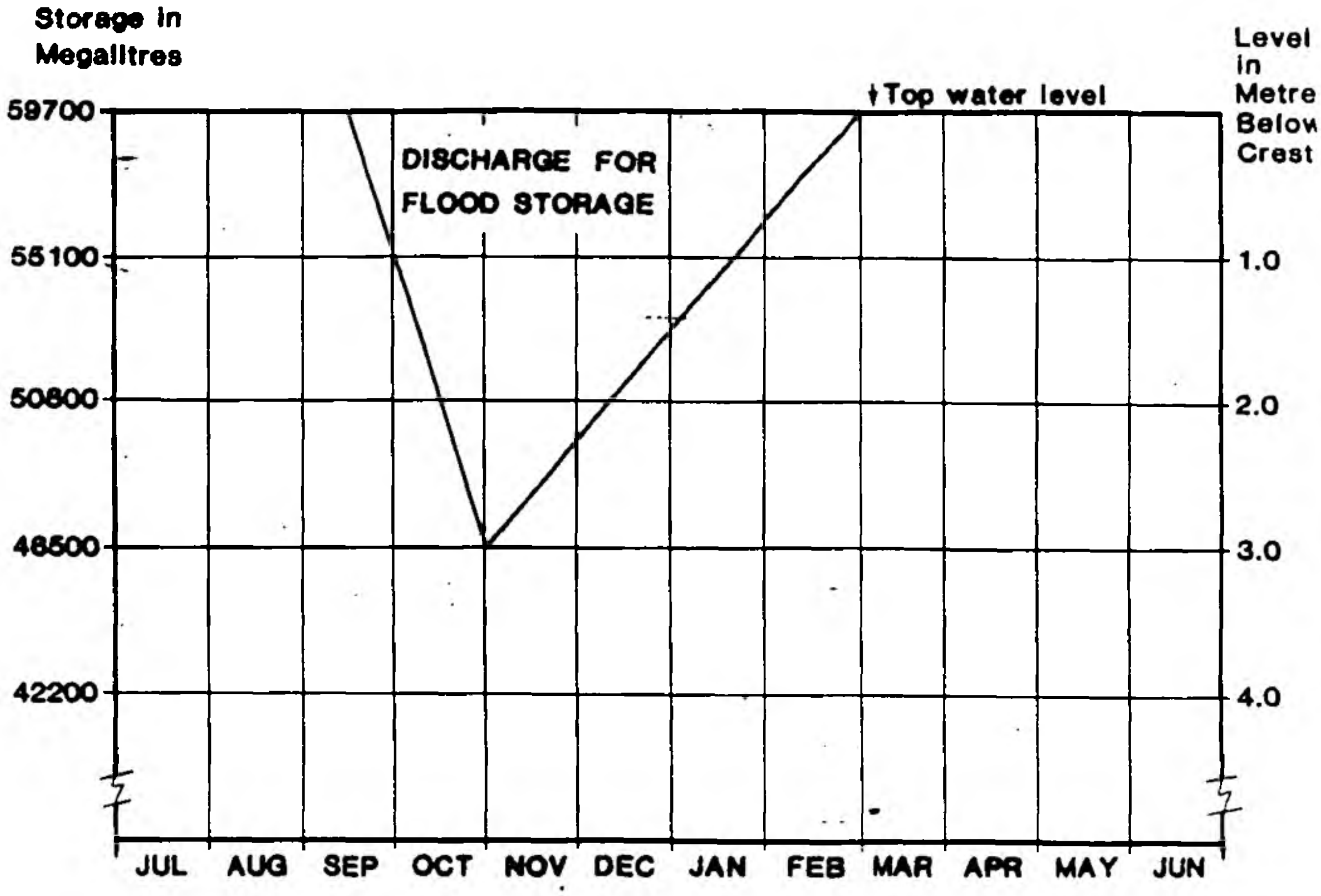
d) Resources will enter the amount of flood drawdown discharges on the bank statement and deduct this from the STWA BANK. In October to mid December this deduction will not reduce the BANK to less than the 725 Ml reserved for fisheries purposes.

3.7 Discharges to Augment the River Severn and maintain statutory river flows

a) Resources Section is responsible for instructing the Resident Agent to make discharges from the STWA BANK. The instructions will normally be sent by a telephone call from Resources to the Resident Agent, and confirmed in writing.

LAKE VYRNWY
CONTROL LINE FOR FLOOD DRAWDOWN

FIGURE 3.1



b) These discharges will only be made when the river flow at Bewdley Control Point requires augmentation to maintain the prescribed value.

c) If the discharge from Llyn Clywedog is approaching 500 Ml/d, Resources will notify the British Waterways Board, Gloucester. In the period March to October, on occasions when the discharge is restricted to 500 Ml/d from Llyn Clywedog, additional discharges may be made from Lake Vyrnwy at the request of the BWB to Resources.

The amount so discharged from the BANK for BWB purposes shall not be in excess of 725 Ml in any month, in addition to the daily compensation water.

d) Resources will enter the amount of river augmentation discharges on the banking statement and deduct this from the STWA BANK.

3.8 Discharges for Fisheries Management Purposes

a) The responsibility for making requests for discharges for fisheries purposes rests with the District Fisheries Officer at Shrewsbury. Requests for discharges will be made to Resources.

b) If Resources feel it would be prudent not to discharge water when flows are above the prescribed value at Bewdley they can, after appropriate consultation with the District Fisheries Officer, decide not to authorise a discharge. Such a situation would arise, for example, if water resources elsewhere in the area, particularly Llyn Clywedog, were thought to be in an unsatisfactory state for the time of the year.

c) Under normal conditions the District Fisheries Officer would be entitled to request discharges of not more than 725 Ml during Spring (April and May) and a further 725 Ml during Autumn (October to mid December).

d) Resources will enter the amount of discharges for fisheries purposes on the banking statement and deduct this from the STWA BANK.

e) The District Fisheries Officer may request discharges to be reduced to the minimum compensation flow (25 Ml/d) for a maximum period of 12 hours on any day in order that fisheries operations can take place downstream of the Dam. Discharges may have to be increased for the remainder of the day to meet the statutory requirements for compensation water. (Section 3.4).

3.9 Discharging the 'BANK'

It is recognised that in some years there will be no useful purpose for the water banked e.g. Llyn Clywedog has ample water in store and flows are sufficient for fisheries purposes. If the water remains in store and high autumn or winter inflows occur

3.11 Overflows

a) The flood drawdown arrangements are designed to reduce the risk of overflows. The amount of overflow recorded at the Vyrnwy Dam gauge will be calculated by Resources.

b) Resources will enter the amount of overflows on the banking statement and deduct this from the STWA BANK. In April and May, and in October to mid December deductions of overflows will not reduce the BANK to less than the 725 Ml reserved for Fisheries purposes.

the Lake would be at higher levels than with the previous arrangements; eventually increased overspill may occur. The maximum authorised discharge capacity is 405 Ml/d and as this can barely keep pace with inflows during average to wet winters the water BANK has to be discharged from a relatively early date if this is thought necessary. The guidelines that have been formulated are as follows:-

a) Resources will assess the current storage in Llyn Clywedog and Lake Vyrnwy, the prospects of significant releases being required in accordance with Sections 3.7 and 3.8 and the probability of overflows occurring later in the year in determining whether to discharge the BANK. It is not normally expected that the BANK will be discharged before August.

b) Resources will consult with the District Fisheries Officer.

c) Resources will instruct the Resident Agent to discharge the BANK, provided the Resident Agent is satisfied the level at Meifod Gauge is less than 0.90 metres above the local datum at the time.

d) Resources will enter the amounts discharged from the BANK on the banking statement and deduct this from the STWA BANK.

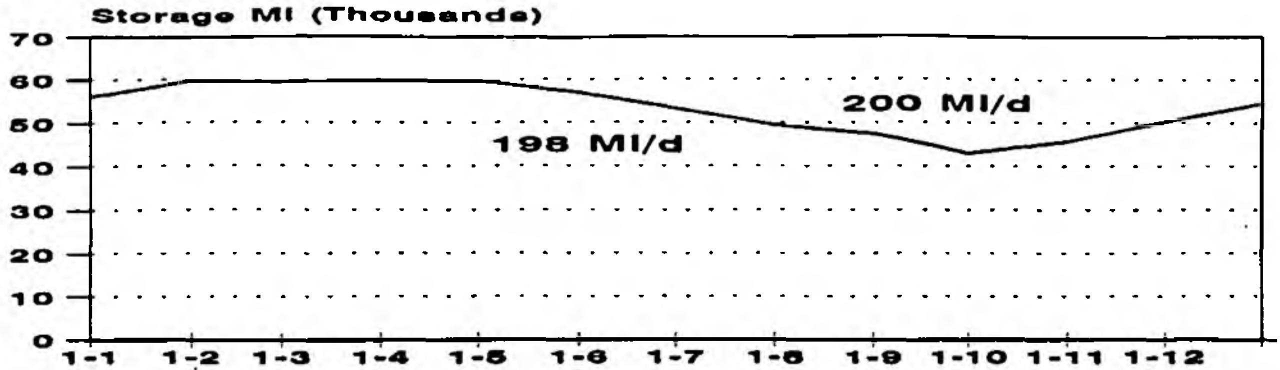
3.10 <u>Guidelines for all discharges from Lake Vyrnwy</u>

a) The selection of discharge valves and the appropriate valve settings is the responsibility of the Resident Agent. Detailed guidance is provided by the Divisional Engineer based on a series of valve calibration tests, which may require from time to time to be repeated.

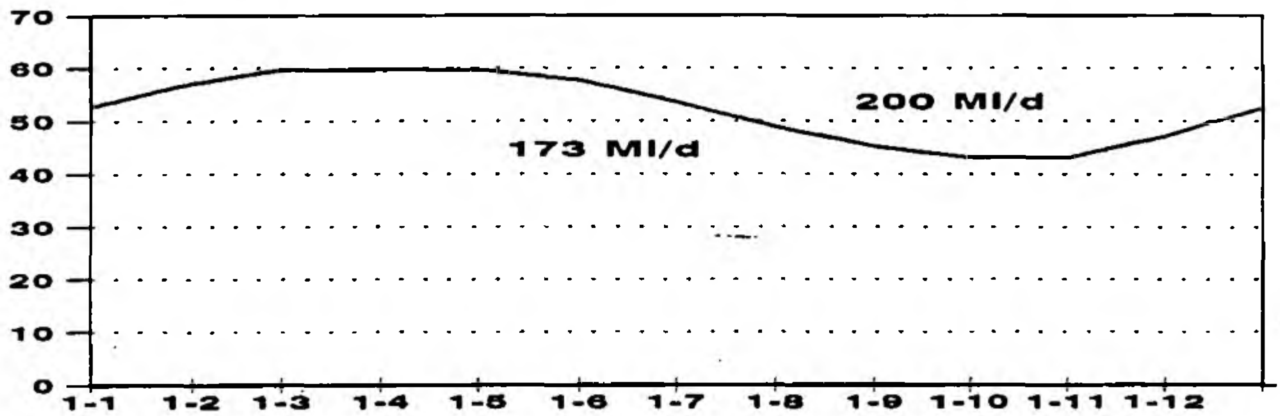
b) In normal circumstances the rate of increase or decrease of all discharges should be not greater than 100 Ml/d per hour. This is to safeguard fisheries downstream of the dam. The rate of shut down of the valves may be swifter if river level at Meifod Gauge is likely to exceed 1.5 metres above local datum.

c) In exceptional circumstances discharges for maintenance, operational or other purposes outside the Operating Guidelines, may be made at the discretion of the Operational Services Co-ordinator or other Divisional Officer designated from time to time. A particular example is for engineering works at the base of the dam because the water cushion may be emptied only when the Lake water level is below 1.00m drawdown. Deductions from the BANK will be made if the discharge is for STWA purposes.

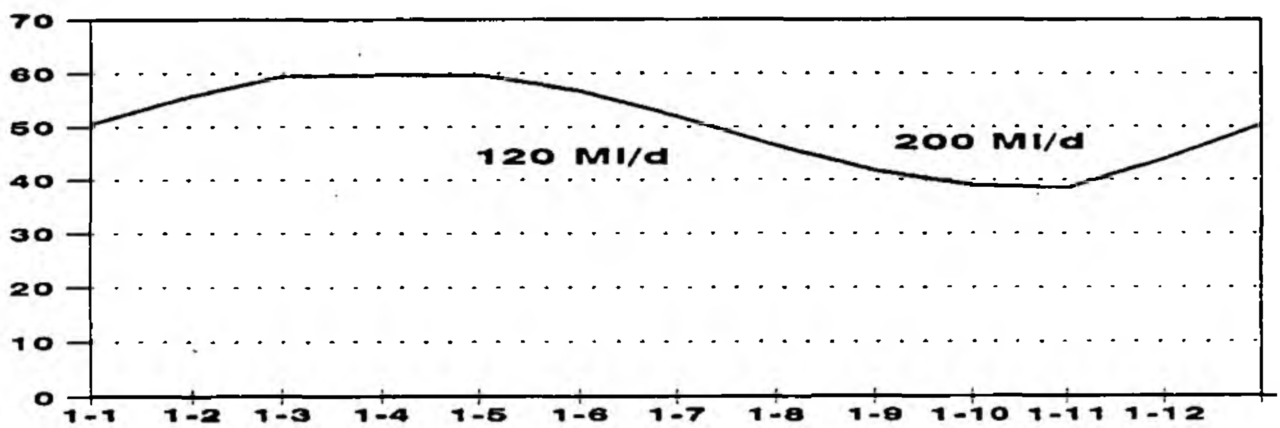
d) Normally the maximum discharge under Sections 3.6 and 3.9 will be 405 Ml/d. Overflows have exceeded this value many times (e.g. 1981 2000 Ml/d). In exceptional circumstances to minimise the risk of overflows Resources may authorise a flood drawdown discharge to the maximum capacity of the discharge valves. This will be confirmed in writing.



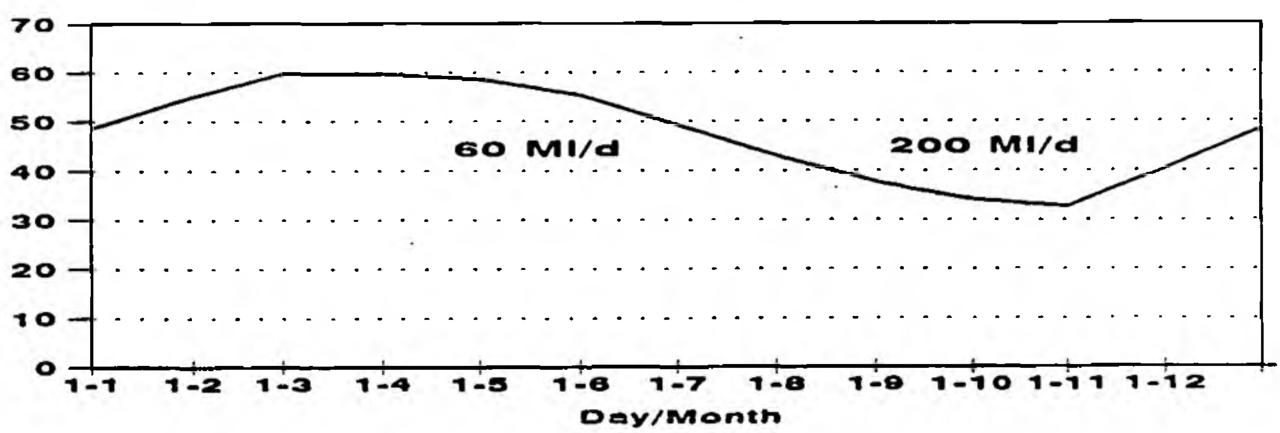
Control Curve NW1



Control Curve NW5



Control Curve NW9



Control Curve NW13

Appendix II - Control Curves for different Supply Option for Lake Vyrnwy

Appendix A4

NRA SEVERN TRENT-REGULATION OF RIVER TRENT FOR TRANSFER TO ANGLIAN REGION-MAY 1993

National Water Resources Strategy
Modelling Report for Inter-Regional Transfer

Regulation of the River Trent for Transfer to Anglian Region

May 1993

NRA Severn-Trent Region

1) Introduction

NRA Severn-Trent Region appointed WS Atkins to carry out, as part of the National Water Resources Strategy, a desktop feasibility an outline engineering study for the transfer of raw water from the Severn to the Trent. One possible purpose of this transfer would be to support an abstraction from the River Trent at Torksey for further transfer into Anglian Region. This short report is derived from the final report produced by WS Atkins

1.1) Transfer Route

The preferred transfer alignments are shown in Figure 1. The most economic solution is provided by Route 1 which runs from Coalport on the Severn to the River Penk at Lower Drayton, the River Sow at Milford and the River Trent at Great Haywood.

1.2) Mode of Operation

The transfer would be initiated by a set of control rules for the Trent. Need for support has been defined as:

'Transfers would be triggered by new abstractions (ie, those licenced after the introduction of control rules on the Trent) having the effect of reducing residual flows below the prescribed flow, or of further reducing residual flows if otherwise below the prescribed values. Transfers would be required to restore flow to the prescribed value, or to make good the full amount of the new abstractions, as may be.'

1.3) Control Rules for the Trent

The prescribed flow control rules for the Trent have been addressed under a separate project. Prescribed flows have only been estimated for the fluvial Trent, further study would be required for them to be estimated for the Tidal Trent. For the purpose of this study three prescribed flows at Colwick were used to provide a trigger for the transfer; 1750 Ml/d, 2050 Ml/d and 2400 Ml/d.

1.4) Capacity of the Severn to provide Transfer Flows

Historically, when the Trent requires augmentation the Severn has also been suffering from low flow conditions. As a result to provide support to the River Trent the River Severn would also require augmentation. Transfers would most likely be required between June and October.

1.5) Operational Considerations

The transfer would normally be drained down over the winter period. However, it should be kept full once used in the summer with a sweetening flow to avoid water quality problems developing in the pipeline. Balancing storage would be provide in the Trent side of the water shed to reduce the operational losses in the system. The balancing storage provide 3 to 4 days flow storage.

2) Modelling

The hydrological study was undertaken using the flow records from Colwick from 1959-1992 along with the simulated river flows in the River Severn produced by the Regional Resource Allocation Model (NRAM). The period of record was 1959 to 1990. By comparing the two flow records, the prescribed flow and the transfer capacity the need for the transfer could be calculated.

3) Yield

If the Severn was already being augmented to support downstream abstractions it was deemed necessary for the transfer to the Trent to also to be supported. Operational and transmission losses were estimated with reference to the experience gained in the River Severn.

The number of days which the flows at Colwick were below certain flows are given in Table 1. The large overlap between the periods of required augmentation for the River Severn and the River Trent (assuming a prescribed flow of 2700 Ml/d) is shown in Figure 2. It is clear that whenever the flows in the Trent require augmentation the flows in the Severn will also have to be augemnt to support the transfer.

The ability to support a continuous abstraction from the Trent at Torksey using flows from the River Severn will be dependent upon the provision of additional support to the River Severn. The storage volume to support this increased augmentation is related to the installed transfer capacity and the prescribed flow rate at Colwick.

The estimated increase in storage required to support the transfer for the different transmission rates and prescribed flows in an extreme year (1976) are given in Table 2. The storage assumes a single year rather than a two year drought. Detailed analysis of the storage location and operation were outside the brief of the WS Atkins study,.

Year	No Days Below Prescribed Flow (Ml/d) River Trent at Colwick					
	2700	2350	2150	2050	1850	1750
1959	137	107	79	49	12	12
1960	27	2	0	0	0	0
1961	29	0	0	0	0	0
1962	18	3	1	0	0	0
1963	0	0	0	0	0	0
1964	16	3	0	0	0	0
1965	0	0	0	0	0	0
1966	0	0	0	0	0	0
1967	0	0	0	0	0	0
1968	0	0	0	0	0	0
1969	0	0	0	0	0	0
1970	14	0	0	0	0	0
1971	8	0	0	0	0	0
1972	17	0	0	0	0	0
1973	0	0	0	0	0	0
1974	40	3	2	0	0	0
1975	133	71	20	4	0	0
1976	132	106	96	92	77	77
1977	78	23	1	0	0	0
1978	33	2	0	0	0	0
1979	48	10	0	0	0	0
1980	0	0	0	0	0	0
1981	21	2	0	0	0	0
1982	0	0	0	0	0	0
1983	12	0	0	0	0	0
1984	61	30	5	1	0	0
1985	0	0	0	0	0	0
1986	37	0	0	0	0	0
1987	0	0	0	0	0	0
1988	0	0	0	0	0	0
1989	122	91	54	39	0	0
1990	123	81	65	51	6	6
Total	1,106	534	323	236	95	95
Average	35	17	10	7	3	3

Table 1 - No of days below certain flows at Colwick, River Trent between 1959-1990

Residual Flow at Colwick (Ml/d)	Installed Transfer Capacity (Ml/d)	Additional Storage for Severn (Ml)	Storage assuming 20% losses
1750	100	7700	9240
	300	24500	29400
2050	100	9200	11040
	300	27900	33480
2400	100	11200	13440
	300	35000	42000

Table 2: Estimated Additional Storage for the Severn (Ml) to Support the Trent for a single extreme drought year (1976)

4) Costs

4.1) Severn to Trent Transfer Construction costs

Estimates of the costs of the routes was carried out using TR61 formulae. Construction costs will be more important than operating costs because of the relatively low forecast usage of the transfer. Table 3 summarises the construction costs associated with the three routes for the two installed capacities.

Transfer Capacity Ml/d	Balancing Storage	Route Cost (£mill)		
		1	2	3
100	without	21	27	28
	with	26	32	33
300	without	62	74	76
	with	70	82	84

Note: All costs to Q1 1993

Table 3: Construction Costs (£k) of the different transfer routes

4.2) Severn to Trent Transfer Operating Costs

Table 3 shows the annual average and extreme annual operating costs, and the discounted value of twenty-five years' operation for the 1750 and 2400 Ml/d prescribed flow constraint at Colwick. Annual fixed costs for staffing, overheads, standing and availability charges for power have been estimated as £120,000 and £175,000 for 100 Ml/d and 300 Ml/d transfer capacities. This cost would occur whether the transfer was operated or not in any year. average costs based on the estimated historic use of the scheme over the whole record are tabulated below, as well as the extreme years such as 1975 or 1976.

Transfer Capacity Ml/d	**Prescribed Flow Ml/d**	**Annual Operating Costs (£k)**		**Discounted Cost of 25 Years' Average Operation (£ million)**
		Average	Extreme	
100	1750	125	400	1.7
	2400	200	530	2.6
300	1750	235	1215	3.0
	2400	505	1705	6.5

Table 3 Average Annual and Extreme Annual Operating Costs

The transfer could be constructed in two phases. The initial capacity of 100 Ml/d could be extended by dualling some pumping capacity to the full 300 Ml/d capacity at a later date.

5) Environmental

An initial environmental assessment suggests that careful design and operational management would be needed to make the transfer scheme acceptable on environmental grounds. The transfer of water from the Severn to the Trent would in general terms improve the water quality in the Trent.

5.1) Impact on the Severn

The location of the increased augmentation for the River Severn was not investigated. Consequently it has not been possible to look in detail at the impact on the flow regime of the Severn. However, concern has been raised over the impact of the period when the Severn would be supporting the transfer without augmentation. Of particular concern was the October to December period, when Salmon migration occurs.

Selected flow duration curves were produced for the Severn for the August to December period. Naturalised historic data was used on the basis of the current level of abstractions and discharges. These were compared with theoretical curves showing the effect of a 300 Ml/d transfer to support a 2400 Ml/d prescribed flow at Colwick on the Trent. This combination of transfer options would have the greatest demand on the unsupported River Severn flows.

The estimated impact on the Severn flow duration curve for the above transfer options in the October to December period for the extreme year, 1975, and for the more average year of 1977 are shown in Figure 3. The effect of the transfer was that the period of low flow in the Severn was increased but flows in excess of twice the Q95 were relatively unaffected.

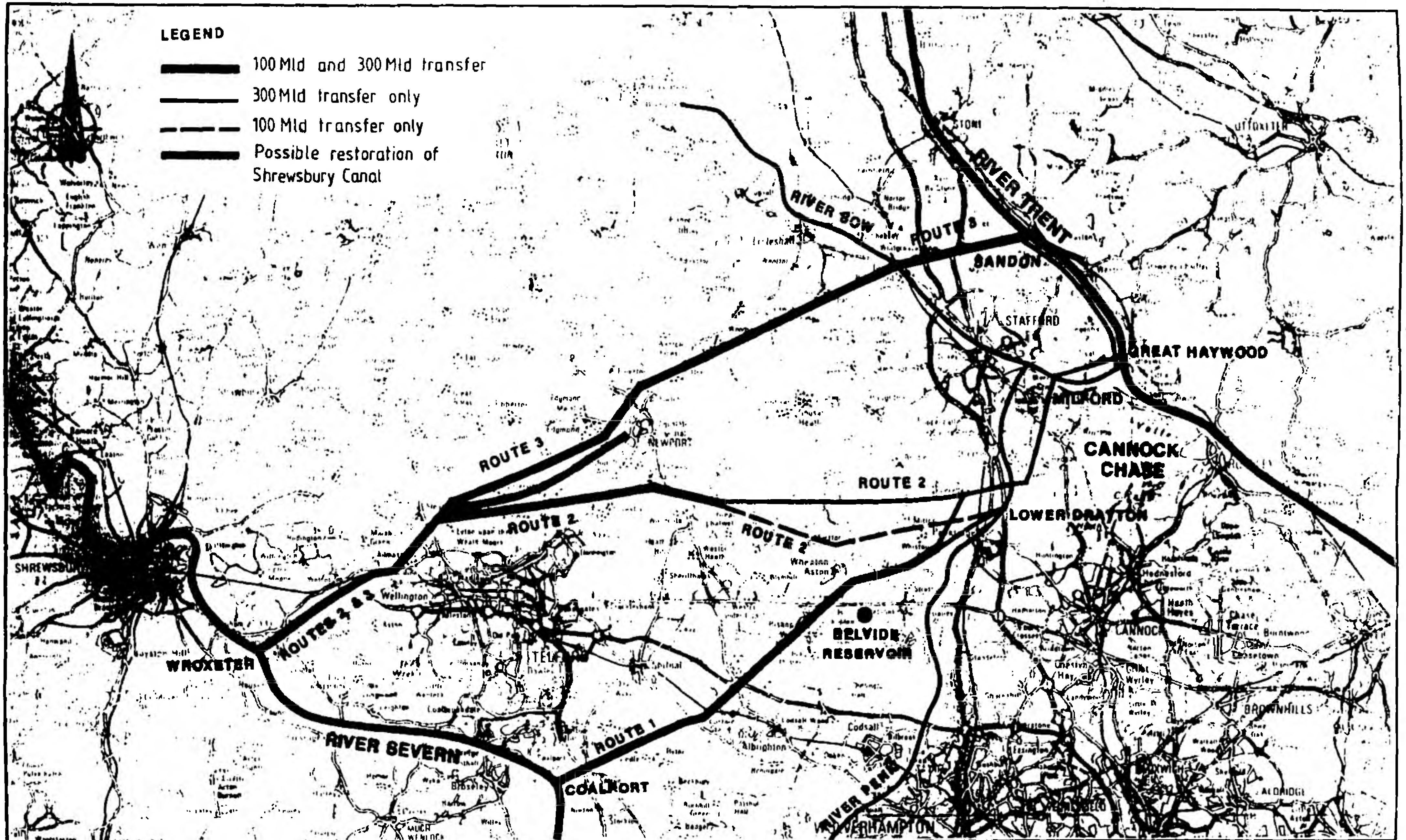
5.2) Receiving water capacities

A comparison of the proposed transfer volumes and the natural seasonal flow regimes for the various receiving waters in the Trent catchment are given in Figures 3 to 5. Mean monthly flows over the past five years are shown with horizontal lines representing the transfer volume plus the ninety-fifth percentile flow.

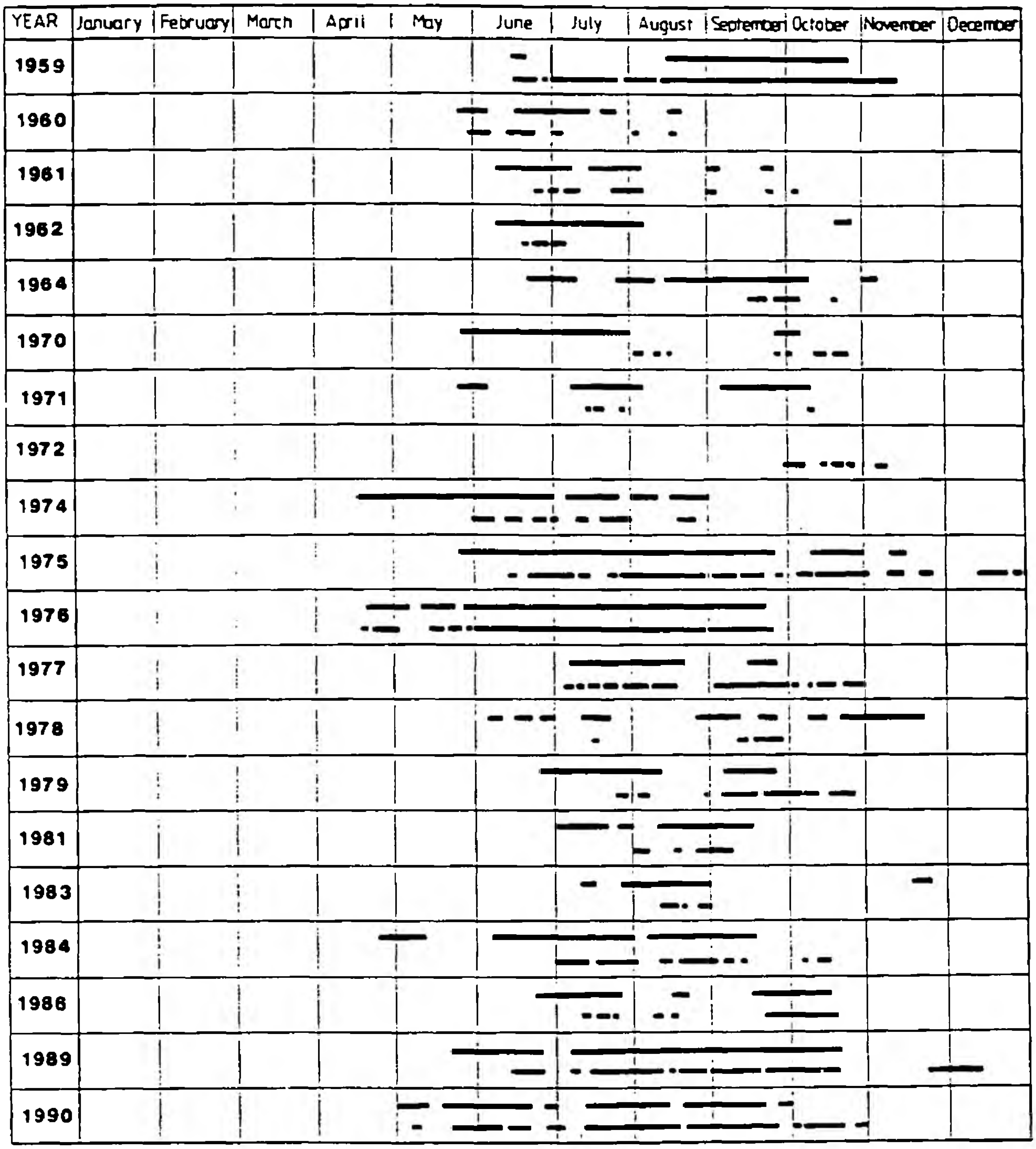
Figure 4 indicates the transfers of 100 Ml/d to Penkridge would be within the natural mean monthly flow regime for all but the months of July and August. It should be noted that the River Penk has already be 'improved' to take higher flows.

Figure 5 illustrates similar information for the River Sow at Milford.where it has been proposed that a cumulative transfer (Penk + Sow) of 200 Ml/d could be discharged. The flow record is for the period 1968 to 1976 as the gauging station has not been operating recently. The 200 Ml/d is well within the mean monthly flow regime and should not impose a threat to the existing habitats.

Figure 6 details the information for the River Trent at Yoxall. There would seem to be no difficultly in putting a cumulative transfer of 300 Ml/d.



	National Rivers Authority NRA	**SEVERN TRENT TRANSFER OPTIONS STUDY** **ROUTE SCHEMATICS**	SCALE :- 1: 250.000 **Figure 1**



LEGEND

——— PERIOD WHEN TRENT WOULD REQUIRE AUGMENTATION

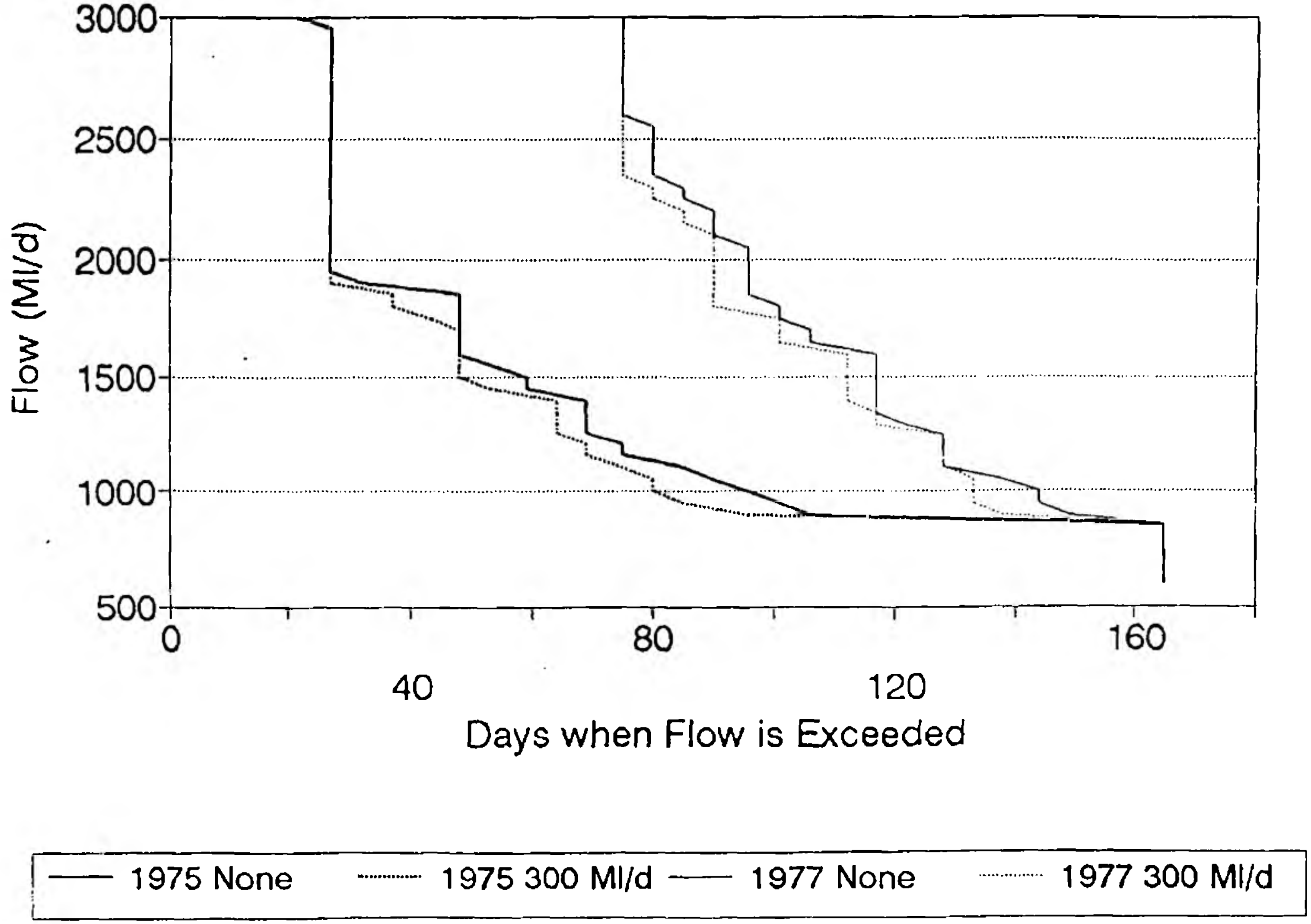
——— PERIOD WHEN SEVERN FALLS BELOW ITS PRESCRIBED FLOW

WS/Atkins

AUGMENTATION PERIODS FOR THE TRENT AND THE SEVERN

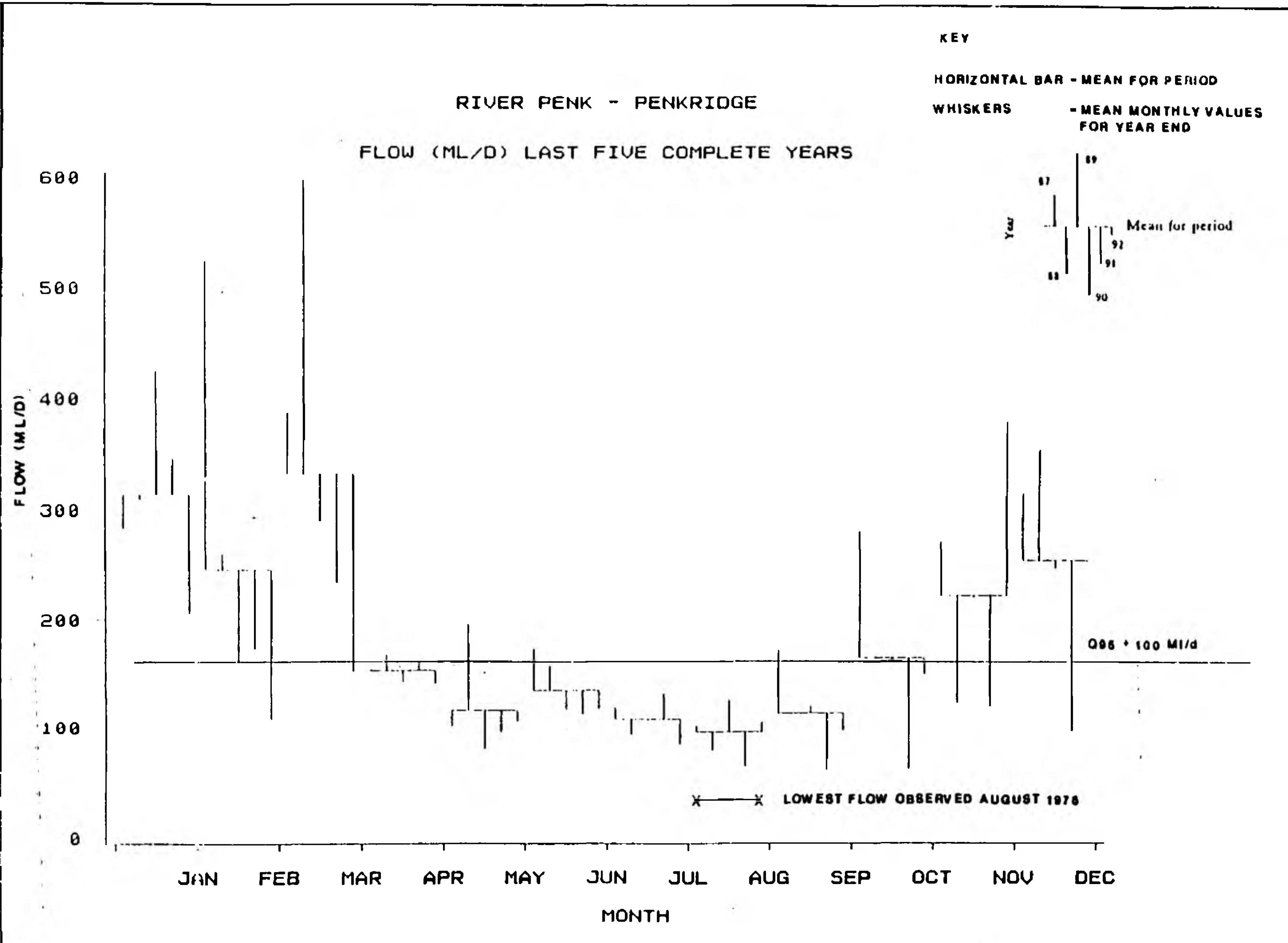
FIGURE 2

Figure 3 Severn Flow Duration Curves - '75 & '77
900 Ml/d Hands Off Flow - Aug to Dec



RIVER PENK - PENKRIDGE
FLOW (ML/D) LAST FIVE COMPLETE YEARS

Figure 4

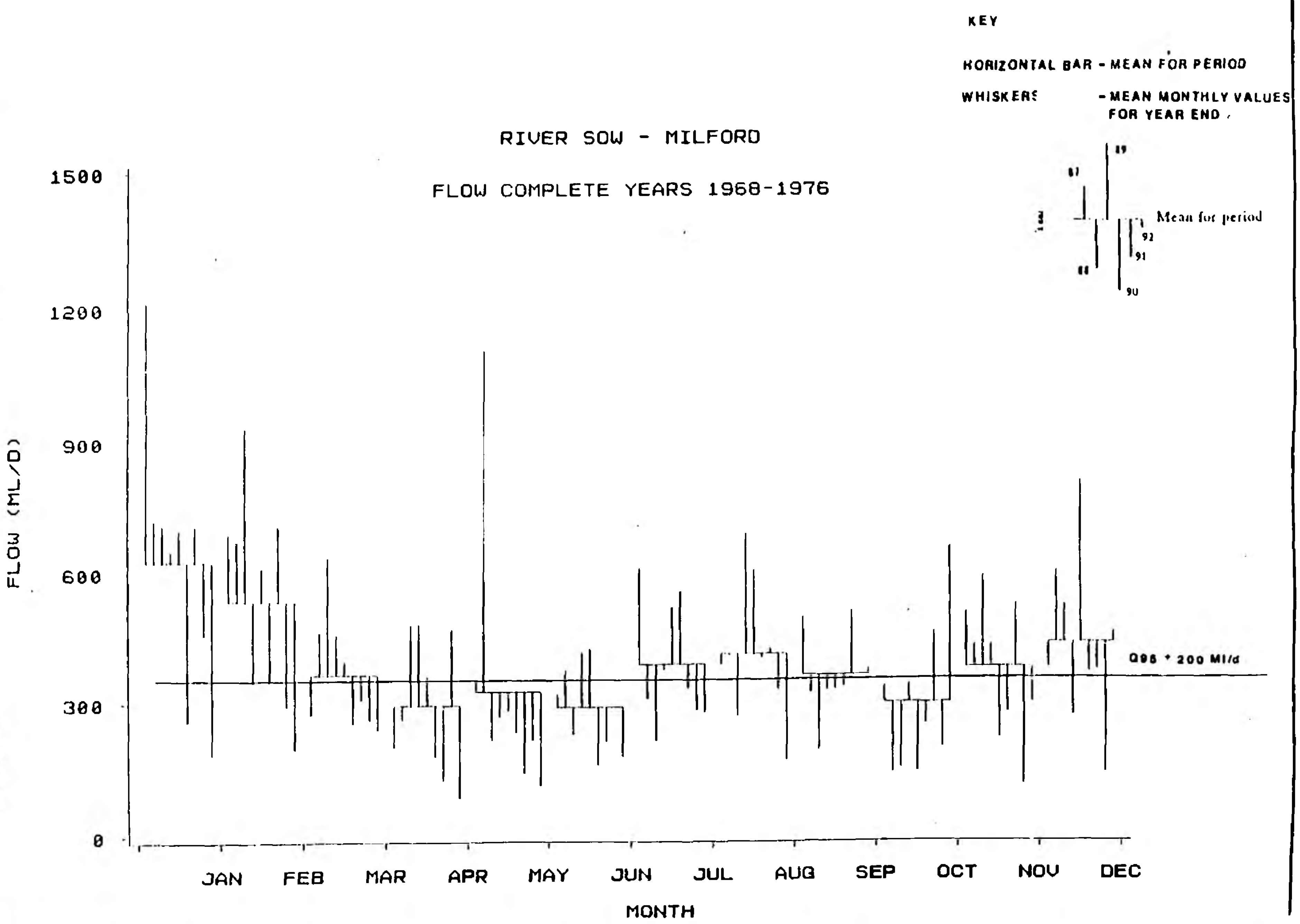


WS Atkins

RIVER SOW - MILFORD

FLOW COMPLETE YEARS 1968 - 1976

Figure 5

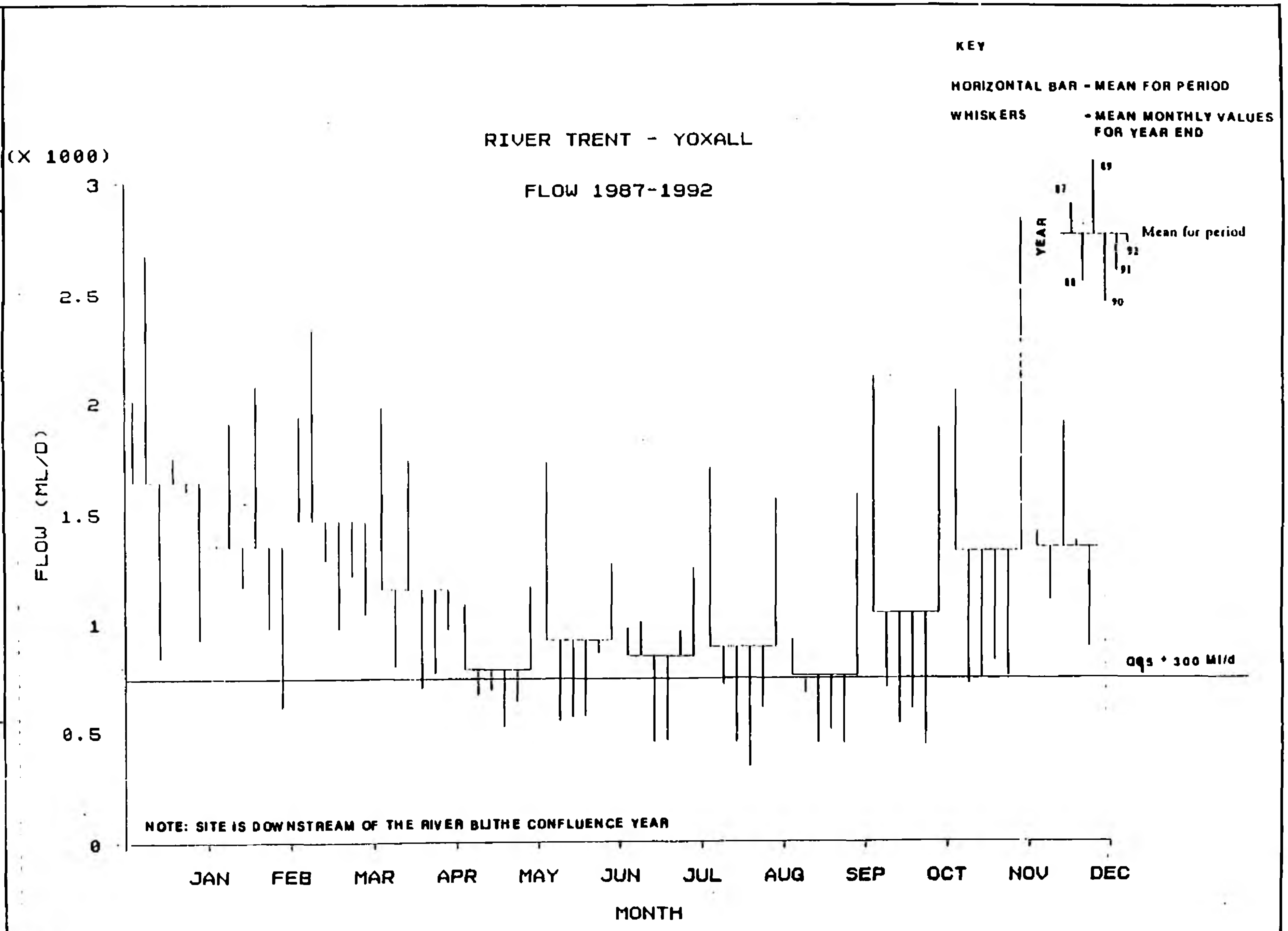


WS/Atkins

RIVER TRENT - YOXALL

FLOW 1987 - 1992

Figure 6



Appendix A5

NRA THAMES-INTER REGIONAL TRANSFERS-JULY 1993

THAMES REGION

NATIONAL WATER RESOURCES STRATEGY
INTER-REGIONAL TRANSFERS
MODELLING REPORT

JULY 1993

This report is part of a national study to identify water resources development options. Within the region these options include transfers from Anglian region and Severn-Trent region.
The Thames Region Water Resource Model (WRM) was used throughout the study to determine how and when the transfer options may be used, to what extent the transfer options could effect river flows and the resource value of the various transfer options. No account was made of the implications of the environmental aspects of the transfer options.

TABLE OF CONTENTS

Not included

1.0 INTRODUCTION

1.1 BACKGROUND

Figure one gives the overview of the transfer options being considered in this report. The four transfer routes considered are :

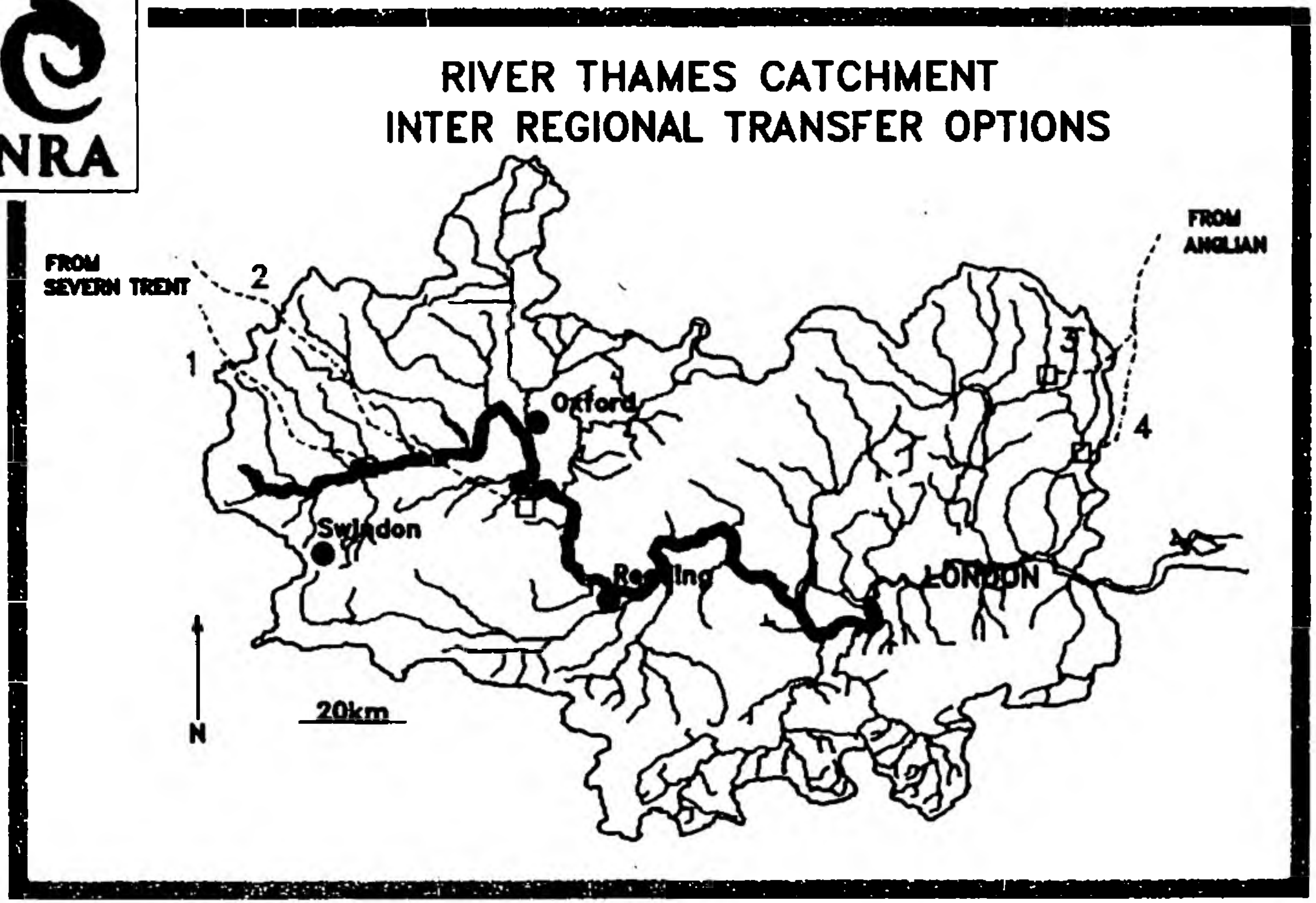
- transfer from the Severn/Trent region directly to the Thames at Buscot
- transfer from the Severn/Trent region directly to the proposed reservoir in South-West Oxfordshire (South-West Oxfordshire reservoir proposal - SWORP).
- transfer from the Anglian region directly to the Roding
- transfer from the Anglian region directly to the Stort.

The forecast demand figures used throughout this study were those supplied by the Water companies as of February 1993. It was assumed that both the Enfield/Haringey and South London artificial recharge schemes would be developed. The WRM showed that with these forecast demands and resources London demands could be satisfied until 1997.

1.2 ENVIRONMENTAL AND FLOW DATA

A separate study is being carried out to investigate the environmental aspects of the transfer options. The results in this report do not take into account any environmental constraints which may be made on the transfer options being considered. Data for the environmental study was obtained from the WRM for key points in the Thames Region. Key points were defined as Days weir for the Severn transfers and Fieldes weir for the Anglian transfers. The following data was supplied for each of the transfer options :

1. Mean Annual Flow (MF)
2. Mean Annual Flood (MAF)
3. Median Flow (Q50)
4. Q95 Long Term: Flow duration curve for full record
5. Q95 Drought Year: Flow duration curve
6. Q95 Wet Year: Flow duration curve
7. Seasonal 6 month flow duration curve (Nov-Apr,May-Oct)
8. Dry Weather Flow, Mean Annual Minimum 7-Day Flow (MAM7)
9. Drought Year AM7
10. Wet Year AM7
11. Low Flow Frequency Curve (AM7)
12. Seasonal Flow Distribution: Monthly Mean./Maximum/Minimum
13. Frequency, duration and quantities of transfer
14. Drought Year Hydrograph
15. Flow accretion diagram (AM7 and mean)



1: Severn/Trent Region–Thames Region transfer to Thames
2: Severn/Trent Region–Thames Region transfer to reservoir
3: Anglian Region–Thames Region transfer to Roding
4: Anglian Region–Thames Region transfer to Stort

FIGURE 1.

The years 1929, 1976 and 1990 were chosen as being representative of droughts in the Thames region. Based on levels of restrictions these years represent a 1:10 year drought (i.e Level 1 restrictions imposed), a 1:50 year drought(i.e Level 3 restrictions imposed), and a 1:10 year drought (i.e Level 1 restrictions imposed) respectively. For the Anglian transfer it was not possible to produce a flow accretion diagram. This is because the WRM does not output flow data at enough points along the Lee. The data for each of the resource development options is presented in appendices A to C.

2.0 THE WATER RESOURCE MODEL

2.1 BACKGROUND

The Water Resource Model (WRM) is a mathematical simulation model of the Thames catchment. It was developed in the mid seventies by Thames Water and is used today by both the NRA and Thames Water Utilities Limited for water resource planning. It models all rivers, aquifers, reservoirs, demand centres, abstraction points and effluent returns. The output from the model helps to determine the performance of surface and groundwater schemes within defined target levels of service.

2.2 HOW IT WORKS

The WRM uses a combination of the archive flow records and aquifer models for each of the major aquifers. Each sub-catchment has an aquifer assigned to it and for each of these various parameters are defined to determine the recharge and storage characteristics of that aquifer.

The base flow from each of these aquifers is calculated on a daily basis from the daily rainfall, mean monthly evaporation and the aquifer parameters. The base flow for the whole Thames catchment is then calculated from the addition of all the base flows of all the aquifers.

By subtracting the calculated baseflow from the archived surface flow data an estimate of the total surface inflow is obtained. The total surface inflow is subdivided into subcatchment surface inflow on an area basis.

2.3 DEMAND CENTRES

The model divides the Thames catchment into demand centres which generally represent self contained water distribution system. For each of these demand centres there is a forecast demand curve supplied by the relevant Water Company.

Large industrial demand centres are also incorporated into the model (i.e Didcot power station, Slough industrial estate).

For each demand centre there is a seasonal demand factor reflecting the increase use in summer. There is a factor included to account for the increased demand in the known drought years in the Thames region. The quantity of effluent returned to the river system is calculated as a fixed percentage of the quantity supplied to the each of the demand centres.

2.4 YIELDS FROM SOURCES

All sources have a licence which defines how much can be taken on a daily and annual basis. Many sources also have a pump capacity associated with them which reflects the operational capacity of the source in a drought situation.
The model determines the daily yield from all sources which depends on the demand placed on the source along with the "rules" for the source (i.e daily and annual licence values, pump capacities, quantity in store, flow constraint etc.).

2.5 THE OPERATING STRATEGY

The operating strategy is a series of curves which define how abstractions to the London reservoirs operate and when certain restrictions on water use should be imposed (1) based on target levels of service as agreed with OFWAT and the NRA :

LEVEL 1 - hosepipe bans, initial publicity campaign
Frequency of imposition 1 year in 10 on average

LEVEL 2 - voluntary restrictions on inessential use, pressure reduction, extensive publicity
Frequency of imposition 1 year in 20 on average

LEVEL 3 - ban on inessential use, further pressure reductions : S 74 - Drought order

Frequency of imposition 1 year in 50 on average

LEVEL 4 - major cuts to supply on rota basis, standpipes : S 75 - Drought order plus emergency powers
Frequency of imposition 1 year in 100 on average

S 74 & 75 refer to provisions within sections seventy-four and seventy-five of the 1991 Water Resource Act

2.6 RESOURCE VALUE

The resource value of any proposed water resource development is determined by increasing demands, on a region wide basis, until the levels of service fall below the above targets. The resource value is the increase in demands which have been met in the London demand zones. No account has been made of the "opportunistic" use of water en-route to London by other abstractors which will by definition increase the overall yield.

3.0 ANGLIAN-THAMES TRANSFER

3.1 BACKGROUND

This scheme has been fully reported by Howard Humphreys and Partners (2) and WS Atkins (3). This scheme relies on increasing the current capacity of the Ely Ouse transfer scheme and development of additional storage in the Anglian Region. Water would be pumped along the existing Ely-Ouse transfer scheme to the proposed reservoir. Augmentation releases from the proposed reservoir would then be pumped, via pipeline, to the Pant/Blackwater. From here a pipeline would transfer water to either the Roding or the Stort. Options are as follows ;

- Transfer to the Roding releasing the TWUL bulk supply to Chigwell (Essex) Currently 90.9 Ml/d
- 100 Ml/d to the Stort for abstraction to Lee valley reservoir system
- 200 Ml/d to the Stort for abstraction to the Lee valley reservoir system
- 100 Ml/d to both the Stort and Roding

3.2 ENGINEERING OUTLINE

- development of reservoir
- increase pump capacity at Kennet Pumping station
- increase transmission capacity between Kennet Pumping station and Kirtling Green
- increase in intake capacity at Wixoe Pumping station
- improve hydraulic regime of Pant between Great Sampford and Great Bardfield
- intake and pumping station at Great Bardfield
- river discharge works
- possible river training works and alterations to navigation structures
- pipelines depending on option used (see Table one)

Common to all options is Kennet-Kirtling Green Pipeline and the Wixoe-Great Sampford pipeline. Transfers to the Roding would require an additional pipeline from Great Bardfield on the Pant to the Roding at High Ongar. Transfers to the Stort would require an additional pipeline from Great Bardfield on the Pant to the Stort at Sawbridgeworth. To limit velocities to less than 1.5 m/s it has been assumed that a 100 Ml/d transfer would require a 1000 mm pipeline and a 200 Ml/d transfer would require a 1400 mm pipeline.

3.3 ASSUMPTIONS

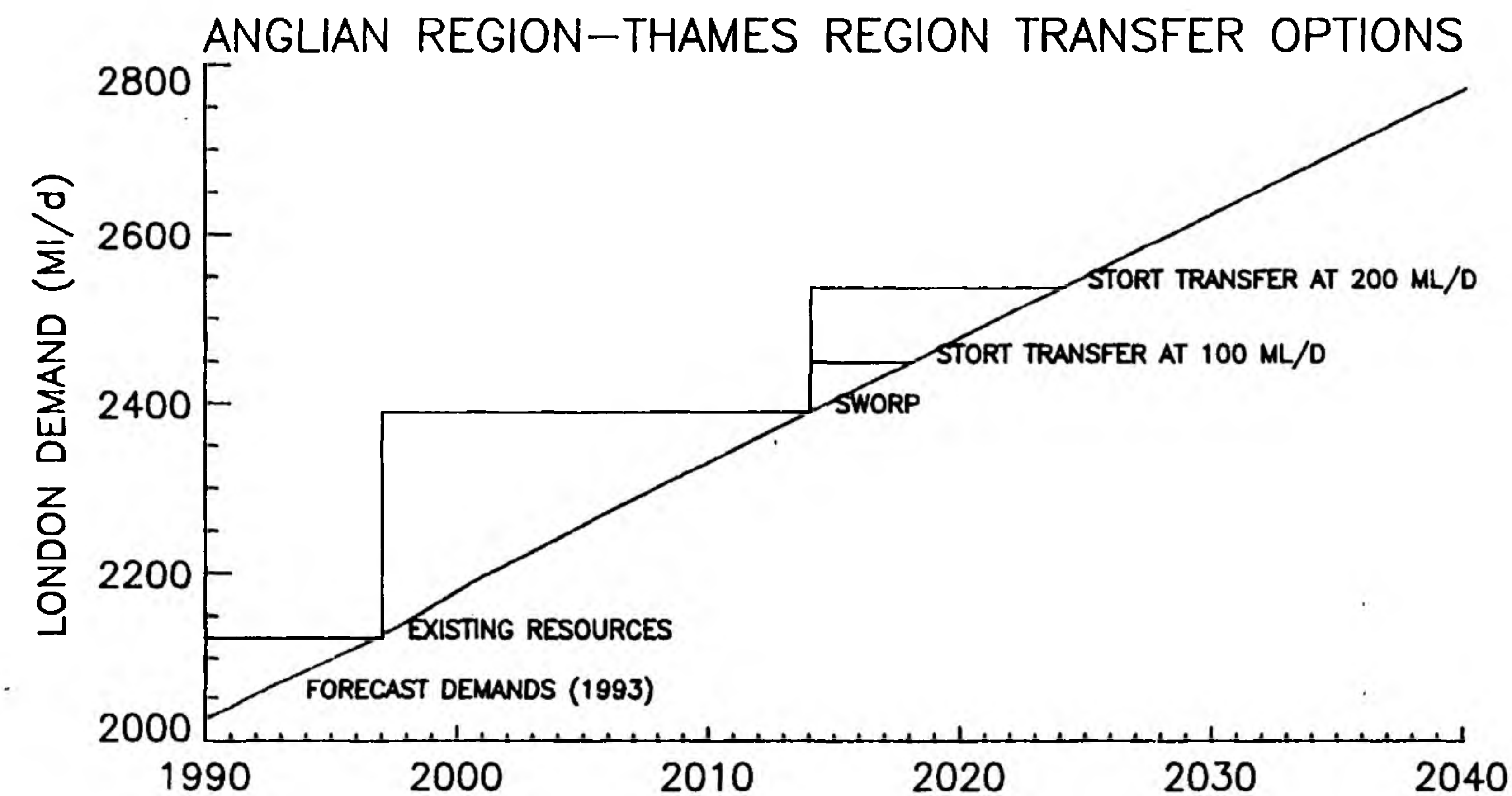
Following discussions with Anglian region it was assumed that the transfer to the Thames Region would be available all year round. The transfer may not necessarily operate all year and could, for example, be triggered by low storage levels in the London reservoir system. The transfer to the Roding would have to operate all year round to replace the current bulk supply agreement.

3.4 MODELLING AND YIELD

The WRM does not adequately model either the Stort or the Roding. Therefore, the Anglian-Thames transfer was modelled as an input to the Lee upstream of Fieldes weir. The WRM showed that the Stort transfer option would give a resource value of 81.1 Ml/d for a pump capacity of 100 Ml/d and a resource value of 176.2 Ml/d for a pump capacity of 200 Ml/d. Figure 2 shows the possible timing of these two options. The Roding transfer option would give a resource value of 90.9 Ml/d as it replaces the existing Chigwell bulk supply. The following table gives summary data on the transfer options.

TRANSFER OPTION	RESOURCE VALUE (ML/d)	YEARS USED	MEAN QUANTITY PER ANNUM (ML)	MEAN NUMBER OF DAYS/YEAR
90.9 Ml/d to RODING	90.9	72	33178	365
100 Ml/d to STORT	81.1	16	15256	153
200 Ml/d to STORT	176.2	20	28730	144
100 to STORT and 90.9 to RODING	172.0	72	48434	365

TABLE ONE : SUMMARY OF ANGLIAN-THAMES TRANSFER (1920 - 1991)



TIMING OF ANGLIAN—THAMES TRANSFER OPTIONS. FIGURE 2.

3.5 ENGINEERING DATA

Capital cost, pipeline data and static head from Howard Humphreys & Partners Limited Consultancy Report (2). Friction head from Hazen-Wiliams formula with C=100.

TRANSFER OPTION	CAPITAL COST (M£)	PIPELINE DATA	FRICTION HEAD + STATIC HEAD (m)
100 ML/D TO RODING	53.4	32 kms, ø1000	88.5 +242
100 ML/D TO RODING AND STORT	51.4	15 kms, ø1400 30 kms, ø1000	77.5 +242
100 ML/D TO STORT	80.7	28 kms, ø1400	113.8 +242
200 ML/D TO STORT	77.4	28 kms, ø1400	57.4 +242

TABLE TWO : CAPITAL COSTS ANGLIAN - THAMES TRANSFER

The above costings do not account for proposed reservoir development or the Trent-Witham and Witham-Denver component.

3.6 OPERATING COSTS

Operating costs are based on TR61 costing formula using costing factor of 7p/Kwh and a pumping efficiency of 70 %. Number of days pumping is obtained from WRM output data for the Stort options and is assumed to be continuous for the Roding option.

TRANSFER OPTION	ANNUAL OPERATING COST (K£)
100 Ml/d to RODING	3,707
100 Ml/d to STORT	333
200 Ml/d to STORT	734
100 Ml/d to RODING and 100 Ml/d to RODING	4,040

TABLE THREE : ANNUAL OPERATING COSTS ANGLIAN - THAMES TRANSFER

4.0 SEVERN THAMES TRANSFER

4.1 BACKGROUND

Details of this scheme are reported by WS Atkins (4). It consists of a transfer from the Severn near Deerhurst to the Thames region. Discharge would be either directly to the Thames at Buscot or to the proposed reservoir (SWORP).

4.2 ENGINEERING OUTLINE

- intake on Severn low lift pumping station bankside storage (1200 Ml)
- high lift pump station
- 1.5m pipeline
- gravity pipelines to discharge point
- restoration of Thames & Severn canal
- bankside storage (1200 Ml) plus works to transfer to Thames

Two possible transfer routes have been considered along with two transfer rates both with and without Severn river regulation. The first option is to transfer directly to the Thames at Buscot. The potential transfer route in this case consists of a pipeline from Deerhurst around Cheltenham ascending the Scarp slope before crossing the rivers Churn, Coln and Leach. The disused Thames and Severn canal could be utilised from here to the discharge point at Buscot. The second option is to transfer to the proposed new reservoir (SWORP). The potential transfer route consists of a pipeline from Deerhurst north of Winchcombe into the Windrush valley to the proposed reservoir.

4.3 ASSUMPTIONS

With no Severn regulation it was assumed that a flow constraint would be imposed at Haw Bridge. Modelling has been carried out using flow constraints of 2500 Ml/d and 4000 Ml/d. Because of the nature of the Severn hydrograph (i.e sharp transition between low flows and high flows) there was little difference in resource value for transfers at the two flow constraints. The modelling for this report was carried out with a flow constraint of 2500 Ml/d. Any flows over and above this value could then be made available to the Thames region (subject to the pump capacity and the Thames region requirement). With Severn regulation it was initially assumed that the requirement in the Thames region could be met by the regulation of Vyrnwy. Studies carried out by Severn-Trent Region showed that Vyrnwy could not support a transfer of 400 Ml/d but could support a transfer of 200 Ml/d. Further work is being carried out on the feasibility of a regulated transfer of more than 200 Ml/d.

4.4 ENGINEERING DATA

Capital cost are set out in table four. Capital cost data, pipeline data and total head (taken as 300 m) are taken from WS Atkins Consultancy Report (4).

TRANSFER OPTION	CAPITAL COST (M£)	PIPELINE DATA
Transfer without SWORP at 200 Ml/d	52	50 kms, ø1000
Transfer without SWORP at 400 Ml/d	75	50 kms, ø1300
Transfer with SWORP at 200 Ml/d	62	80 kms, ø1100
Transfer with SWORP at 400 Ml/d	99	80 kms, ø1400

TABLE FOUR : SEVERN - THAMES TRANSFER WITH SEVERN REGULATION ENGINEERING DATA

5.0 WITHOUT SEVERN REGULATION

5.1 MODELLING AND YIELDS

The WRM showed that with a pump capacity of 200 Ml/d this transfer option would give a resource value of 100 Ml/d and at 400 Ml/d pump capacity the resource value increases to 146.1 Ml/d. The transfer, working in conjunction with a new reservoir, would give a resource value of 102.7 Ml/d at 200 Ml/d pump capacity and 176.2 Ml/d at a pump capacity of 400 Ml/d. Figure 3 shows the possible timing of this transfer without SWORP. Figure 4 shows the possible timing of this transfer with SWORP.

TRANSFER OPTION	PUMP CAPACITY(Ml/d)	RESOURCE VALUE (Ml/d)	YEARS USED	MEAN QUANTITY PER ANNUM (ML)	MEAN NUMBER OF DAYS PER/YEAR
WITHOUT SWORP	200	100.0	23	13569	78
	400	146.1	27	24900	83
WITH SWORP	200	102.7	35	13425	82
	400	176.2	36	24844	82

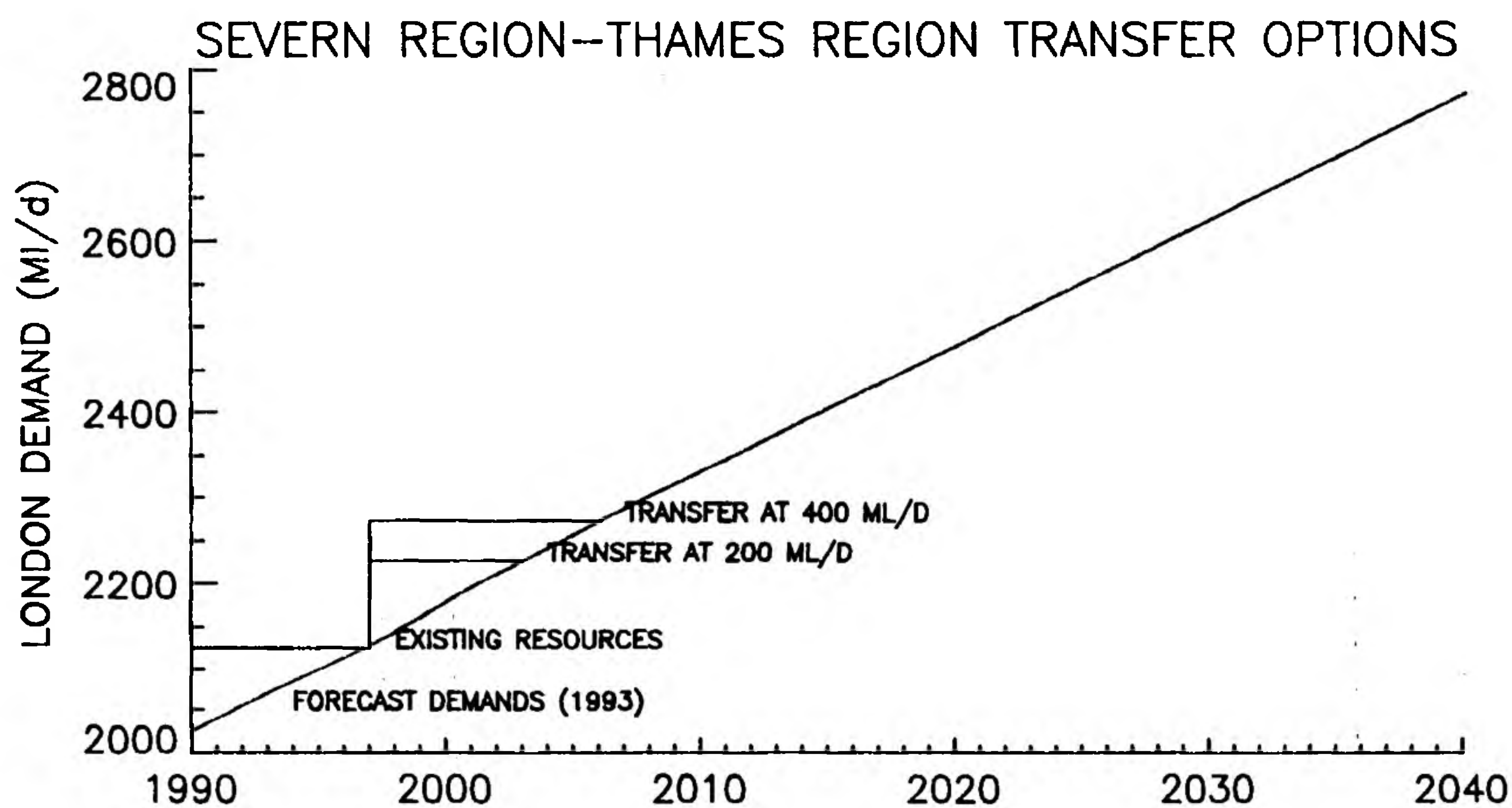
TABLE FIVE : SUMMARY OF SEVERN - THAMES TRANSFER WITHOUT SEVERN REGULATION

5.2 OPERATING COSTS

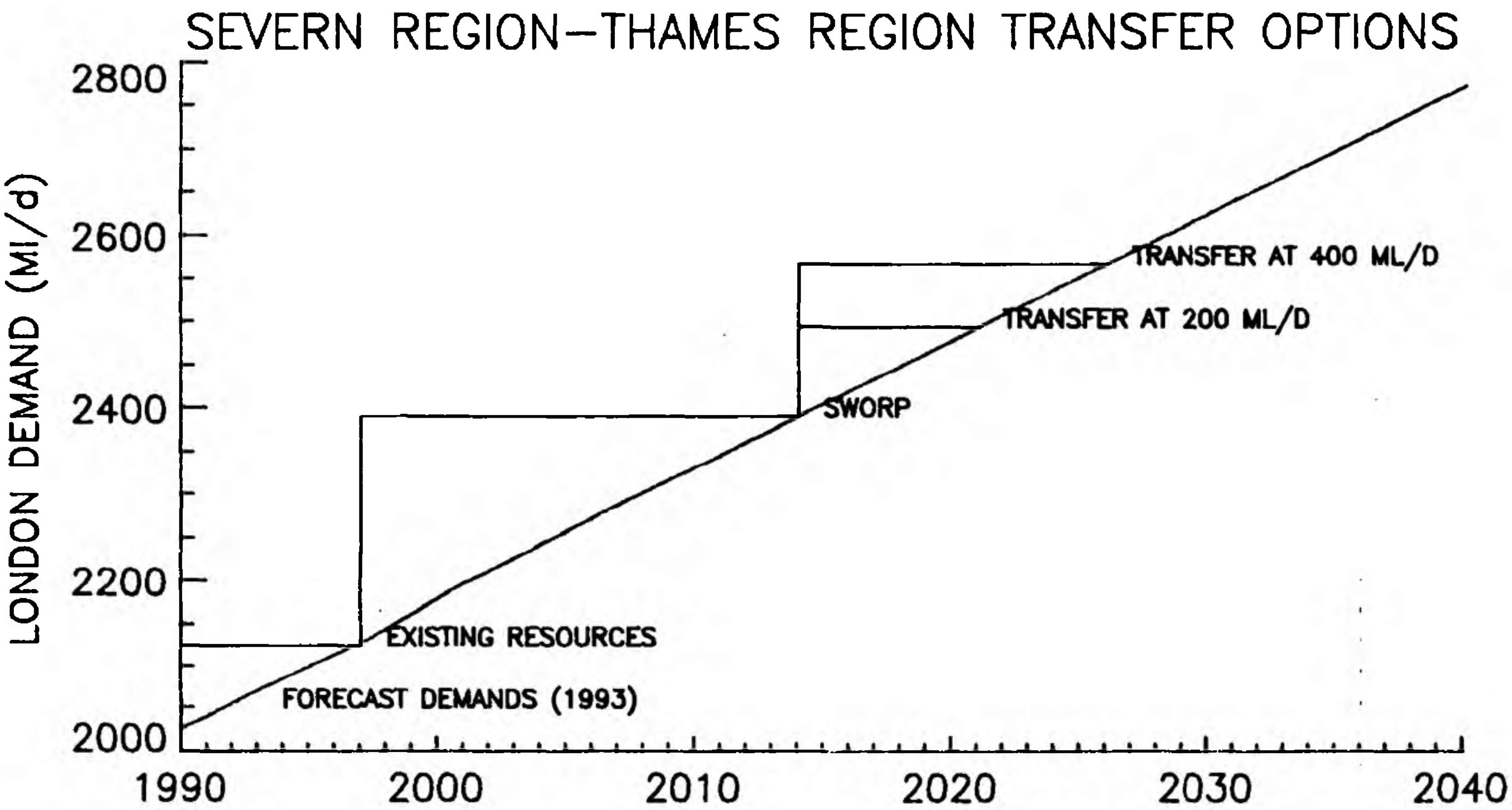
Operating costs are based on TR61 costing formula using costing factor of 7p/Kwh and a pumping efficiency of 70 %. Number of days pumping is obtained from WRM output data.

TRANSFER OPTION	ANNUAL OPERATING COST (K£)
WITHOUT SWORP 200 ML/D	460
WITHOUT SWORP 400 ML/D	963
WITH SWORP 200 ML/D	735
WITH SWORP 400 ML/D	1,507

TABLE SIX : ANNUAL OPERATING COSTS SEVERN - THAMES TRANSFER



TIMING OF SEVERN–THAMES TRANSFER OPTIONS.
WITHOUT SEVERN REGULATION. FIGURE 3.



TIMING OF SEVERN—THAMES TRANSFER OPTIONS.
WITHOUT SEVERN REGULATION. FIGURE 4.

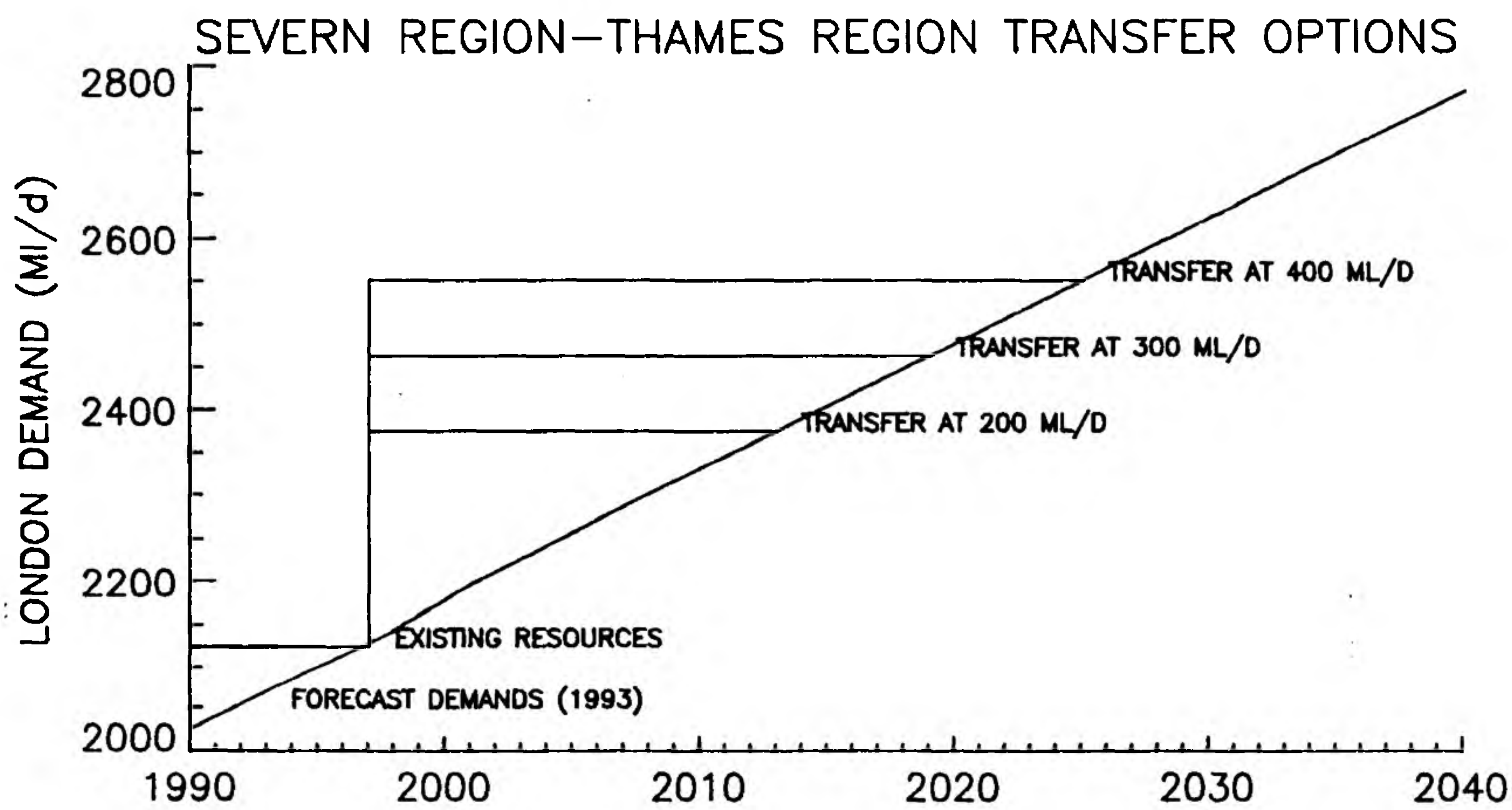
6.0 WITH SEVERN REGULATION

6.1 MODELLING AND YIELDS

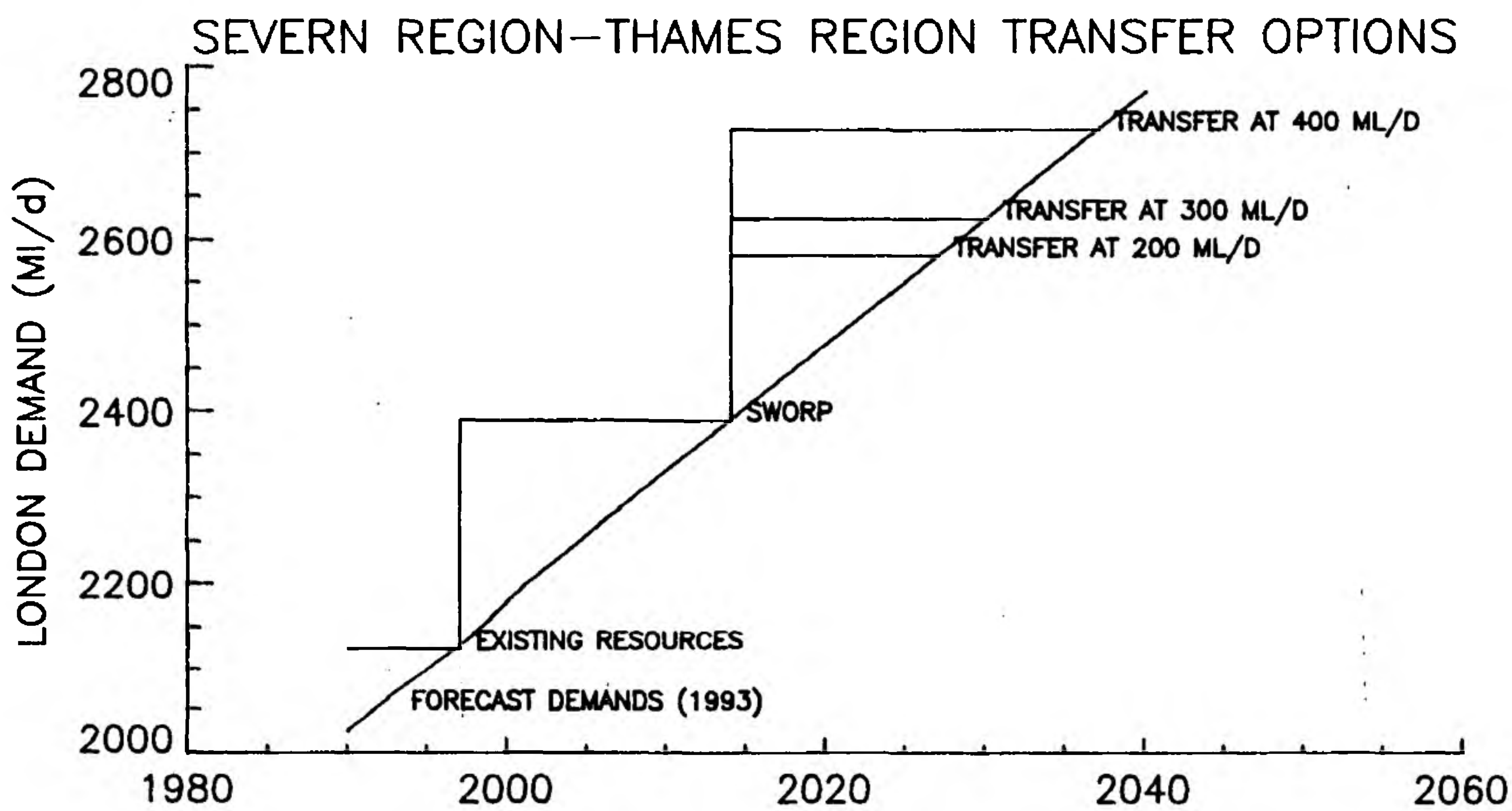
The WRM showed that with a pump capacity of 200 Ml/d this transfer option gave a resource value of 248.9 Ml/d at 300 Ml/d pump capacity the resource value increases to 337.0 Ml/d and at 400 Ml/d the resource value is 425.1 Ml/d. The transfer, working in conjunction with a new reservoir, would give a resource value of 190.9 Ml/d at 200 Ml/d pump capacity a resource value of 234.9 Ml/d at a pump capacity of 300 Ml/d and a resource value of 337.7 Ml/d with a pump capacity of 400 Ml/d. Figure 5 shows the possible timing of this transfer without SWORP. Figure 6 shows the possible timing of this transfer with SWORP.

TRANSFER OPTION	PUMP CAPACITY	RESOURCE VALUE	YEARS USED	MEAN QUANTITY PER ANNUM (ML)	MEAN NUMBER OF DAYS/ YEAR
WITHOUT SWORP	200	248.9	29	18012	99
	300	337.0	33	26386	110
	400	425.1	33	39205	121
WITH SWORP	200	190.9 (+350)	36	24641	143
	300	234.9	36	35085	144
	400	337.7	37	48748	150

TABLE SEVEN : SUMMARY OF SEVERN - THAMES TRANSFER WITH SEVERN REGULATION



TIMING OF SEVERN–THAMES TRANSFER OPTIONS.
WITH SEVERN REGULATION. FIGURE 5.



TIMING OF SEVERN–THAMES TRANSFER OPTIONS.
WITH SEVERN REGULATION. FIGURE 6.

6.2 OPERATING COSTS

Operating costs are based on TR61 costing formula using costing factor of 7p/Kwh and a pumping efficiency of 70 %. Number of days pumping is obtained from WRM output data.

TRANSFER OPTION	ANNUAL OPERATING COST K£
WITHOUT SWORP AT 200 ML/D	917
WITHOUT SWORP AT 300 ML/D	1,526
WITHOUT SWORP AT 400 ML/D	2,223
WITH SWORP AT 200 ML/D	1,315
WITH SWORP AT 300 ML/D	1,986
WITH SWORP AT 400 ML/D	2,771

TABLE SEVEN : ANNUAL OPERATING COSTS SEVERN - THAMES TRANSFER WITH SEVERN REGULATION

REFERENCES

1. TEDDINGTON FLOW PROPOSAL

Statement of case - Thames Water (1986)

2. HOWARD HUMPHREYS AND PARTNERS LIMITED

National Rivers Authority, Thames Region,Water Resource Development Options (April 1992)

3. WS ATKINS

National Rivers Authority, Anglian Region, Strategic Options Study, Option for transfer of water from River Trent and reservoir storage at Great Bradley (January 1993)

4. WS ATKINS

National Rivers Authority, Thames Region, Severn-Thames Transfer Feasibility Study (June 1993)

Appendix A6

NRA ANGIAN-WATER STORAGE AND TRANSFERS IN ANGLIAN REGION PRELIMINARY REPORT-MAY 1993

NATIONAL RIVERS AUTHORITY
ANGLIAN REGION

PRELIMINARY MODELLING OF WATER STORAGE AND TRANSFERS IN THE ANGLIAN REGION

Steve Cook
Glenn Watts
Nigel Fawthrop

Supporting Documentation for the
Regional Water Resources Strategy

May 1993

CONTENTS

1. INTRODUCTION

A draft Water Resources Strategy was produced by NRA Anglian Region in April 1993. It contains information on the current resources within the Region, and the development options to meet future demands for water. The NRA is also working towards a national water resources strategy, for publication early in 1994. Yield assessment of current and possible future surface water resource schemes has been based on computer models which simulate operation of the region's major reservoirs and transfer schemes. This report documents the modelling work undertaken by NRA staff in support of both the regional and national strategies.

Figure 1 shows the existing major sources and transfer schemes, together with those possible new and enhanced strategic links which are considered in this report. The major components of the existing system are :-

- Trent-Witham-Ancholme Scheme
- Rutland Water
- Grafham Water
- Ely Ouse to Essex Transfer Scheme

Separate models exist for each of these systems.

The Water Resources Strategy refers to five major surface water development options ;

- Reducing the Offord MRF (the figures quoted in the strategy were provided by Anglian Water Services and therefore are not discussed in this report)
- Reducing the Denver MRF
- Constructing a new reservoir either at Great Bradley or between Feltwell and Ely (the 'Fenland' site).
- Re-routing Chelmsford effluent to upstream of the Hanningfield intake.
- Imports from the River Trent to Lincolnshire and onward transfer to Essex.

More details are given the draft Regional Water Resources Strategy, especially chapters 3, 10, 11 and 12.

The baseline yields of the existing resources have been reassessed and the marginal yield of each of the options then considered, both individually and conjunctively.

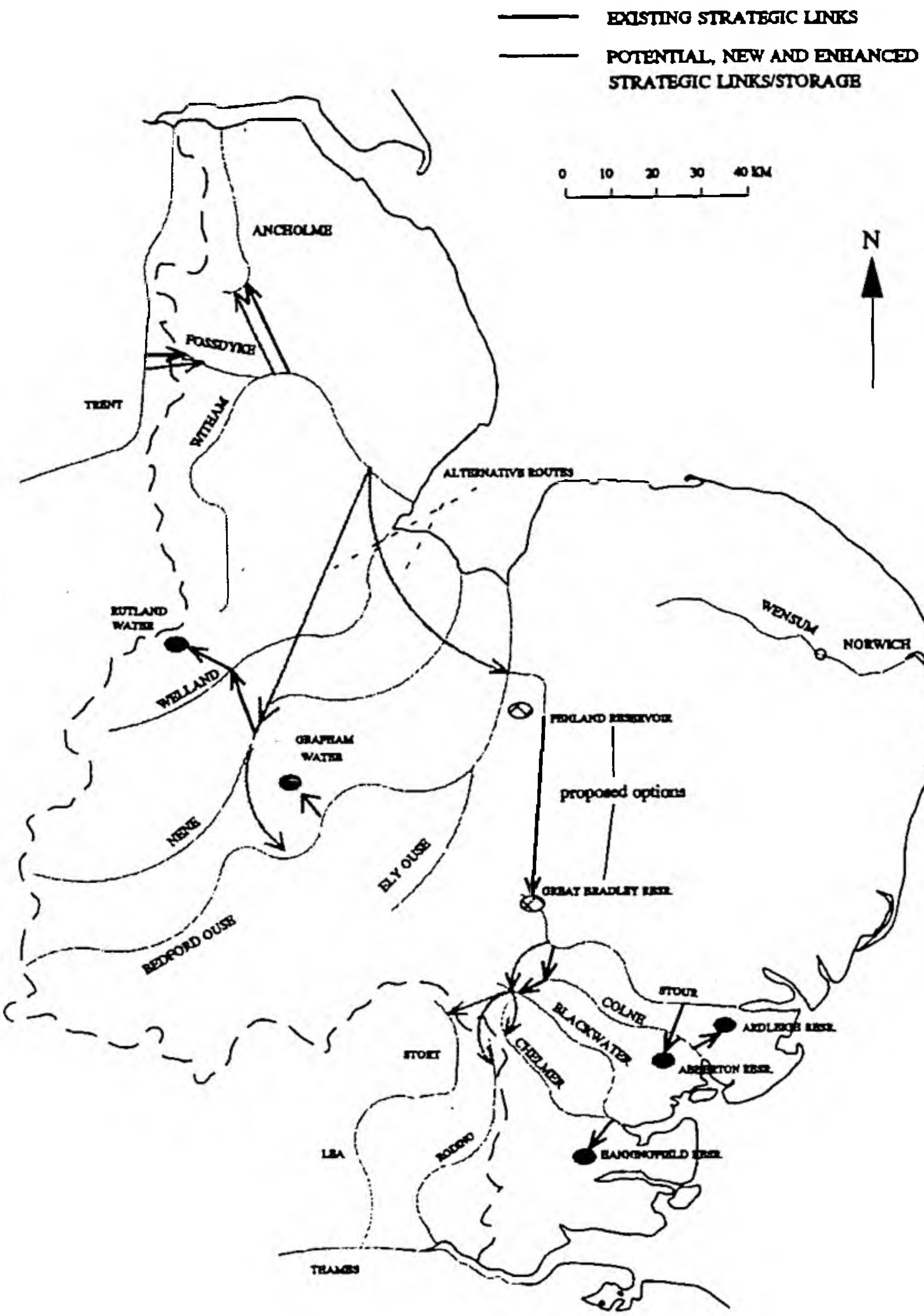


Figure 1:

Strategic transfer links - proposed and existing

2. OVERVIEW OF THE MODELLING WORK

The four separate models for the Trent Witham Ancholme Scheme, Rutland Water, Grafham Water and the Ely Ouse to Essex Scheme are described in Sections 3.1 to 3.3. Some of the proposals for future development options involve major transfers between the systems and a fully integrated model would have been desirable. In the time available it was necessary to utilise the existing models, but this does have certain advantages ;

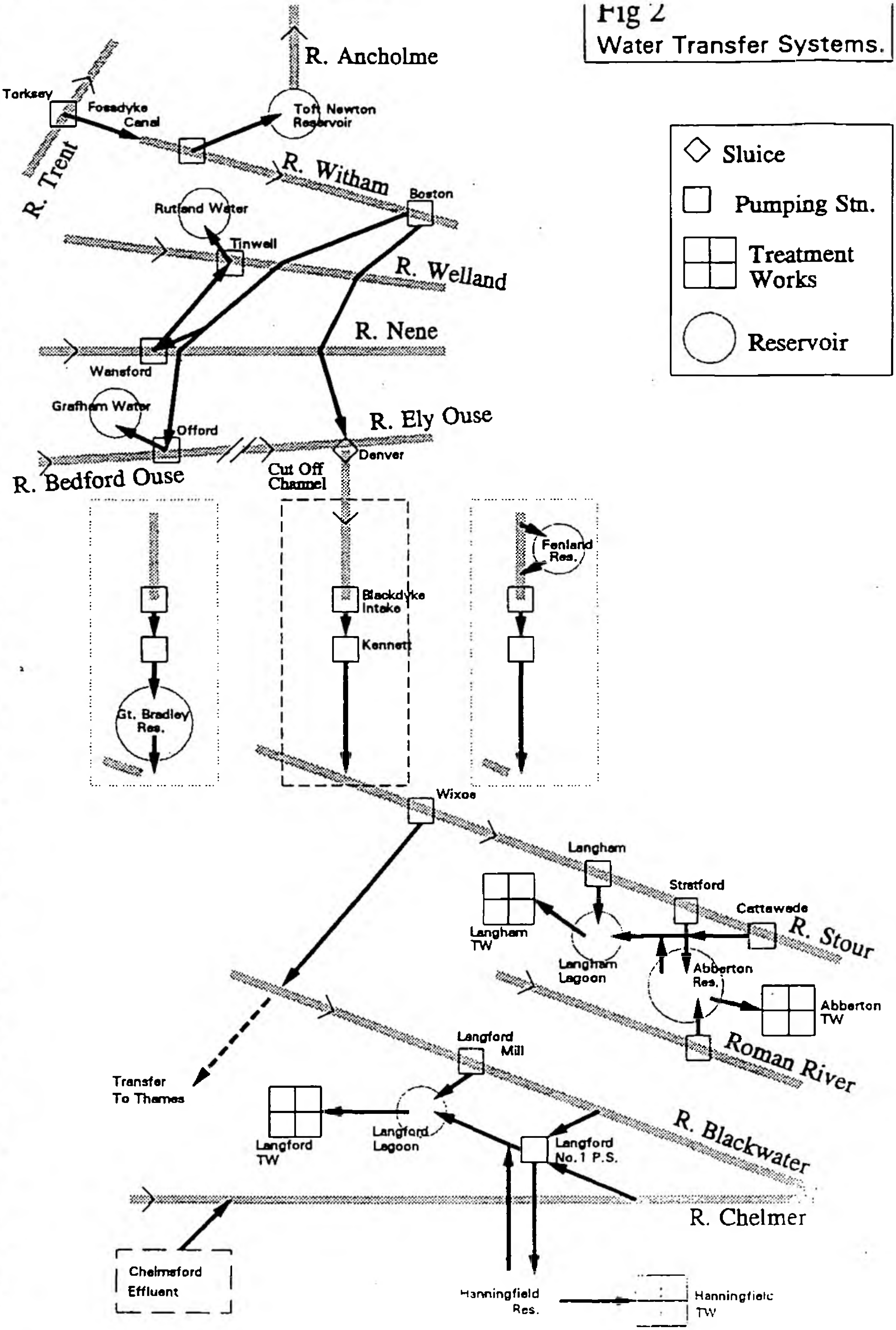
- the amount of modification and verification was minimised.
- results are comparable with previous work.

The strategic options study carried out by W S Atkins (1993) defined details of the possible new and enhanced links between the four major systems. These are shown schematically in Figure 2 which also shows key locations such as major pumps and intakes.

There are literally hundreds of possible combinations of transfer routes, link sizes, pump capacities, reservoirs sizes and operational assumptions. Given the complexity of the system it was only possible to simulate certain combinations. A link programme has been developed to allow for the transfer of data between the various models according to the assumed mode of operation (see section 4). Results are in the form 'given a, b, c and d then the yield of e is f'. This meets the requirements for RESPLAN Modelling (the economic planning model being used for the National Strategy).

This first phase of modelling work has identified the most promising options and provided some initial results for the regional strategy. However, numerous assumptions were necessary and there are some important differences between the component models. These are described in section 6. It is anticipated that additional work will be required later in the planning process.

Fig 2
Water Transfer Systems.



3. DESCRIPTION OF THE COMPONENT MODELS

3.1 TRENT-WITHAM-ANCHOLME SCHEME

The T-W-A scheme was originally designed to augment flows in the River Ancholme to meet demands in South Humberside. Flows in the River Ancholme are regulated by transferring water from the Lower River Witham at Short Ferry to the Upper River Ancholme at Toft Newton. The River Witham is also augmented in low flow periods by transfers of water from the River Trent at Torksey via the Fossdyke Canal. The option to increase the transfer capacities would make available additional water at the lower end of the Witham for transfer further South.

The model performs a daily simulation of the T-W-A scheme. A number of nodes are defined at strategic points in the system for which daily inputs and outputs are balanced. Daily transfers from the Witham to Ancholme and Trent to Witham are assessed over the historic data period. Demands can be specified for a given scenario.

Demands in the Ancholme and Witham are satisfied first using local water supplemented if necessary by transfers subject to transfer capacities and available flows in the Trent. A daily time series of flow available at Boston for onward transfer is produced, made up from excess Witham flow and/or available Trent transfer from Torksey.

Inputs to the model are the gauged flow records at key stations on the Ancholme and Witham; the gauged flow record for the Trent; pump/ transfer capacities; demands for the scenario under consideration.

Output includes daily Witham-Ancholme and Trent-Witham transfers required to satisfy Witham/Ancholme demands and a daily time series of flows available at the lower end of the Witham (Boston) for onward transfer made up from excess Witham flow and/or available Trent transfer from Torksey. Where relevant this is used as an input to the other models.

Losses of 5 percent are assumed on Trent transfers from Torksey.

3.2 RUTLAND AND GRAFHAM YIELD AND SIMULATION MODELS

3.2.1 Background

Rutland Water is a pumped storage reservoir with a volume of 137 million cubic metres occupying the upper part of the valley of the River Gwash in Leicestershire. Rutland is filled from the River Nene at Wansford and the River Welland at Tinwell. Water abstracted from the Nene is pumped to the Welland catchment at Tinwell and from there this water and the abstractions from the Welland are pumped into the reservoir. Abstractions from both the Nene and the Welland are controlled by minimum residual flows; above the minimum residual flow all water may be taken up to a maximum licensed volume.

Grafham Water is also a pumped storage reservoir. Situated in the Great Ouse catchment in Cambridgeshire, it has a volume of 56 million cubic metres. Water is pumped from the Great Ouse at Offord; the abstraction is controlled by a minimum residual flow. Above this flow 75% of the excess may be taken, up to a maximum controlled by the abstraction licence.

3.2.2 Yield calculation

The systems feeding Rutland and Grafham are sufficiently alike to allow them to be modelled using similar methods. Yields are calculated by the Operating Strategies method of Assessing Yield (OSAY). The principles and the method used are described by Clarke et al (1980). The method involves the derivation of control rules for the introduction of water conservation measures, the simulation of these rules over the historic period and the comparison of the resulting frequencies of introduction of the conservation measures with target levels of service. Yield is defined as the volume of water that can be abstracted from the reservoir such that it does not fail during a design drought (calculated by the OSAY program) and that restrictions on supply do not have to be enforced more often than the target frequency.

The OSAY program requires as input potential reservoir inflow sequences. These are used to calculate the design drought and to test iteratively the behaviour of the system through the historic period.

The reservoir inflow sequence is prepared from historic flow records. It is necessary to provide inflow sequences for as long as possible for the conditions under which the yield is to be calculated. Therefore the inflow sequences have to be simulated for future conditions. This is done by taking naturalised flows for the rivers in question and denaturalising them for predicted abstraction and discharge conditions. The flow records created can be used in conjunction with the licence conditions to create potential inflow sequences for all the years of the historic record. This allows examination of the behaviour of the reservoir under all of the flow conditions experienced through the historic record.

Calculating the yield of the reservoirs is a three stage process.

1. Calculate reservoir inflow sequences

Daily gauged river flows at the abstraction points are naturalised to remove the effects of abstraction and effluent. Future catchment abstractions and discharges are predicted and added to the naturalised flow record to create a flow record which demonstrates how much water would have been in the river had the predicted future abstraction and discharge conditions existed during the historic record. Licence conditions are used to calculate the volume of water that could have been abstracted from the river on each day. At this stage no consideration of the reservoir level is made; the sequences produced are potential inflow rates. For Rutland, natural inflows to the reservoir are also calculated; these include flow into the reservoir from small streams and direct rainfall on the reservoir surface. Evaporation from the reservoir surface is also considered; during summer months this can make the natural inflow to the reservoir negative. Monthly totals are created by summing daily inflows.

2. Calculate reservoir yield using OSAY

OSAY is a computer program to calculate reservoir yield. Yield is defined as the volume of water that can be abstracted from the reservoir such that it does not fail during a design drought and that restrictions on supply do not have to be enforced more often than a target frequency. Input to OSAY is the monthly reservoir inflow sequence, information about the reservoir size, target levels of restriction and the impact on demand of such restrictions. The first stage in OSAY is to calculate the design drought from the provided inflow sequence; this drought is usually more severe than any recorded during the historic period and therefore is calculated from the four worst sequences in the historic record. This is the drought through which the reservoir must not fail. Levels of demand restriction can be introduced during severe years. The levels of restriction are typically hosepipe bans (reducing demand by 10 to 12% in the summer), publicity campaigns and non-essential use bans (saving 25 to 32% in the summer), and finally standpipes (saving around 50% in summer). As each is introduced, the demand on the reservoir is reduced and therefore supply can be sustained for a longer period. Target frequencies for these restrictions are typically 1 in 10 years, 1 in 20 years and 1 in 100 years. MRF reductions have not been allowed. OSAY simulates reservoir behaviour at different demands, searching for the maximum demand that can be sustained with restrictions introduced no more often than the targets. This demand is the maximum yield of the reservoir.

3. Simulate reservoir behaviour

OSAY calculates the maximum yield sustainable from the reservoir. To achieve this yield may not require at all times all of the water that could be abstracted from the river according to the licence conditions. To determine how much water would actually be needed, the behaviour of the reservoir is simulated over the historic period using the demand calculated by OSAY.

Details of assumptions made when calculating the baseline yields are given in Appendix 1.

3.3 ELY OUSE-ESSEX SYSTEM

The basic water resources and associated water supply systems of the Ely Ouse-Essex System are represented in a daily simulation model of two parallel systems;

- the River Stour-Abberton system
- the River Blackwater/River Chelmer-Hanningfield system

Both systems are supported by the Ely Ouse Transfer Scheme (Figure 2). There are 3 abstraction points on the River Stour at Langham, Stratford and Cattawade. Abberton reservoir is filled from Stratford and Cattawade with an additional intake from the Roman River. Langham Treatment Works is supplied via a raw water lagoon from Langham and Stratford. Abstractions at Stratford are subject to a minimum residual flow but all the flow at Cattawade may be abstracted. There is a minimum residual flow on the Roman River. Hanningfield reservoir is filled from intakes on the Rivers Chelmer and Blackwater at Langford, both subject to an MRF. A second intake on the Blackwater at Langford Mill supplies Langford Treatment Works via a raw water lagoon. Flows in the Stour can be augmented by transferring water from the Ely Ouse at Denver via Kennett. Part of the transfer can be reabstracted at Wixoe and discharged into the Upper Blackwater to support the Hanningfield system. An MRF is imposed at Denver.

The model has been adapted to incorporate the various future development options including the alternatives of new reservoirs at Great Bradley or the Fenland Site.

The operation of the system is simulated on a daily timestep for the period of historic flow data. The yield of the system is defined as the maximum uniform demand (subject to monthly demand factors) which could be met over the historic data period without failure. Failure occurs when one of the reservoirs in the system empties. This is a different definition to that used within OSAY for Rutland and Grafham. The significance is discussed in Section 6.

The Great Ouse Groundwater Scheme (GOGWS) and Stour Augmentation Groundwater Scheme (SAGS) are not represented in the model. Their separate yields are approximately 13 and 25 tcmd (but only 36 tcmd in combination) under present operating conditions. Further work will be necessary to model conjunctive use with the Ely Ouse - Essex system.

To run the model for a given option involves specifying values for all relevant parameters including reservoir capacities, intake and pump capacities, treatment works capacities and MRF's. The operating rules including any control curves required must be defined and incorporated. Essex Water Co. provided a provisional schedule of possible/probable future upgrade works which could be linked to various development options. All variables are specified within a parameter file. An example (for the baseline case) is shown in Table 1.

3.3.1 Simulation of the system

In all cases the combined yield of the Abberton/Hanningfield system has been assessed. The marginal yields of the future development options have been calculated as the additional yield obtained with the total demand on the Abberton/Hanningfield system set equal to the baseline.

For options which do not include an additional reservoir at either Great Bradley or the Fenland Site, support from the Ely Ouse is called upon whenever there is a shortfall of local water.

For options which include an additional reservoir, support from the Ely Ouse and/or new reservoir is determined according to the combined storages of Abberton/Hanningfield reservoirs relative to a control curve. For consistency the same control curve has been used for all relevant options.

Great Bradley is represented in line between Kennett and the River Stour. Releases are made to support Abberton/Hanningfield when required, limited only by pump and link capacities. The reservoir is filled from the Ely Ouse via Kennett pumps.

Table 1

Ely Ouse to Essex System model parameter file for the baseline case.

All values are in tcmd except where indicated otherwise.

Kennett pump capacity		334
Abberton reservoir capacity		21910 (tcm)
Hanningfield reservoir capacity		23175 (tcm)
Hanningfield reservoir compensation		1.1
Langham lagoon capacity		91 (tcm)
Langford lagoon capacity		160 (tcm)
Langham pump capacity		60
Langham mrf		32
Stratford St.Mary pump capacity		209
Cattawade (Brantham) pump capacity		55
Roman River mrf		0.3
Roman River pump capacity		20
Wixoe pump capacity		227
Sandford Mill pump capacity(=abstraction capacity)		0
Langford Mill pump capacity		45
Langford No.1 pump capacity to lagoon		68
Langford No.1 pump capacity to Hanningfield reservoir		240
Langham treatment works capacity		45
Langford treatment works capacity		45
Blackwater mrf		1
Chelmer mrf		1
Max. abstraction rate from Blackwater at Langford		160
Max. abstraction rate from Chelmer at Langford		165
Denver mrf	Sep.-Feb.	318
	Mar.-Aug.	114
Layer (Abberton) treatment works capacity		165
Hanningfield treatment works capacity		270
Trent to Denver transfer		0
Chelmsford effluent		0

The Fenland Site Reservoir has been represented as an offstream reservoir. Support for Abberton/Hanningfield is assumed to draw first upon the Ely Ouse directly, any remaining shortfall being made up by releasing from reservoir storage. The total support is limited by Kennett pump capacity. The reservoir is filled from the Ely Ouse by variable speed pumps with a realistic maximum value.

The total demand on the Abberton/Hanningfield system is distributed as follows: Langham and Langford Treatment Works are assumed to operate at full capacity continuously. The remainder of the demand is split between Abberton and Hanningfield reservoirs in such a way as to attempt to keep both reservoirs at equal risk of failure. The relative proportions vary from day to day and are limited by treatment work capacities at Layer and Hanningfield.

When the available support quantity is limited, water is allocated preferentially to the system with the least number of days supply capacity.

All support water input to the River Stour is subject to 15 percent losses.

The reservoirs and off-river storage lagoons are assumed to be full at the start of the simulation period.

For options involving Trent transfers the daily record of additional water made available at Denver is added to the available Ely Ouse flow at Denver. Only the normal Denver flow is subject to the MRF. The resulting flow is made available for support.

3.3.2 Data

The naturalised daily flow records for the Rivers Stour, Blackwater and Chelmer were recently reworked by the Institute of Hydrology and Binnie and Partners (1993). The period of record is October 1932 to December 1992. All flows have been denaturalised to 2001 conditions.

Chelmsford effluent has been represented by a constant 40 tcmd added to the denaturalised Chelmer flow at Langford. More realistic seasonal data was not available in time to be included in the analysis.

The gauged Ely Ouse flow record at Denver was revised recently by Binnies from January 1960 to August 1992. A naturalised flow record is not available. There are no major imports or exports. The implicit assumption in using gauged flows is that the effect of past artificial influences is representative of the effect they will have in 2001. The impact of this is discussed in Section 6.

The gauged flow record for the River Trent at Colwick is available for the period 1958 to December 1992. This has been multiplied by 1.045 on advice from NRA Severn Trent Region to account for the ungauged catchment between Colwick and Torksey. A project to naturalise the Trent flows has been initiated by Severn Trent Region.

The earliest common start date for the necessary Lincolnshire river flow data is January 1972. Witham flows have been simulated using upstream gauges and flow duration curves.

Due to the short flow data records the yields for options including Trent transfers were assessed using data for the period January 1972 to August 1992 only. For options not involving Trent transfers yields were assessed using data for the period October 1932 to August 1992 and also January 1972 to August 1992 in order to allow a direct comparison with the Trent options. The significance of this is discussed in section 6.

4. LINKING THE COMPONENT MODELS

For those options which involve the transfer of Trent water into Essex it was necessary to set up a procedure to run the separate component models in a structured way so that the appropriate flows could be passed from one to the other. This was facilitated by the use of a linking program which calculated the flows available for transfer to the next stage.

There are two basic alternatives ;

- Water transferred direct from the Lower Witham to Denver.
  This involves running only the T-W-A and Ely Ouse - Essex models.
- Water transferred from the Lower Witham to Denver via Wansford (intake for Rutland) and Offord (intake for Grafham)
  This involves running all four models.

The steps necessary are outlined below:

1. A daily record of 'gauged' flows for the River Trent at Torksey is available.

2. The Trent-Witham-Ancholme model is run using best estimates of 2001 demands.. For a specified MRF applied to the River Trent flow record a single run produces
   a) a daily record of transfers required from the Trent to meet Ancholme and Witham demands and
   b) daily records of additional Trent transfer water and excess Witham flows available at Boston for transfer further South.

   Direct Boston-Denver Link

3. For a given link capacity a daily record of additional transfer water available at Denver is produced. Losses in this link are assumed to be zero.

4. The Ely Ouse-Essex simulation model is run in yield mode for the option under consideration with the additional water from step 3 added to the Ely Ouse flows at Denver. The yield for the option is assessed and a daily record of the Trent water actually used is produced.

   Long route Boston-Wansford-Offord-Denver

5. For the option under consideration link capacities are defined for the Boston-Wansford pipeline link, the Wansford-Offord pipeline link and the maximum dropoff to the River Bedford Ouse for transfer down to Denver (Offord-Denver link). Losses are assumed to be zero for the pipeline links and 10 percent for the River Ouse link.

6. The three dropoff locations (Wansford, Offord and Bedford Ouse for Denver) are each assigned a priority to determine in which order of preference transfer water is to be allocated if there is insufficient water available to meet the demands of all three systems.

7. Using the record of available transfer water at Boston from step 2 with consideration of link capacities and loss factors a daily record of Trent/Witham water available to the first priority location is produced. The appropriate model is run to assess the increased yield of the system and to produce a daily record of Trent/Witham water actually used.

8. Step 7 is repeated for the second and third priority locations each time accounting for transfer water already used at the higher priority location(s).

9. The total transfer quantity actually used from steps 7 and 8 is then calculated. Given that Witham excess flows are used in preference to Trent transfers the total transfer from the Trent can be calculated, hence allowing the creation of a residual flow record for the Trent at Torksey.

10. The 'dropoff' quantities considered are:

Wansford	50 tcmd
Offord	50 or 100 tcmd
Denver	200 or 400 tcmd (180 or 360 after losses).

The link capacities relate to dropoff quantities:

Boston-Wansford	550 tcmd max.
Wansford-Offord	500 tcmd max.
Offord-Denver	400 tcmd max.

The order of dropoff priorities considered is either Denver-Offord-Wansford or Offord-Denver-Wansford.

5. RESULTS

5.1 OPTIONS INVESTIGATED

It is not possible to evaluate the impact on yield of all the possible combinations of variables. The Strategic Options Study by W S Atkins defined details of possible new and enhanced links. The variables investigated in this work are shown in Table 2; this can be cross referenced to the column headings in the results (tables A2.1 and A2.2).

Table 2: options investigated

VARIABLE	DESCRIPTION	OPTIONS
Trent transfer	is transfer from Trent included in this simulation?	yes/no
Trent MRF	minimum residual flow in Trent after abstraction	2000 TCMD (this value has been used for all simulations)
Witham - Denver direct transfer capacity	capacity of direct (short) pipeline	200 TCMD 400 TCMD
drop-offs Wansford, Offord & Denver	transfers from Trent routed through the long pipeline and different volumes dropped off at the three locations	Wansford: 50 TCMD Offord: 50 & 100 TCMD Denver: 200 & 400 TCMD
drop-off priority	transfers from Trent routed through the long pipeline: different priorities given to different locations	Denver-Offord-Wansford Offord-Denver-Wansford
Chelmsford effluent	re-use of Chelmsford effluent by discharging upstream of intake instead of to tide	40 TCMD constant
Great Bradley store	size of Great Bradley reservoir	106 & 46 million cubic metres (some simulations with 77 and 22 million cubic metres have been completed)
Kennett pump size	maximum pump capacity at Kennett for Ely Ouse - Essex transfers	334 - 796 TCMD
Wixoe pump size	maximum pump capacity at Wixoe for transfer from Stour to Blackwater	227, 341, 455 & 568 TCMD
Blackwater intake capacity	total intake capacity from Blackwater (Langford Mill and Langford Pumping Station)	205 & 305 TCMD
Chelmer intake capacity	intake capacity from Chelmer	165 & 205 TCMD
Langford - Hanningfield link capacity	link capacity between Langford pumping station and Hanningfield reservoir	240 - 300 TCMD
Denver MRF	Minimum residual flow at Denver	current conditions (318 TCMD Sep - Feb, 114 TCMD Mar - Aug) 114 TCMD all year 50 TCMD all year
Transfer to Thames	volume of water from Essex allocated to Thames region	0, 100 & 200 TCMD
Fen Reservoir Storage	volume of Fenland reservoir	35, 70 & 106 million cubic metres

5.2 YIELDS

For options involving Trent transfers, simulations start in January 1972 and end in August 1992. While this period includes some droughts, it may not be long enough to assess the yields of the systems with confidence. However, it is possible to compare the effectiveness of different options using this period. Therefore all of the simulations (including those not involving Trent transfers) have been carried out based on this 20 year period. The results of these simulations are given in Table A2.1 (Appendix 2). The results are expressed as the total yield of the Ely Ouse - Essex system (including additional reservoirs, if appropriate) and the individual yields of Rutland Water and Grafham Water. The table also shows the values of the variables used in each case.

For options not involving Trent transfers, much longer flow records are available for yield assessment. For Rutland Water and Grafham Water the record starts in October 1941 and ends in December 1992. For the Ely Ouse - Essex system, flows for all relevant rivers are available from October 1932 to August 1992. Therefore where possible simulations have been carried out using this longer record; these results are presented in Table A2.2. The importance of the differences between these tables is discussed in Section 6.1.

5.3 INPUT TO WATER RESOURCES STRATEGY

These tables have been used to provide information for the yields of these systems for the Water Resources Strategy. Strategy Table 1 gives the present yield of surface water resources. For Rutland, Grafham and the Ely Ouse - Essex system the yields quoted have been calculated using the long period of record and the methods described here. Strategy Table 11 presents the increase in yield associated with development options. Where appropriate the figures presented in the strategy have been taken from this modelling work. Where possible figures have been based on the long period of record; options involving Trent transfer have been based on the short record. Strategy Table 11 also presents the costs associated with these options.

5.4 IMPACT ON DOWNSTREAM FLOWS

Any change in abstraction or augmentation regime will have an impact on flows in the rivers affected. Each of the different simulations detailed here affects the flows in various rivers. Some of the changes decrease flows, while others increase them. The environmental consequences of such changes will require further investigation. It is not possible here to show the impact on flows of each simulation. To help to demonstrate the impact of the changes in the flow regime, flows have been produced for the simulation giving the largest total increase in system yield. This simulation (43 in Table A2.1) has Trent transfers to Rutland, Grafham and Denver, and increased Kennett pump sizes, but no additional reservoirs. Hydrographs and flow duration curves for various locations for 1989 are given in Appendix 3.

6. DISCUSSION OF THE RESULTS

6.1 IMPORTANT ISSUES

6.1.1 Model differences

The models used were developed in different ways for different applications. All are daily simulation models calculating yield by simulating performance over the historic record. The Ely Ouse - Essex model is a relatively complicated model simulating reservoir control curves and conjunctive use of the system. It simulates operation through the historic period with increasing yields, searching for the maximum yield that can be sustained without any of the component reservoirs failing. The Rutland and Grafham models simulate the theoretical operation of the reservoirs, taking into account licence conditions. Levels of service are incorporated in the simulation, and failure is deemed to occur if required levels of service are not met. Yield is defined as the greatest sustainable output that does not require restrictions on water use more often than levels of service allow. Therefore yield calculations from the models are not strictly comparable. Increases in yield due to developments should be broadly comparable. This is an area where more work is required.

6.1.2 Length of record

All yields have been calculated using the period 1972 to 1992. Where possible, longer records have also been used. The impact of length of record on yield depends on the type of model used. If yield is defined as the demand sustainable through the worst drought in the historic period, the impact of record length depends on the timing of the worst historic drought. If the worst historic drought occurred during the last twenty years, extending the record back to the 1930s will have no impact on yield. However, in the case of the Ely Ouse - Essex system, the worst measured drought is 1934 to 1935. Therefore yields calculated for this system with the long record are lower than those calculated with the short record. The definition of the drought through which demand should be sustainable is the subject of an NRA Research Project. At present it is thought that the demand sustainable through the 1934 - 1935 drought is more representative of the yield of the Ely Ouse - Essex system than that calculated from the short period of record.

If yield is calculated using a levels of service approach, the length of the record determines how many restrictions are allowed. For example, if hosepipe bans are allowed once every 10 years on average, in a 50 year period 5 hosepipe bans are allowed while in a 20 year period only 2 may occur. In the 50 year period, all of the hosepipe bans could occur in the same 20 years. However, with the shorter record three of these bans would not be allowed. Thus even if the last twenty years contains the worst drought on record, the yield can be lower with a short record than with a longer record. This is the case with Grafham where the yield 1972 to 1992 is 265 tcmd, but the yield 1941 to 1992 is 269 tcmd. With Rutland, the reverse is the case, and the longer record gives the lowest yield (314 tcmd 1972-92, 274 tcmd 1941-92).

Consistent methods of yield calculation and suitable record lengths are an area generally in need of rationalisation.

6.1.3 Availability of flow records

The flow records available for this work varied both in length and in type. Ideally long records of naturalised flows would be used. These are available for the Nene, Welland, Bedford Ouse (at Offord) and the Essex rivers. Their derivation is documented and they are thought to be as accurate as possible.

Only gauged flows are available for the Ely Ouse at Denver and the Trent at Torksey. Flows in the Witham and Ancholme have been calculated using low flow equations and by matching theoretical flow duration curves with gauged flows at representative upstream gauging stations; no reliable alternative flows are available at the required locations. Severn Trent NRA are investigating the naturalisation of Trent flows. The naturalisation of Ely Ouse flows at Denver is perceived to be almost impossible because of the impact of legal but unlicensed and unmeasured abstractions into the Fens. The magnitude of the effect of using gauged flows in this work is uncertain. The assumption implicit in their use is that the impact of abstraction and effluent on the catchment has been almost constant through the historic record, and that this will continue to the planning horizon. In the case of the Ely Ouse it has been argued that most groundwater abstractions are discharged back into the catchment and therefore that flows are on average altered little by abstraction. The impact of Fen abstractions is less certain. A sensitivity analysis is required to assess the effect of uncertainties in the Ely Ouse flow record on the yield of the transfer.

6.1.4 Sensitivity to control rules

In the case of Ely Ouse - Essex transfers, control rules are built into the simulation model to determine the operation of the complex system. For all simulations including either Great Bradley or the Fenland reservoir, the operation of the system has been simulated with a constant demand at Abberton and Hanningfield; this demand is equal to the baseline yield of the system without the additional reservoir. A standard control curve has been used to determine when augmentation is required. A limited sensitivity analysis has been carried out to determine the effect on the total system yield of modifying the control curve and varying the demand on Abberton and Hanningfield from the baseline. The results indicate that the yields presented here are **generally** not improved by more than 2 to 3 percent by varying the control rules. However, further work on the optimisation of control rules is required.

The issues discussed in this section do not invalidate the results presented in this report. However, they should be noted and the results should be treated with an appropriate degree of caution.

6.2 BASELINE YIELDS

	Ely Ouse-Essex tcmd	Grafham tcmd	Rutland tcmd
1932 - 92 / 1940 - 92	340	269	274
1972 - 92	412	265	314

These are the baseline yields against which all other simulations can be compared. They represent the system in its present configuration and for the abstraction and discharge conditions predicted for 2001.

6.3 MODIFICATION TO THE ELY OUSE - ESSEX SYSTEM WITHOUT TRENT TRANSFERS

6.3.1 Chelmsford effluent

The re-use of Chelmsford effluent has a direct impact on the yield of the Essex system. Adding 40 tcmd of effluent on each day increases the yield of the system by 40 tcmd (about 10%). In practice this effluent would vary seasonally and the impact on the yield is not likely to be as great.

6.3.2 Great Bradley reservoir

Kennett pump size (tcmd)	Great Bradley 106 x 10^6 m^3				Great Bradley 46 x 10^6 m^3			
	increase tcmd		increase %		increase tcmd		increase %	
	72-92	32-92	72-92	32-92	72-92	32-92	72-92	32-92
334 (current size)	117	166	28	49	52	70	12	20
455	148	196	35	58	82	98	19	28
568	167	215	40	63	101	117	24	34
681	181	226	43	66	115	129	27	37
796	189	233	45	69	123	132	29	38

Two different sizes for the Great Bradley reservoir have been considered in detail; 106 million cubic metres and 46 million cubic metres. Both increase the yield of the Ely Ouse - Essex system. With current pump sizes, the 106 million cubic metre reservoir has more than twice the impact of the 46 million cubic metre reservoir, increasing the yield by between 120 and 170 tcmd depending on the record length used. Increasing Kennett pump size increases the yield of both reservoirs, although the magnitude of the impact decreases with increasing pump size.

A few simulations were carried out with Great Bradley at 77 million cubic metres and 22 million cubic metres, although the results have not been presented here. With Great Bradley at 77 million cubic metres, performance is between those at 46 and 106 million cubic metres. A Great Bradley of 22 million cubic metres seems to add little to the yield compared to the baseline without the reservoir.

6.3.3 Fenland Reservoir

Kennett pump size (tcmd)	Fen Res 106 x 10^6 m^3				Fen Res 70 x 10^6 m^3				Fen Res 35 x 10^6 m^3			
	increase tcmd		increase %		increase tcmd		increase %		increase tcmd		increase %	
	72-92	32-92	72-92	32-92	72-92	32-92	72-92	32-92	72-92	32-92	72-92	32-92
334	180	233	43	68	137	173	33	50	98	106	23	31
455	165	203	40	59	126	144	30	42	93	89	22	26

The Fenland reservoir has been treated as an offstream reservoir; Great Bradley is assumed to be an onstream reservoir. Support for Abberton and Hanningfield is assumed to draw first directly on the Ely Ouse; if this can not provide the water required, the Fenland reservoir is used. The Fenland Reservoir seems to be a more efficient store than Great Bradley, although this is related to pump configuration and capacity. If the Fenland Reservoir is the same size as the large Great Bradley at 106 million cubic metres, it gives a yield of around 60 tcmd (about 15%) more in the entire system. A Fenland reservoir of 70 million cubic metres gives a yield of 10 to 20 tcmd more than the 106 million cubic metre Great Bradley. A Fenland Reservoir of 35 million cubic metres gives a yield 40 tcmd more than a 46 million cubic metre Great Bradley.

These differences are large. They are explained by the different assumptions made about the pump configuration and capacity of each system, which need to be considered carefully before any firm conclusions about the relative merits of the two reservoirs can be formulated. It should be noted that the maximum augmentation to the system from the Ely Ouse with the Great Bradley option is governed by Kennett pump capacity whereas for the Fenland Reservoir option this is governed by Kennett pump capacity **plus** the Fenland Reservoir fill pump capacity (400 tcmd). When Kennett pumps are increased to 681 (short record) or 796 (long record) with Great Bradley (106 mcm) a similar yield is obtained as for the same size Fen Reservoir with current Kennett pumps.

Increasing Kennett pump capacity to 455 tcmd from current size surprisingly results in a reduction in yield for all Fenland reservoir sizes considered. This highlights an inadequacy in using the same 'standard' control rules for all options. As part of the exercise to investigate the sensitivity of yield to the control rules it was found to be possible to obtain a similar yield for the largest size reservoir with both pump sizes. This indicates that the current pump capacity at Kennett is adequate for the sizes of Fenland Reservoir considered.

6.3.4 Reducing Denver MRF

Gt.Bradley size x 10^6 m^3	MRF=114 tcmd				MRF=50 tcmd			
	increase tcmd		increase %		increase tcmd		increase %	
	72-92	32-92	72-92	32-92	72-92	32-92	72-92	32-92
None	30	18	7	5	49	35	11	10
46	39	42	9	10	62	54	13	13
106	39	20	7	4	62	30	12	6

At present Denver MRF is 318 tcmd for the winter months between September and February, and 114 tcmd from March to August. Without the Great Bradley reservoir, reducing this to 114 tcmd throughout the year increases the yield of the Ely Ouse Essex system by 5 to 7%. Reducing the MRF to 50 tcmd throughout the year increases yield by about 10% compared to the base case.

With the Great Bradley reservoir the increase in yield due to MRF reductions at Denver is generally greater. With the small reservoir, a constant MRF of 114 tcmd increases yield by around 40 tcmd, while an MRF of 50 tcmd increases yield by around 50 to 60 tcmd (about 13%). With the 106 million cubic metre reservoir the reduced MRFs increase the yield by the same amount as the 46 million cubic metre reservoir for the short record, but are less significant for the long record. This difference is due to the timing and severity of the critical droughts during the two periods; the impact of record length on yield has been discussed in Section 6.1.

With the large reservoir increased Kennett pump capacities increase the effect of a constant 114 tcmd MRF by about 5 tcmd for every extra 100 tcmd pump capacity.

6.4 TRENT - WITHAM TRANSFER WATER DELIVERED DIRECTLY TO DENVER

6.4.1 Without additional reservoirs

Kennett pump size (tcmd)	Trent - Denver transfer capacity			
	200 tcmd		400 tcmd	
	increase tcmd	increase %	increase tcmd	increase %
334	83	20	90	22
681	100	24	116	28

This has been simulated with two Witham - Denver transfer capacities (200 and 400 tcmd) and different Kennett pump sizes. With present Kennett pump sizes, yield of the Ely Ouse

Essex system is increased by about 80 tcmd with a 200 tcmd Trent - Denver transfer capacity and by about 90 tcmd with a 400 tcmd Trent - Denver capacity. Doubling the Kennett pump size adds 20 tcmd to the yield with the 200 tcmd Trent - Denver capacity, and 25 tcmd to the yield with the 400 tcmd Trent Transfer capacity.

6.4.2 With Great Bradley

Direct transfers from the Witham to the Ely Ouse - Essex system have been simulated only with the 106 million cubic metre reservoir and with Kennett pumps at twice their present capacity. With a Witham - Denver transfer capacity of 200 tcmd, the yield of the system is increased by 150 tcmd (about 36%) compared to the system without transfers from the Trent, while a Witham - Denver capacity of 400 tcmd increases the yield by 250 tcmd (about 60%) compared to the system without Trent transfers.

6.4.3 With Fenland Reservoir

For the largest Fenland reservoir with current Kennett pumps and Witham-Denver transfer capacity of 200 tcmd, yield is increased by 130 tcmd (22%) compared to the yield calculated without Trent transfers. Doubling the transfer capacity to 400 tcmd increases yield by 210 tcmd (35%). With increased Kennett pump capacity to 455 tcmd similar increases in yield are obtained from the addition of Trent transfers.

6.5 TRENT - WITHAM TRANSFER WATER ROUTED VIA RUTLAND AND GRAFHAM

Drop offs tcmd			Priority	Rutland		Grafham		Ely Ouse - Essex	
Wansford	Offord	Denver		increase tcmd	increase %	increase tcmd	increase %	increase tcmd	increase %
50	50	200	D-O-W	23	7	29	11	100	24
50	50	200	O-D-W	22	7	36	14	98	24
50	50	400	D-O-W	21	7	26	10	113	27
50	50	400	O-D-W	22	7	36	14	108	26
50	100	200	D-O-W	22	7	56	21	100	24
50	100	200	O-D-W	22	7	63	24	96	23
50	100	400	D-O-W	21	7	52	20	113	27
50	100	400	O-D-W	21	7	63	24	103	25

There are many possible combinations of link capacities and priorities for this option. All have been simulated without either the Great Bradley or the Fenland reservoir. Two Kennett pump sizes have been used; one is about 70% bigger than the current capacity while the other is twice as big. Maximum augmentation values for each system have been specified. Different priorities for different systems have been considered so that if there is insufficient transfer water available to satisfy the demands of all three systems the preferred system is supplied first. In all cases Rutland has been given the lowest priority.

Both Kennett pump sizes considered give the same yields in the Ely Ouse - Essex system. This suggests that all the available water during critical periods can be handled by the small pumps.

Compared with the direct transfer to Denver, dropping water off at Rutland and Grafham makes very little difference to the yield of the Ely Ouse - Essex system. When Denver has first priority, allowing water to be fed to Rutland and Grafham reduces yield by about 3 tcmd for a maximum augmentation at Denver of both 200 and 400 tcmd. This 3 tcmd is probably due to assumed losses in the transfer system, which are greater for the long transfer route. When Grafham has the first priority, there is slightly more impact on Ely Ouse - Essex yields. If a maximum transfer of 50 tcmd is allowed to Grafham (in addition to the water normally available), yield of the Ely Ouse - Essex system is reduced by between 5 and 8 tcmd, depending on the maximum augmentation rate at Denver. If Grafham is allowed to take up to 100 tcmd of transferred water, Ely Ouse - Essex yield is reduced by between 7 and 13 tcmd, which is less than 3 percent. Yield is still over 20% higher than for the Ely Ouse - Essex system without augmentation from the Trent.

The impact of such transfers on the yields of Rutland and Grafham is much greater. In all cases, Rutland was allowed to accept an additional 50 tcmd of transferred water. This increases its yield compared to the base case by 24 or 25 tcmd (about 8%), depending on the exact configuration of the rest of the system.

The impact of transfers on Grafham yield depends on the maximum transfer rate and the priority given to Grafham. If Grafham is given first priority, 50 tcmd maximum transfer increases Grafham yield by 36 tcmd over the base case (14%), and 100 tcmd maximum transfer increases Grafham yield by 63 tcmd (24%). If Denver has first priority and Grafham is allowed to take up to 50 tcmd, Grafham yield increases by between 26 and 29 tcmd (about 10%) depending on the maximum transfer rate to Denver. If Grafham is allowed up to 100 tcmd, yield increases by between 52 and 56 tcmd (about 20%).

It should be noted that different methods have been used to calculate the yields of the different systems. This means that the absolute figures for the effect of augmentation from the Trent are not directly comparable; the method used for Rutland and Grafham yield calculation would give higher yields for a given system than that used for the Ely Ouse - Essex system. However, the increases in yield are probably broadly comparable.

6.6 TRANSFERS TO THAMES REGION

This option has been considered only in conjunction with Great Bradley Reservoir. Simulations with constant transfers of 100 and 200 tcmd have been considered. The transfer is simulated as part of the constant demand on the new reservoir (routed through Wixoe and reabstracted from the River Blackwater). Hence the marginal yield of Great Bradley is reduced by the same amount as the transfer. Further simulations are required to assess the impact on yield when water is made available to Thames at specific times rather than as a constant transfer.

6.7 SUMMARY OF RESULTS

These results help to indicate the hydrological effectiveness of modifications to the water resources systems of much of East Anglian. In terms of its hydrological impact, the most important change considered is the transfer of water from the Trent to the Witham and then to Essex. The most effective route for this is to take the water past Rutland and Grafham, dropping off water on the way. This long route affects the yield of the Ely Ouse - Essex transfer very little compared to the short route, but presents a significant improvement to the yield of Rutland and Grafham. The total yield of the system is marginally greater if Grafham has priority over Denver, but this may be an artefact of the different methods used in yield calculation. Incorporating an additional reservoir in the Ely Ouse - Essex system increases the yield of the system considerably, especially when transfers from the Trent are involved.

Based on the yields calculated here and the cost of the work involved, the Anglian Region draft Water Resources Strategy suggests that Trent transfers will not be required. Sufficient additional yield to meet Anglian's needs is available from a new reservoir, either at Great Bradley or the Fenland site.

7. FURTHER WORK

This report represents the first stage in modelling the combined yields of the major surface water supply systems of East Anglian. These results have fed into the Anglian Region Water Resources Strategy and are being used to help to make decisions about preferred development options. However, as well as the Anglian Regional Strategy, a National Water Resources Strategy is being prepared. This will require further modelling input, possibly including additional exploration of large scale inter-regional transfers. Further modelling may also be required to investigate the exact configuration of the Anglian Region's preferred options. The following areas have been identified as needing further work. Priorities will depend on the needs of the different projects.

7.1 ADDITIONAL INFORMATION

7.1.1 Trent flow record

For options involving consideration of Trent transfers, a long naturalised record for the Trent is required. Severn Trent NRA are pursuing this.

7.1.2 Witham flow record

The Witham flow record is short and derived from gauging stations far upstream. Additionally large areas of the catchment are not gauged. A method for recreating the Witham flow record needs to be developed and a long natural flow sequence should be created.

7.1.3 Natural Denver flows

The possibilities of creating these should be investigated; if it is found to be impossible to naturalise the flows, the possible impact of using the gauged flows should be investigated through a sensitivity analysis.

7.1.4 Extended natural records for the Nene, Welland and Bedford Ouse

To extend these records further will probably require modelling. As there are extensive naturalised records, this should be possible.

7.1.5 Acceptable Trent MRFs

The impact of reducing flow in the lower Trent is the subject of ongoing work by Severn Trent region. Revised acceptable MRFs will allow refinement of the modelling work.

7.2 IMPROVED METHODS

7.2.1 Consistent methods of yield analysis

Consistent methods of yield analysis for all of the systems under consideration will help to determine more accurately the relative merits of different options. Levels of Service analysis of some kind seems to be the most promising method. The options are either to develop an approach in the Region for use in the short term, or to await the outcome of the National Research and Development Project on this matter.

7.2.2 An integrated model

Tied in with consistent methods of yield analysis is the development of an integrated model of all of these supply systems. This should be flexible enough to evaluate all sorts of options without the reprogramming required in the current models, and will ensure a consistent approach to modelling. This is a long term aim and may be the result of a National initiative towards modelling. Development of such a model would need to be started soon if it were to be of use in the next phase of regional resource planning.

7.2.3 Incorporate conjunctive use of Great Ouse Groundwater Scheme and Stour Augmentation Groundwater Scheme

This refinement would provide a more integrated model of the region's water resources systems.

7.3 FURTHER SIMULATIONS

7.3.1 Sensitivity analysis and error estimation

This report presents absolute figures for the yields of the different systems under different scenarios. The quality of these values depends on the quality of the data used to derive them and the sensitivity of the models to different parameters. A sensitivity analysis will allow the important components of the models to be assessed, and identify areas where more care is required in data provision. Estimation of the errors involved in the simulations and therefore the range of values of yield will help to identify the most secure options and the degree of reliability which could be placed on new resources. This should be carried out as soon as possible.

7.3.2 Trent transfers including Grafham, Rutland and the new reservoir

None of the simulations involving Trent transfer have included all three reservoirs in the system. While present Anglian Region thinking is that this combination is not required to meet the demands of the Anglian Region, national strategy may deem that this is an effective way to supply the increasing demand of London and the south-east. Therefore this should be simulated.

7.3.3 Optimising control rules

The impact of control rules on the yield of the Ely Ouse - Essex system has been identified. Determining optimum control rules is important not only to the operation of the current system but also to any future developments. As well as increasing the yield of the system, optimal control rules may help to identify the best development options.

7.3.4 Impact of alternative Trent minimum residual flows

The results of work defining acceptable Trent MRFs will initiate further simulations to evaluate their impact on yield.

8. CONCLUSIONS

This work has helped to establish the impact of surface water developments in East Anglian on the yield of the water supply system. While there is scope for improvement of this work, the results achieved demonstrate the importance of a flexible and rigorous modelling approach in supporting water resource management decisions.

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APPENDIX 1
BASELINE RESERVOIR YIELD ANALYSIS FOR RUTLAND AND GRAFHAM

The yields of Rutland Water and Grafham Water have been reassessed using the OSAY methodology which is described in section 3.2.

Assumptions specific to Rutland

1. Orton flows (Nene), Tinwell flows (Welland) and Rutland natural inflows renaturalised using the methods described in:
   Naturalisation of the Orton flow record (Glenn Watts, 18 November 1992)
   Naturalisation of Tinwell flows (Glenn Watts, 4 December 1992)
   Natural inflows to Rutland Water (Glenn Watts, 1 December 1992).

2. Eye Brook abstractions 4.9 tcmd; 70% of this is discharged into the Nene at Corby.

3. Licence conditions: MRF of 136 tcmd at Orton (127 tcmd at Wansford), 36 tcmd at Tinwell. All water above this level may be abstracted.

4. Maximum pumping rates: Wansford 764 tcmd (full licence)
   Tinwell 545 tcmd (full licence)
   The hydraulic capacity of the Rutland intake system was designed to cope with these levels of pumping.

5. No pump scheduling: all water above the MRF is available without consideration of pump capacities and stepped rates.

6. No reduction in MRF allowed even with levels of service restrictions.

7. Reservoir capacity 137 million cubic metres.

8. Dead storage 7 million cubic metres.

9. A further 4 million cubic metres dead storage to make sure that NRA Gwash-Glen transfer water is always available when required (gives total of 11 million cubic metres). This reduces yield by 5 tcmd.

10. Additional support (beyond compensation releases) for the Welland catchment is available to the NRA. However, this does not have to be included as part of the yield as it is made available only on request if there is sufficient water in the reservoir.

11. Compensation releases included (reduces yield by 5 tcmd).

12. Leakage from Rutland to the Chater Valley at 9 tcmd (Report on Seepages in River Chater Valley, Watson Hawksley, November 1978). This reduces yield by 11 tcmd.

Assumptions specific to Grafham

1. Offord naturalisation extended from 1990 to 1992 with method used by Nigel Fawthrop and Gerry Spraggs in 1991.

2. Licence conditions: MRF of 136 tcmd at Offord, 75% take above this value.

3. Maximum pumping rate: 454 tcmd. This adds between 4 and 10 tcmd compared to a maximum pumping rate of 363 tcmd.

4. No pump scheduling: available water above the MRF is available without consideration of pump capacities or stepped rates.

5. No reduction in MRF allowed even with levels of service restrictions.

6. Reservoir capacity 56 million cubic metres.

7. Dead storage 5 million cubic metres.

8. Brownshill abstraction not used (increases yield by approximately 140 tcmd).

9. Compensation releases are 1.136 tcmd in the summer and 0.316 tcmd in the winter. This reduces the yield by 2 tcmd.

10. Grafham leakage assumed to be 2 tcmd (in the absence of any better figures).

11. No natural inflows.

12. Little Barford Power Station abstraction assumed to give a net loss to the river of 14 tcmd on all days when Offord flow is above 136 + 14 = 150 tcmd. On days when Offord flow is between 136 and 150 tcmd, Little Barford abstraction reduces flow to 136 tcmd.

General assumptions

In both cases, OSAY levels of service restrictions have been set at:

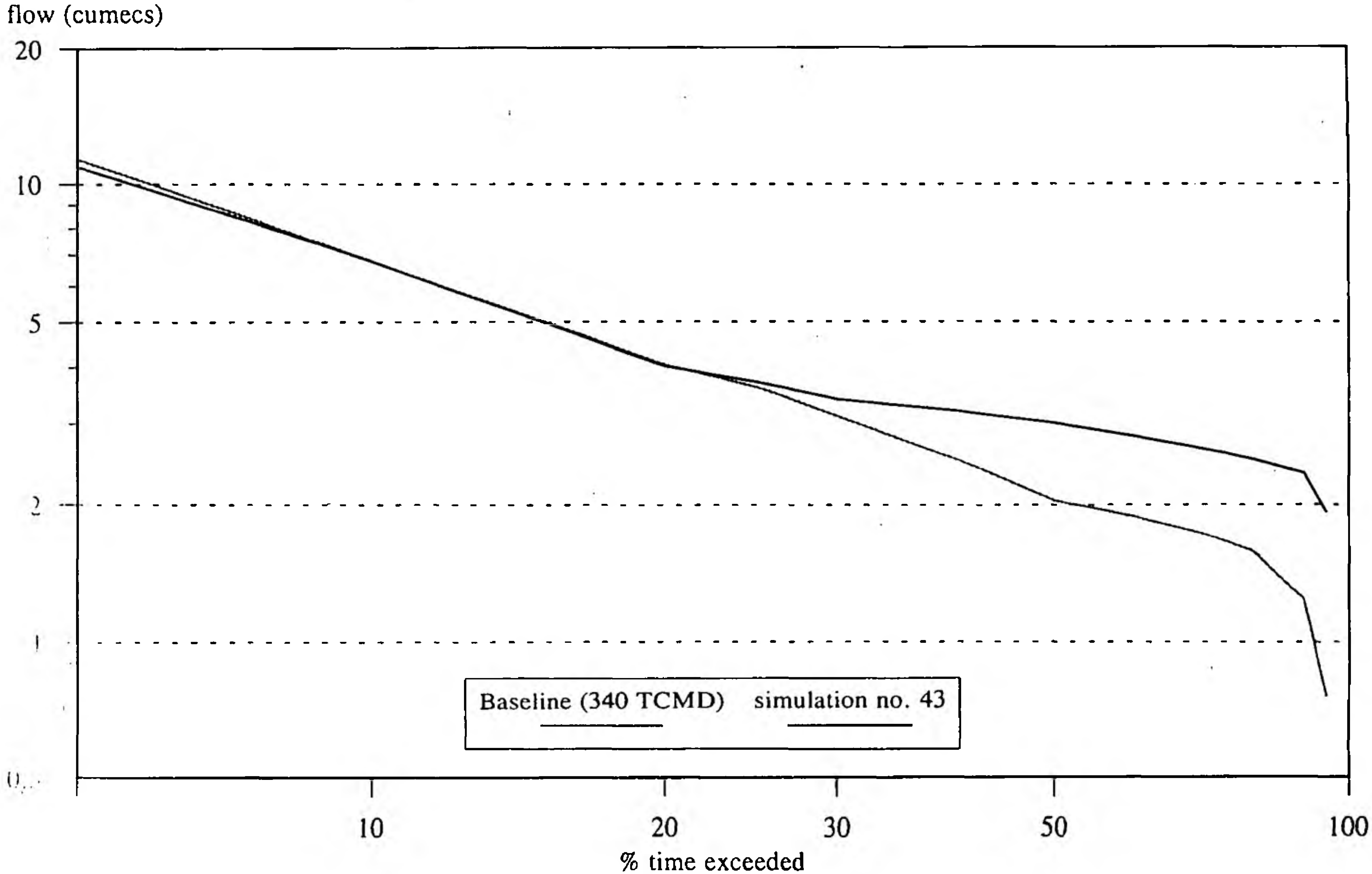
hosepipe ban: 1 in 10 years

publicity campaigns and non-essential use bans: 1 in 20 years

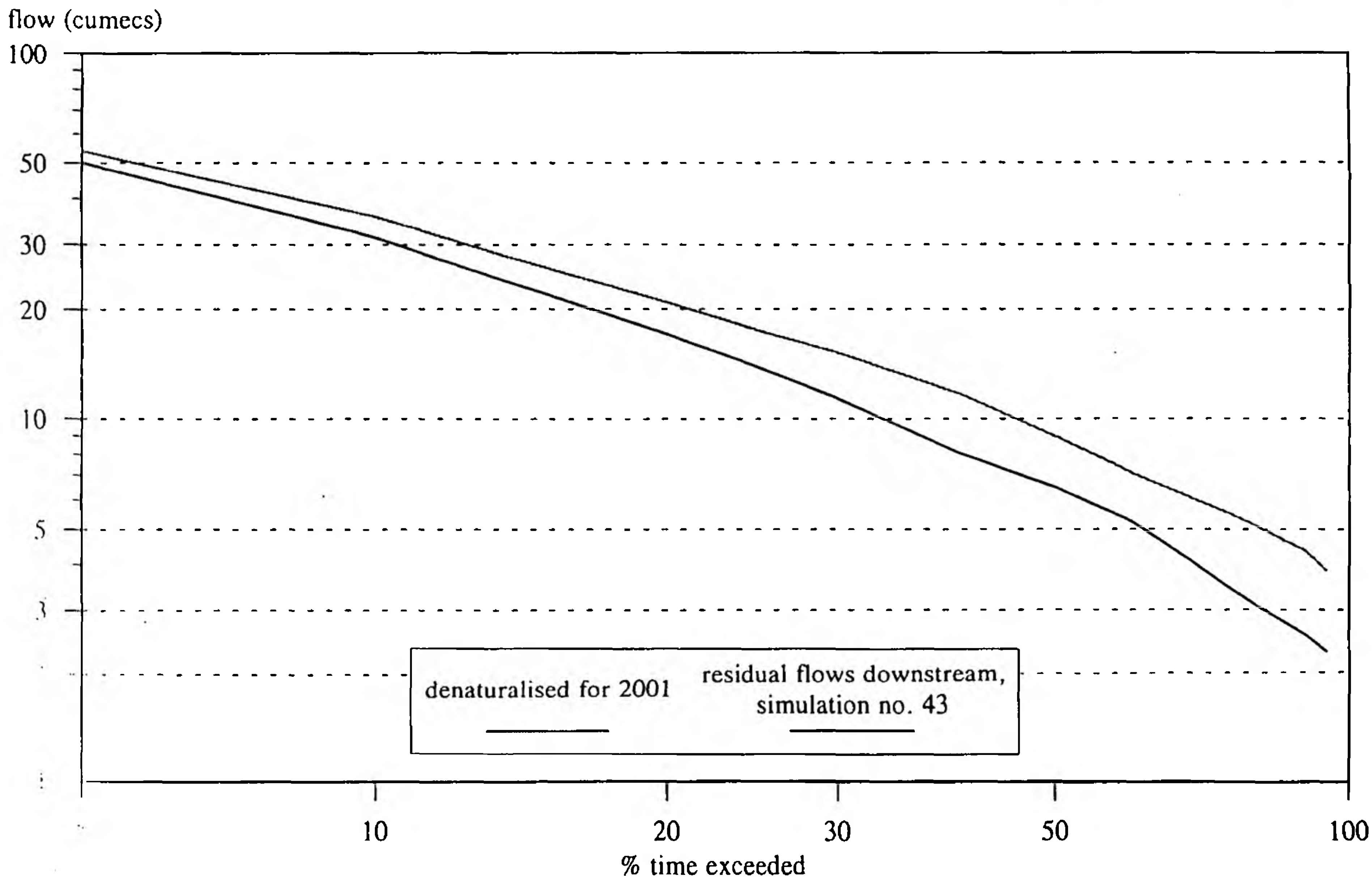
standpipes: 1 in 100 years.

No additional augmentation has been allowed at any time. It is possible to increase the yield of reservoirs by introducing drought orders to reduce river MRFs, effectively making more water available for pumping. However, there is no guarantee that drought orders will be awarded, and therefore they can not be considered to be a dependable additional source of water. Thus they should not be used to calculate reliable yield.

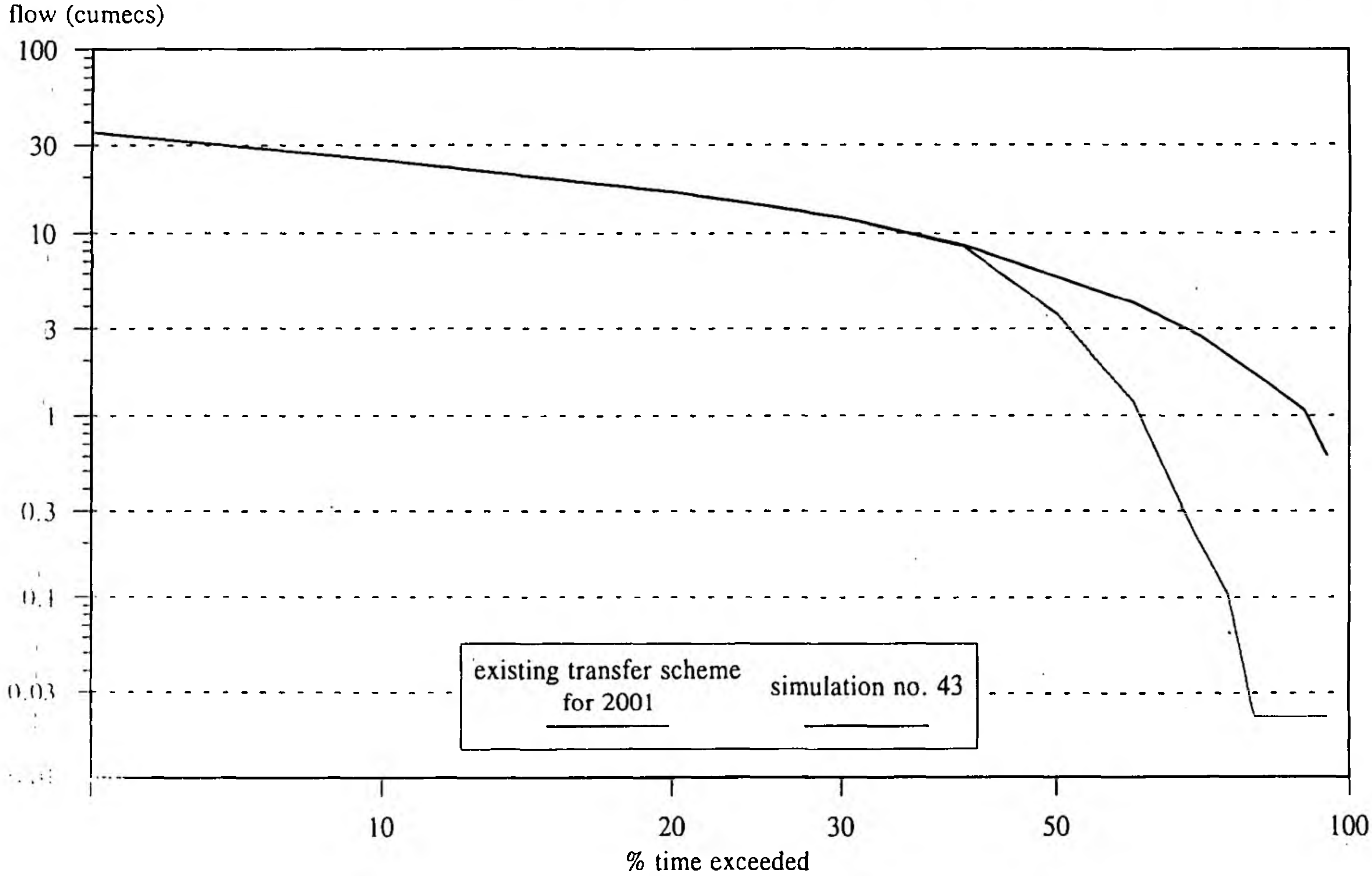
For both Rutland and Grafham, theoretical yield has been calculated. The analysis does not take into account current operating regimes or restrictions on pumping rates imposed by the inability of pumps to abstract all water available. The quoted yields are those which could



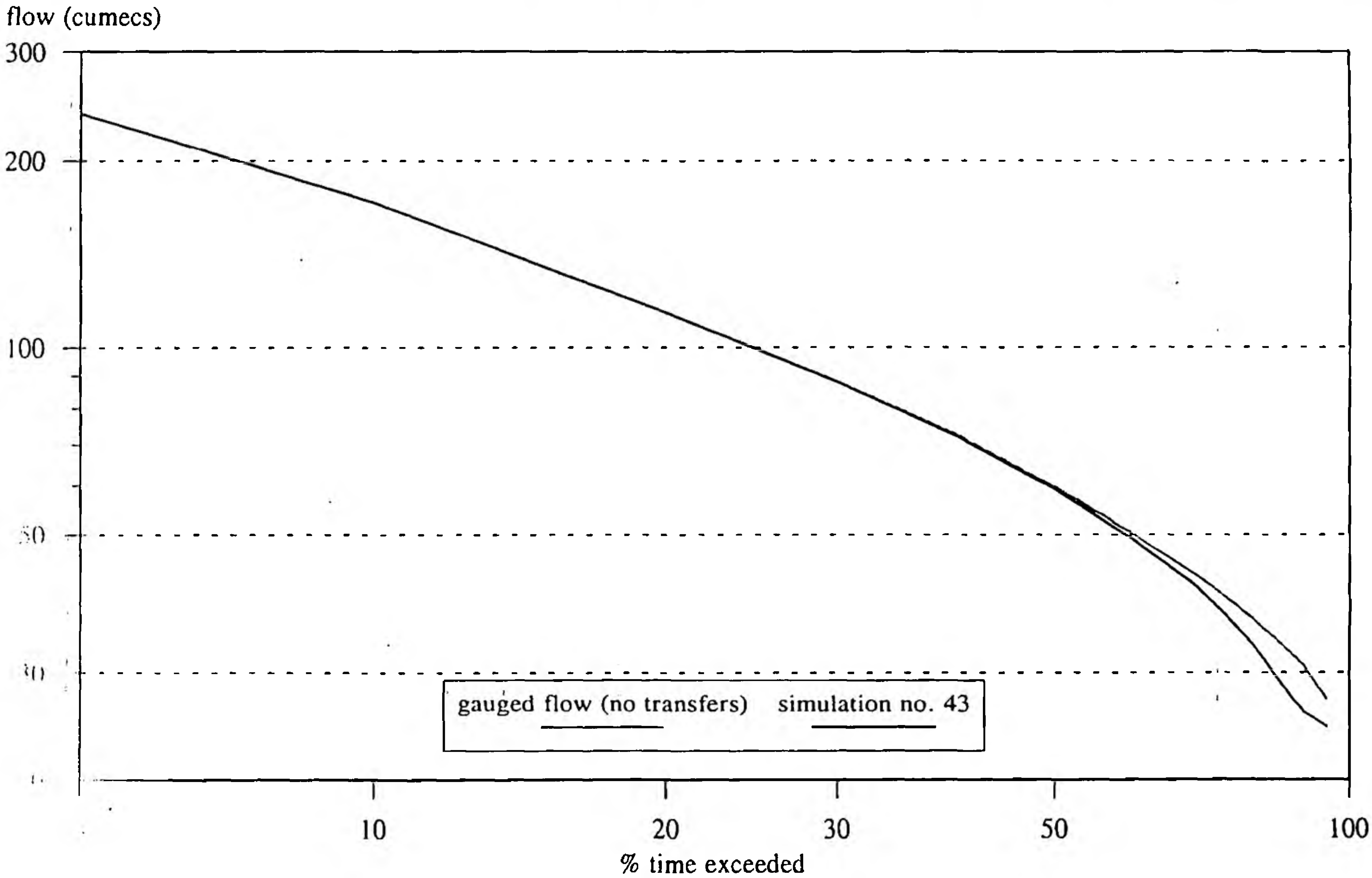
Stour at Langham
Simulated flow duration curves 1972 - 1992



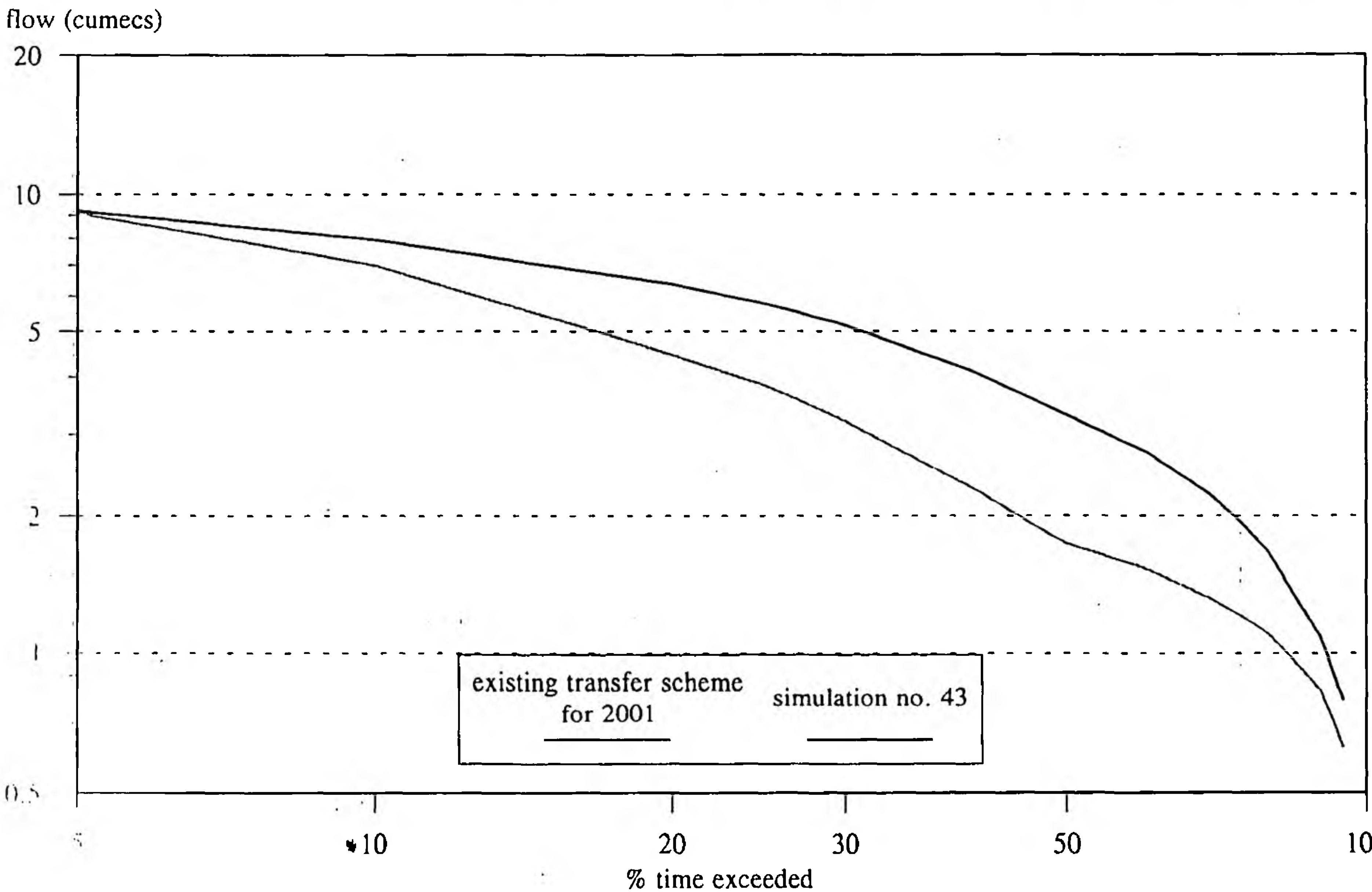
Bedford Ouse at Offord
Simulated flow duration curves 1972 - 1992



Witham upstream of Boston
Simulated flow duration curves 1972 - 1992



Trent at Torksey
Simulated flow duration curves 1972 - 1992



Witham downstream of Fossdyke
Simulated flow duration curves 1972 - 1992

APPENDIX 3: SIMULATION OF DOWNSTREAM FLOWS

These plots illustrate the type of data which is available for Environmental Impact studies. Flow data may be presented numerically, as summary statistics, as hydrographs or as flow duration curves.

be obtained were the systems to be operated at full efficiency. These yields are unlikely to be achieved operationally, although as the systems are refined they may be approached.

APPENDIX 2: SIMULATION RESULTS

TABLE A.2.1 RESULTS FOR SIMULATIONS 1972 - 1992

	Trent Tran ?	Trent mrf	TWA demand	Wit-Den direct cap	Drop offs W-O-D	Drop off Pri'ty	Chelm Eff	Great Brad Store	Kenn. Pump Size	Wixoe pump size	Black water int. cap	Chelm int. cap	Lang Hann. link cap	Denv mrf	Tran to Thames	Fen Resv Storage	EOE yield	Graf yiel	Rut yiel
	y / n	tcmd	option	tcmd	tcmd		tcmd	m^3*10^6	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	m^3*10^6	tcmd	tcmd	tcmd
0	n						0		334	227	205	165	240				412	265	314
1	n						40		334	227	205	205	280				452		
2	n							22	334	341	305	165	300				-		
3	n							77	334	341	305	165	300				-		
4	n							106	334	341	305	165	300				529		
5	n							46	334	341	305	165	300				464		
6	n						40	106	334	341	305	205	300				572		
7	n						40	46	334	341	305	205	300				504		
8	n						40	106	455	341	305	205	300				603		
9	n						40	106	568	341	305	205	300				622		
10	n						40	106	681	341	305	205	300				636		
11	n						40	106	796	341	305	205	300				644		
12	n						40	46	455	341	305	205	300				534		
13	n						40	46	568	341	305	205	300				553		
14	n						40	46	681	341	305	205	300				567		
15	n						40	46	796	341	305	205	300				575		
16	n								334	227	205	165	240	114			442		
17	n								334	227	205	165	240	50			455		
18	n						40		334	227	205	205	280	114			482		

Table A.2.1 Results for simulations 1972 - 1992

	Trent Tran ?	Trent mrf	TWA demand	Wit-Den direct cap	Drop offs W-O-D	Drop off Pri't y	Chelm Eff	Great Brad Store	Kenn. Pump Size	Wixoe pump size	Black water int. cap	Chelm int. cap	Lang Hann. link cap	Denv mrf	Tran to Thames	Fen Resv Stor-age	EOE yield	Graf yiel	Rut yiel
	y / n	tcmd	option	tcmd	tcmd		tcmd	m^3*10^6	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	m^3*10^6	tcmd	tcmd	tcmd
19	n						40		334	227	205	205	280	50			501		
20	n						40	106	334	341	305	205	300	114			611		
21	n						40	106	334	341	305	205	300	50			634		
22	n						40	46	334	341	305	205	300	114			543		
23	n						40	46	334	341	305	205	300	50			566		
24	n						40	106	455	341	305	205	300	114			652		
25	n						40	106	568	341	305	205	300	114			678		
26	n						40	106	681	341	305	205	300	114			696		
27	n						40	106	796	341	305	205	300	114			707		
28	n						40	106	681	455	305	205	300		100		535		
29	n						40	106	681	568	305	205	300		200		436		
30	n						40	106	681	455	305	205	300	114	100		596		
31	n						40	106	681	568	305	205	300	114	200		496		
32	y	2000	a	200					334	341	205	165	300				495		
33	y	2000	a	400					334	341	205	165	300				502		
34	y	2000	a	200					681	341	205	165	300				515		
35	y	2000	a	400					681	341	205	165	300				528		
36	y	2000	a		50-50-200	D-O-W			681	341	305	165	300				512	294	337
37	y	2000	a		50-50-200	O-D-W			681	341	305	165	300				510	301	336

Table A.2.1 Results for simulations 1972 - 1992

	Trent Tran ?	Trent mrf	TWA demand	Wit-Den direct cap	Drop offs W-O-D	Drop off Pri'ty	Chelm Eff	Great Brad Store	Kenn. Pump Size	Wixoe pump size	Black water int. cap	Chelm int. cap	Lang Hann. link cap	Denv mrf	Tran to Thames	Fen Resv Storage	EOE yield	Graf yiel	Rut yiel
	y / n	tcmd	option	tcmd	tcmd		tcmd	m^3*10^6	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	m^3*10^6	tcmd	tcmd	tcmd
38	y	2000	a		50-50-400	D-O-W			681	341	305	165	300				525	291	335
39	y	2000	a		50-50-400	O-D-W			681	341	305	165	300				520	301	336
40	y	2000	a		50-100-200	D-O-W			681	341	305	165	300				512	321	336
41	y	2000	a		50-100-200	O-D-W			681	341	305	165	300				508	328	336
42	y	2000	a		50-100-400	D-O-W			681	341	305	165	300				525	317	335
43	y	2000	a		50-100-400	O-D-W			681	341	305	165	300				515	328	335
44	y	2000	a		50-50-200	D-O-W			568	341	305	165	300				512	294	337
45	y	2000	a		50-50-200	O-D-W			568	341	305	165	300				510	301	336
46	y	2000	a		50-50-400	D-O-W			568	341	305	165	300				525	291	335
47	y	2000	a		50-50-400	O-D-W			568	341	305	165	300				520	301	336

Table A.2.1 Results for simulations 1972 - 1992

	Trent Tran ?	Trent mrf	TWA demand	Wit-Den direct cap	Drop offs W-O-D	Drop off Pri't y	Chelm Eff	Great Brad Store	Kenn. Pump Size	Wixoe pump size	Black water int. cap	Chelm int. cap	Lang Hann. link cap	Denv mrf	Tran to Thames	Fen Resv Storage	EOE yield	Graf yiel	Rut yiel
	y / n	tcmd	option	tcmd	tcmd		tcmd	m^3*10^6	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	m^3*10^6	tcmd	tcmd	tcmd
48	y	2000	a		50-100-200	D-O-W			568	341	305	165	300				512	321	336
49	y	2000	a		50-100-200	O-D-W			568	341	305	165	300				508	328	336
50	y	2000	a		50-100-400	D-O-W			568	341	305	165	300				525	317	335
51	y	2000	a		50-100-400	O-D-W			568	341	305	165	300				515	328	335
52	y	2000	a	200				106	681	341	305	165	300				746		
53	y	2000	a	400				106	681	341	305	165	300				849		
54	y	2000	a	200				106	681	455	305	165	300		100		646		
55	y	2000	a	400				106	681	455	305	165	300		100		749		
56	y	2000	a	200				106	681	568	305	165	300		200		546		
57	y	2000	a	400				106	681	568	305	165	300		200		649		
58	n								334	341	305	165	300			106	592		
59	n								334	341	305	165	300			70	549		
60	n								334	341	305	165	300			35	510		
61	n								455	341	305	165	300			106	577		
62	n								455	341	305	165	300			70	538		
63	n								455	341	305	165	300			35	505		
64	y	2000	a	200					334	341	305	165	300			106	723		

Table A.2.1 Results for simulations 1972 - 1992

	Trent Tran ?	Trent mrf	TWA demand	Wit-Den direct cap	Drop offs W-O-D	Drop off Pri't y	Chelm Eff	Great Brad Store	Kenn. Pump Size	Wixoe pump size	Black water int. cap	Chelm int. cap	Lang Hann. link cap	Denv mrf	Tran to Thames	Fen Resv Storage	EOE yield	Graf yiel	Rut yiel
	y / n	tcmd	option	tcmd	tcmd		tcmd	m^3*10^6	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	m^3*10^6	tcmd	tcmd	tcmd
65	y	2000	a	400					334	341	305	165	300			106	802		
66	y	2000	a	200					455	341	305	165	300			106	702		
67	y	2000	a	400					455	341	305	165	300			106	788		

Table A.2.1 Results for simulations 1972 - 1992

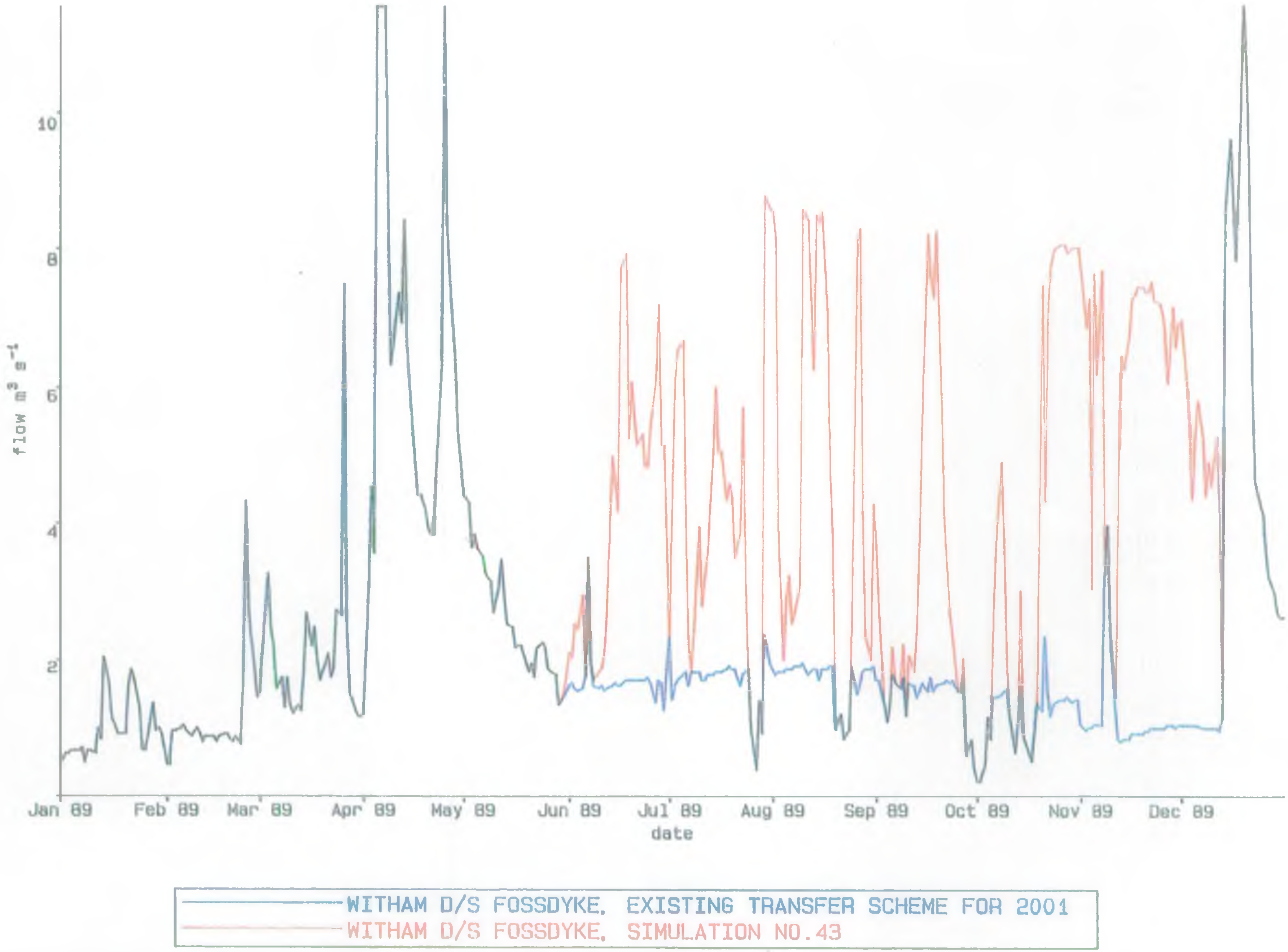
TABLE A.2.2 RESULTS FOR SIMULATIONS 1932 - 1992

	Trent Tran ?	Chelm Eff	Great Brad Store	Kenn. Pump Size	Wixoe pump size	Black water int. cap	Chelm int. cap	Lang Hann. link cap	Denv mrf	Tran to Thames	Fen Resv Storage	EOE yield
	y / n	tcmd	m^3*10^6	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	m^3*10^6	tcmd
0	n	0		334	227	205	165	240				340
1	n	40		334	227	205	205	280				380
2	n		22	334	341	305	165	300				360
3	n		77	334	341	305	165	300				455
4	n		106	334	341	305	165	300				506
5	n		46	334	341	305	165	300				410
6	n	40	106	334	341	305	205	300				546
7	n	40	46	334	341	305	205	300				444
8	n	40	106	455	341	305	205	300				576
9	n	40	106	568	341	305	205	300				595
10	n	40	106	681	341	305	205	300				606
11	n	40	106	796	341	305	205	300				613
12	n	40	46	455	341	305	205	300				472
13	n	40	46	568	341	305	205	300				491
14	n	40	46	681	341	305	205	300				503
15	n	40	46	796	341	305	205	300				506
16	n			334	227	205	165	240	114			360
17	n			334	227	205	165	240	50			375
18		40		334	227	205	205	280	114			398
19		40		334	227	205	205	280	50			415
20	n	40	106	334	341	305	205	300	114			566

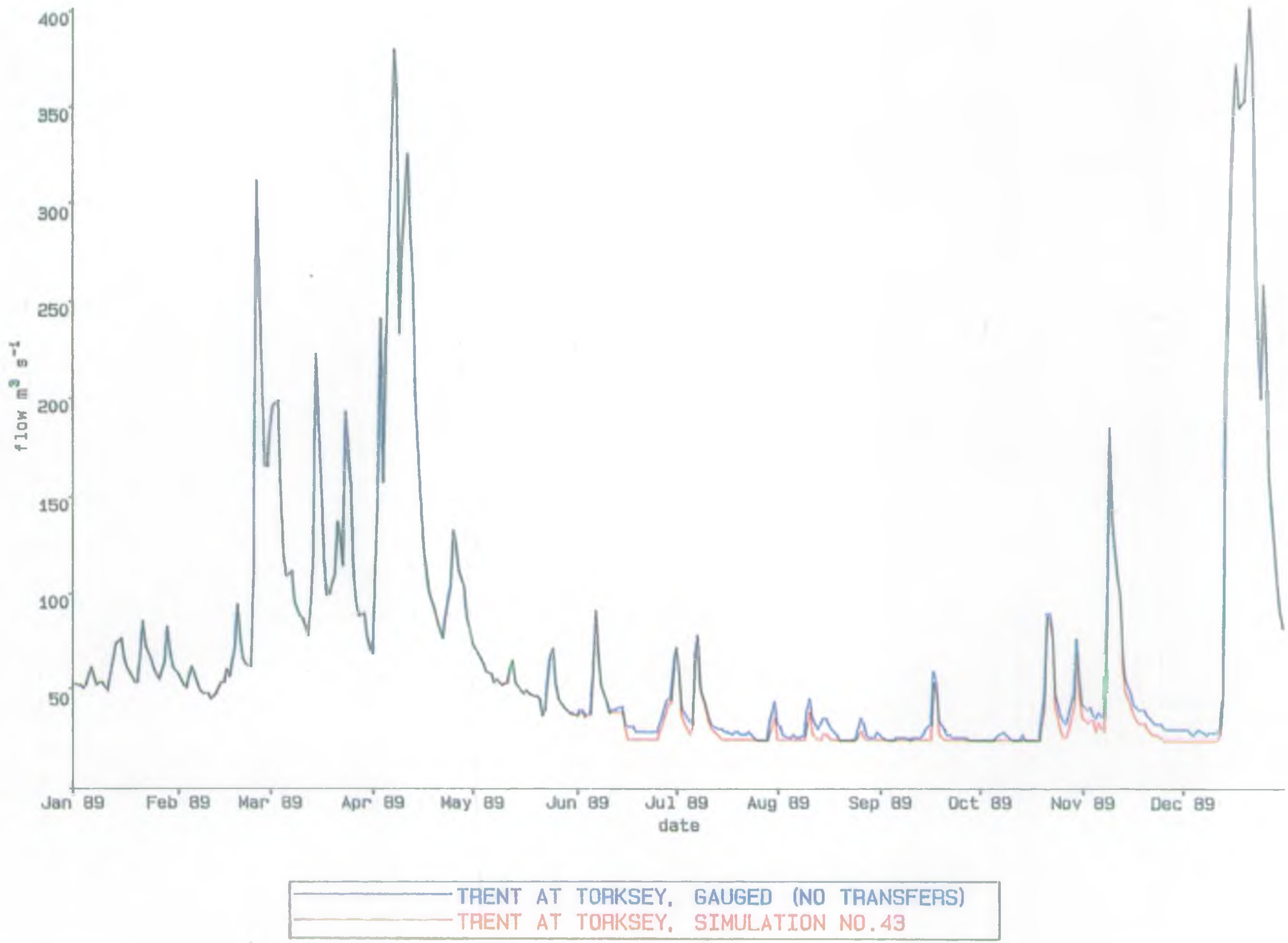
Table A.2.2 Results for simulations 1932-1992

	Trent Tran ?	Chelm Eff	Great Brad Store	Kenn. Pump Size	Wixoe pump size	Black water int. cap	Chelm int. cap	Lang Hann. link cap	Denv mrf	Tran to Thames	Fen Resv Storage	EOE yield
	y / n	tcmd	m^3*10^6	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	m^3*10^6	tcmd
21	n	40	106	334	341	305	205	300	50			576
22	n	40	46	334	341	305	205	300	114			486
23	n	40	46	334	341	305	205	300	50			498
24	n	40	106	455	341	305	205	300	114			617
25	n	40	106	568	341	305	205	300	114			658
26	n	40	106	681	341	305	205	300	114			678
27	n	40	106	796	341	305	205	300	114			691
28	n	40	106	681	455	305	205	300		100		506
29	n	40	106	681	568	305	205	300		200		406
30	n	40	106	681	455	305	205	300	114	100		578
31	n	40	106	681	568	305	205	300	114	200		478
58	n			334	341	305	165	300			106	573
59	n			334	341	305	165	300			70	513
60	n			334	341	305	165	300			35	446
61	n			455	341	305	165	300			106	543
62	n			455	341	305	165	300			70	484
63	n			455	341	305	165	300			35	429

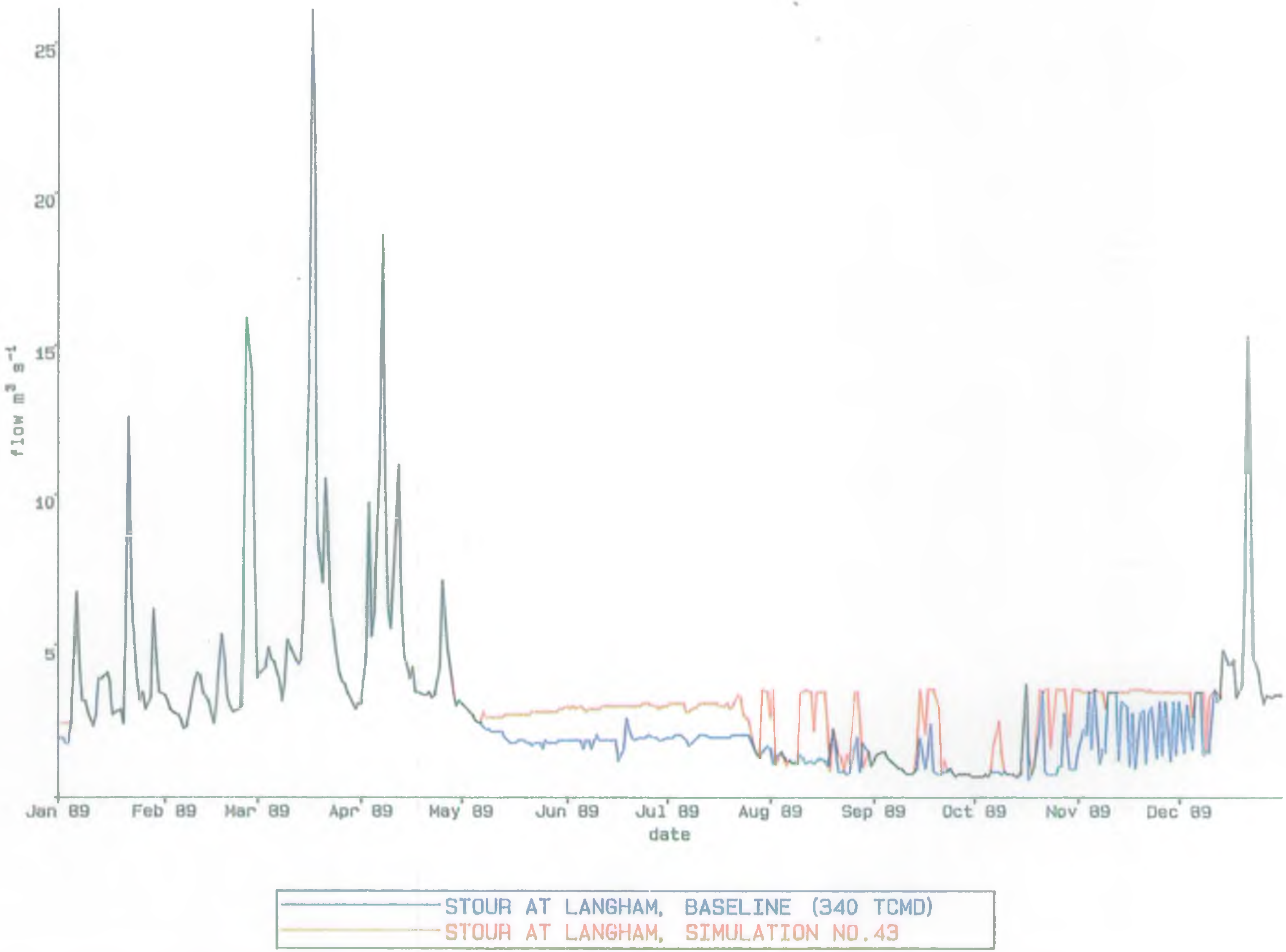
Table A.2.2 Results for simulations 1932-1992



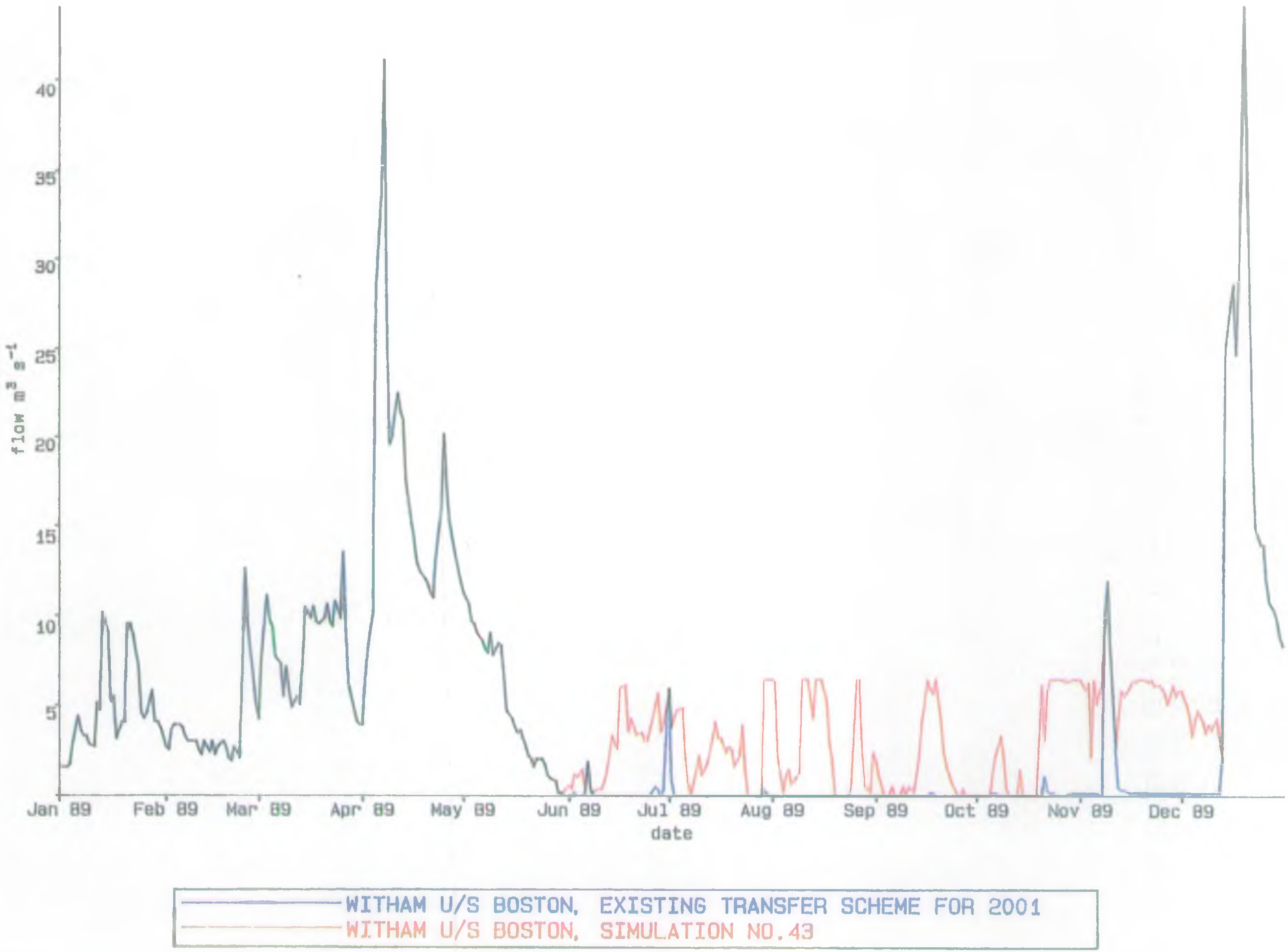
10
8
6
4
2
flow m³ s⁻¹
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
WITHAM D/S FOSSDYKE, EXISTING TRANSFER SCHEME FOR 2001
WITHAM D/S FOSSDYKE, SIMULATION NO.43

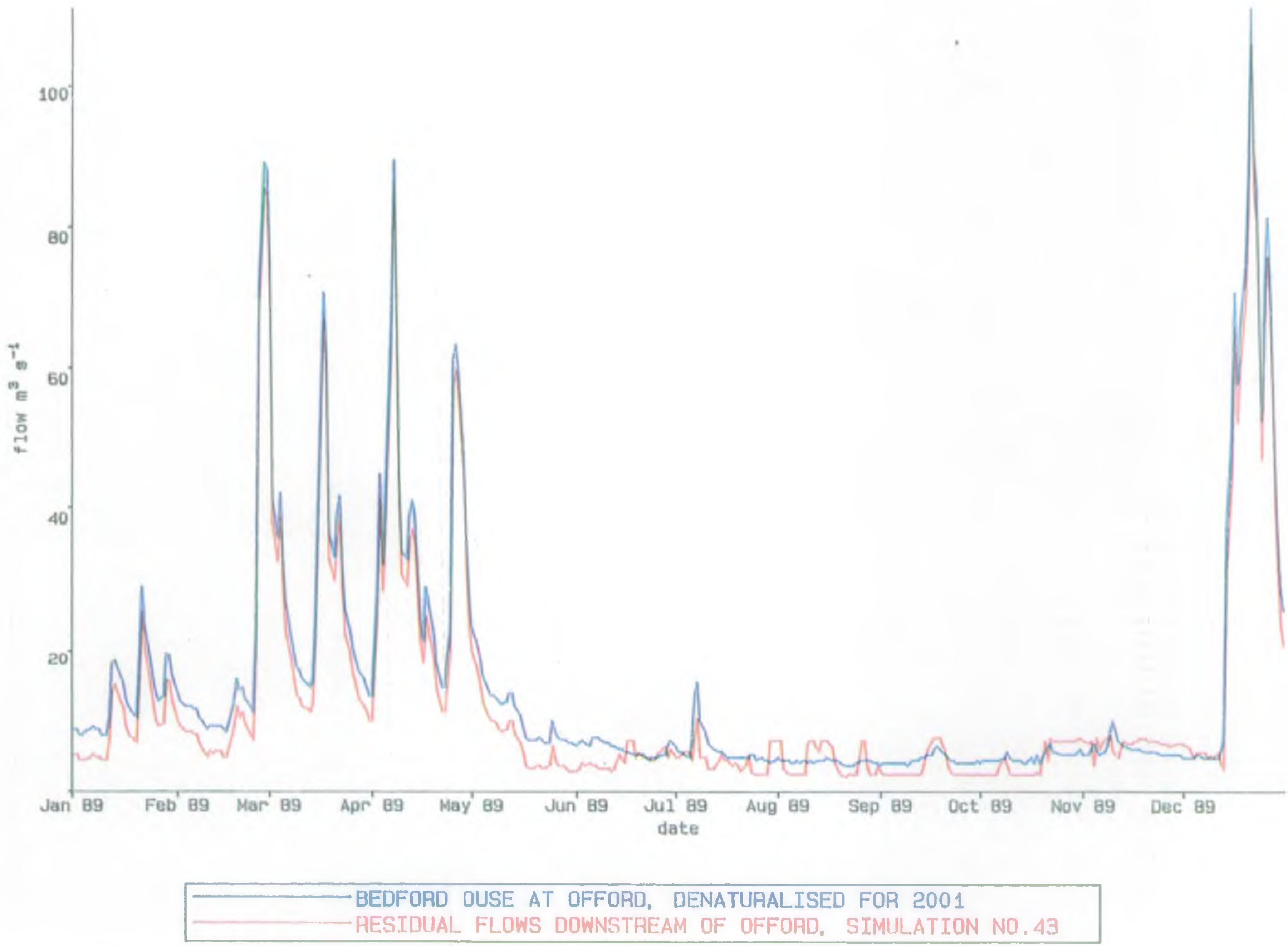


400
350
300
250
200
150
100
50
flow m³ s⁻¹
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
TRENT AT TORKSEY, GAUGED (NO TRANSFERS)
TRENT AT TORKSEY, SIMULATION NO.43



flow m3 s-1
25
20
15
10
5
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
STOUR AT LANGHAM, BASELINE (340 TCMD)
STOUR AT LANGHAM, SIMULATION NO.43


40
35
30
25
20
15
10
5
flow $m^3 s^{-1}$
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
WITHAM U/S BOSTON, EXISTING TRANSFER SCHEME FOR 2001
WITHAM U/S BOSTON, SIMULATION NO.43



100
80
60
40
20
flow m³ s⁻¹
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
BEDFORD OUSE AT OFFORD, DENATURALISED FOR 2001
RESIDUAL FLOWS DOWNSTREAM OF OFFORD, SIMULATION NO.43

Appendix B

SAMPLE OUTPUT DATA FROM THE NRA MODELLING STUDIES, AS PROVIDED TO THE ENVIRONMENTAL CONSULTANTS

Appendix B1

NRA SEVERN TRENT

5) Environmental

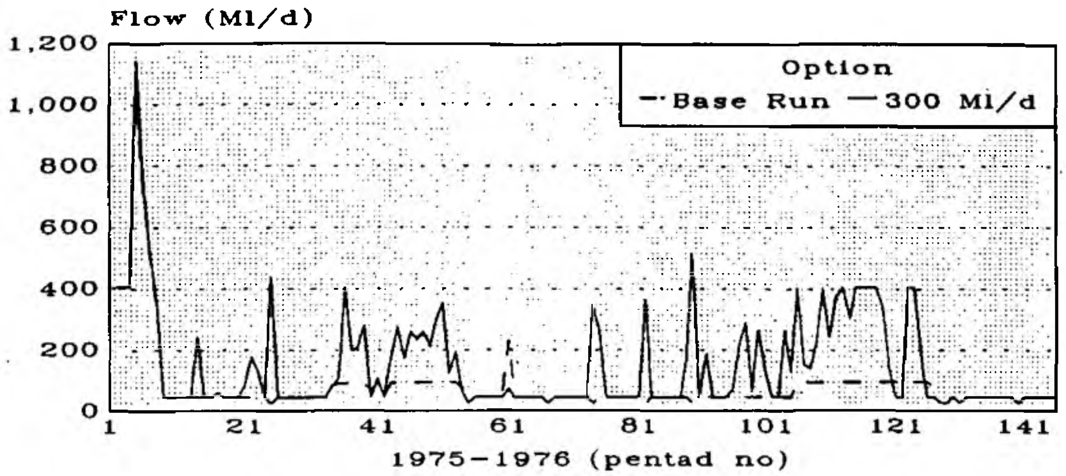
The redeployment of Lake Vyrnwy will have an impact on the flow regime of the Afon Vyrnwy and to a lesser extent on the Afon Clywedog and the River Severn at Bewdley. The flow series for these three locations for 1975 and 1976 are given in Figure 3. The diagrams illustrate the difference between the current situation simulation and the flows for the rule 3, 300 Ml/d transfer with SWOR. In addition the difference between the base run and the 300 Ml/d transfer is shown in the Bewdley diagram.

The large impact on the flow regime below Vyrnwy can clearly be seen. There is a lesser impact on the flows below Clywedog, and very little impact, relatively, at Bewdley

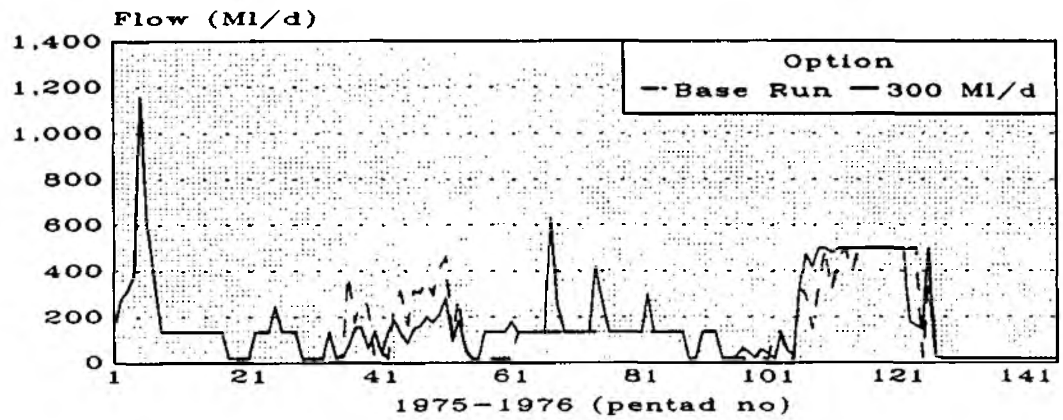
The environmental impact of the increased flows, particularly in the Afon Vyrnwy will need to be investigated more closely during the Environmental Impact Study being undertaken by Howard Humpries.

Figure 3 - Flow changes below Vyrnwy and Clywedog and at Bewdley for 300 Ml/d Severn to Thames Transfer with SWOR as compared to NRAM 1990 Base Run

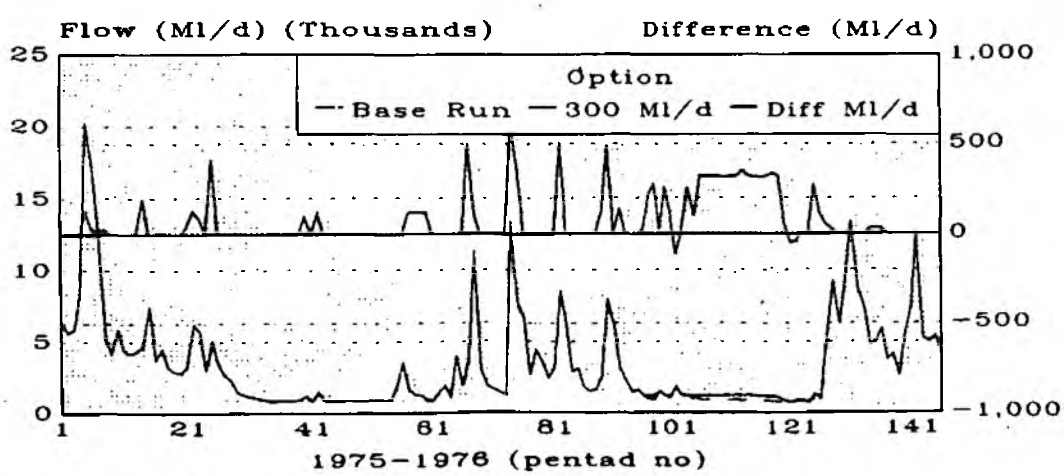
Flow below Vyrnwy



Flow below Clywedog



Flow at Bewdley



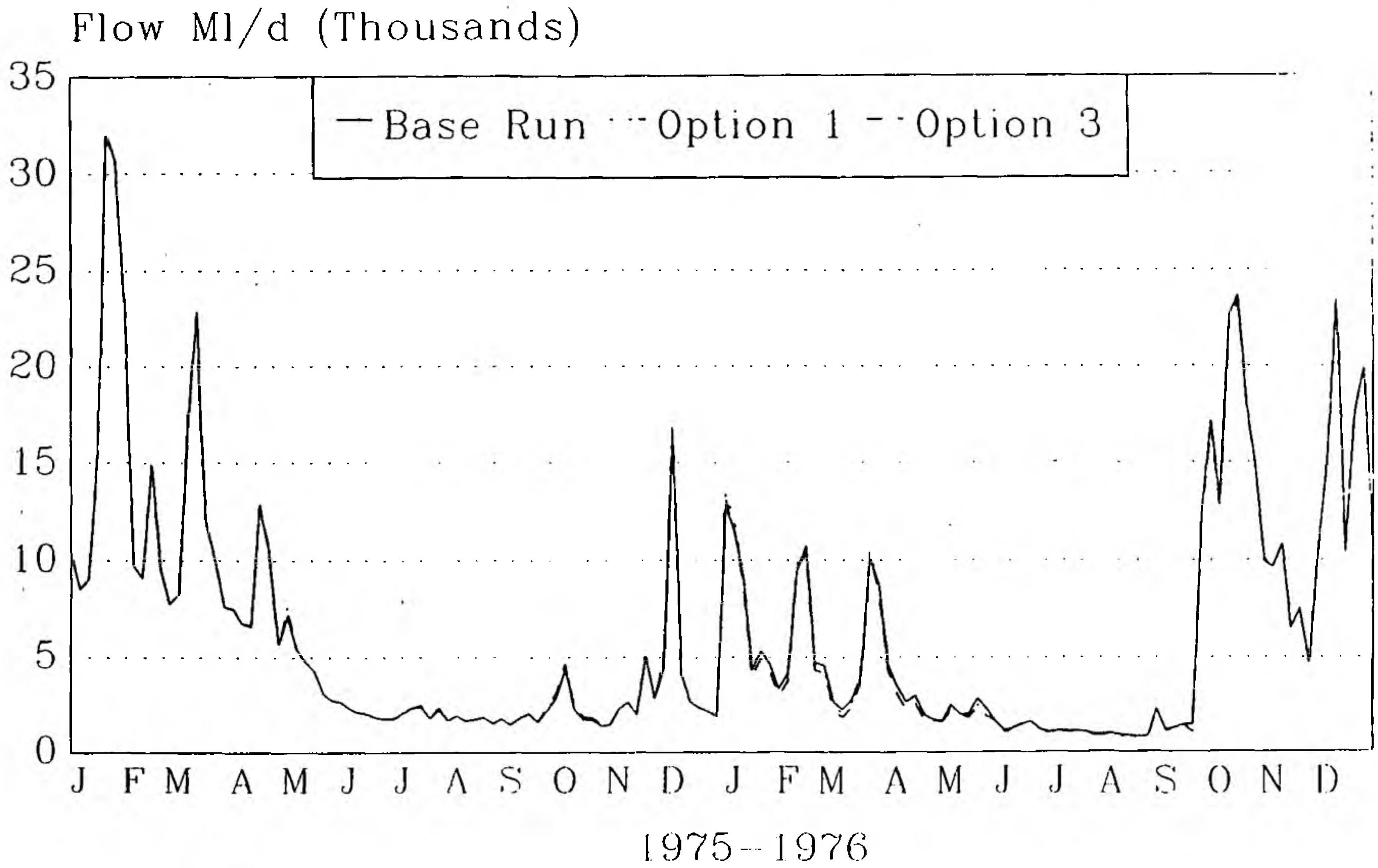


Figure 4 - Simulated Changes in the River Severn flow at Haw Bridge during 1975-76 for the Base Run, Option 1 and Option 3

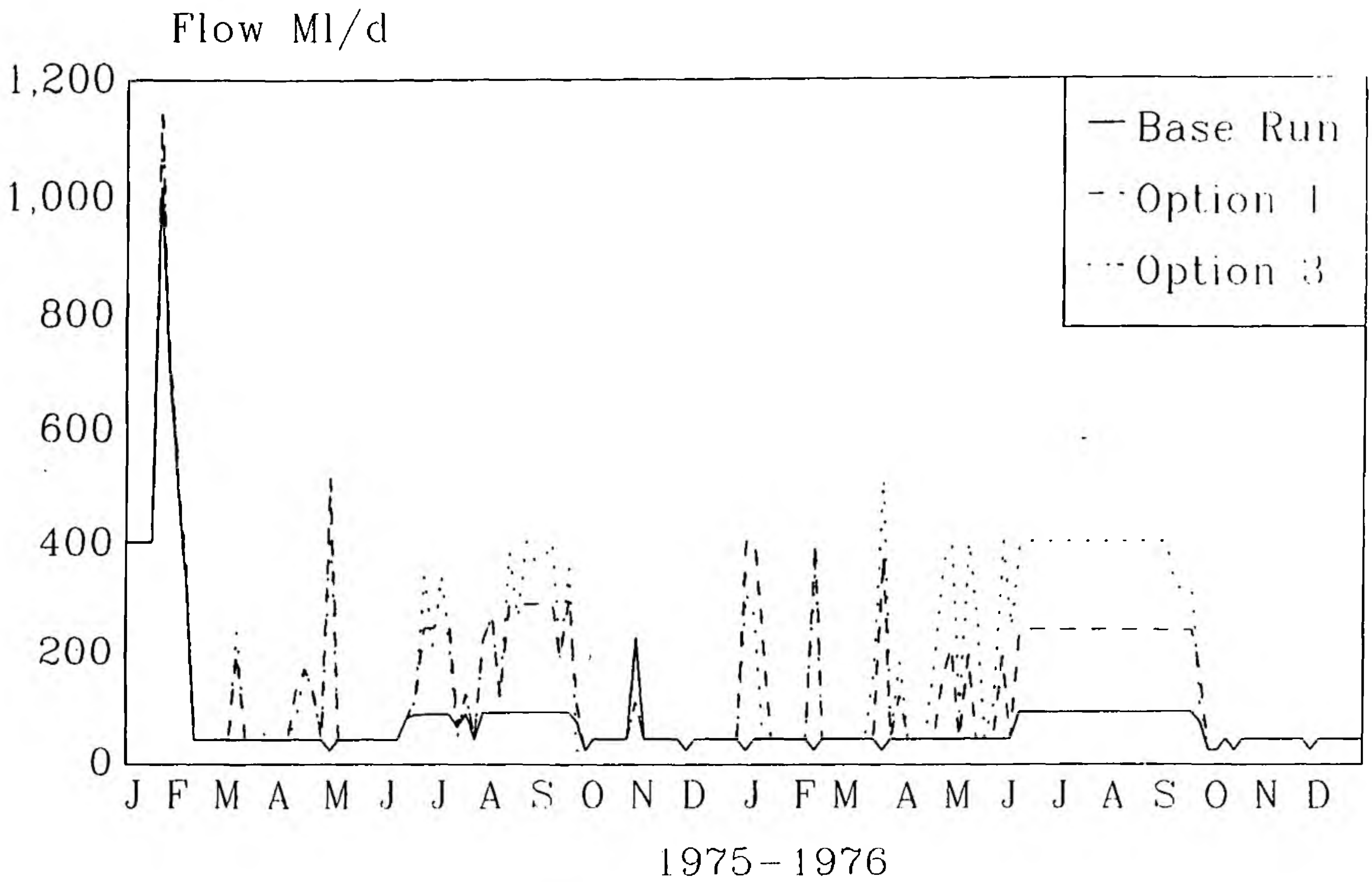


Figure 3 - Simulated Changes in Vyrnwy River Flow during 1975-76 for the Base Run, Option 1 and Option 3

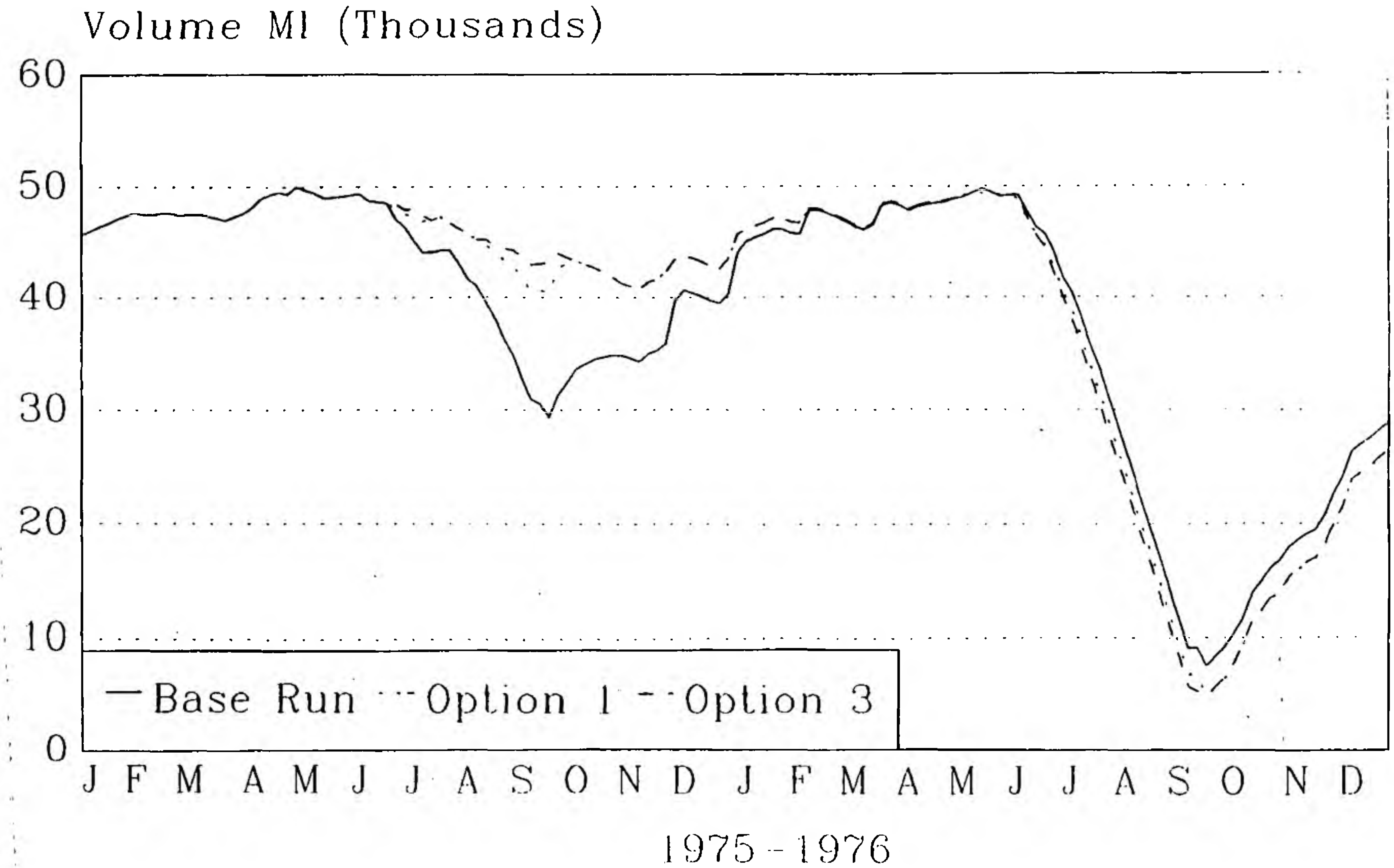


Figure 2 - Simulated Changes in Clywedog Volume during 1975-76 for the Base Run, Option 1 and Option 3

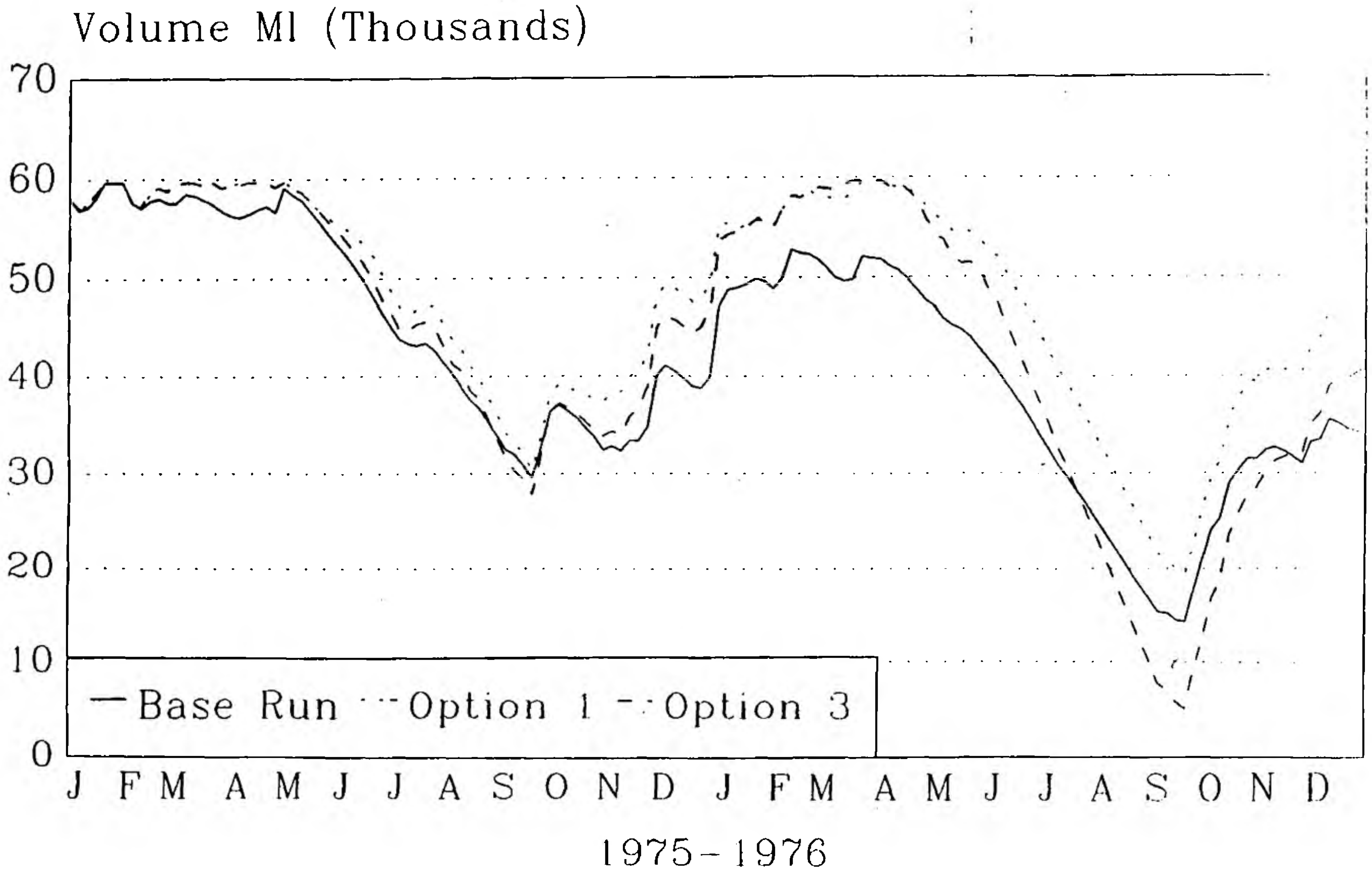
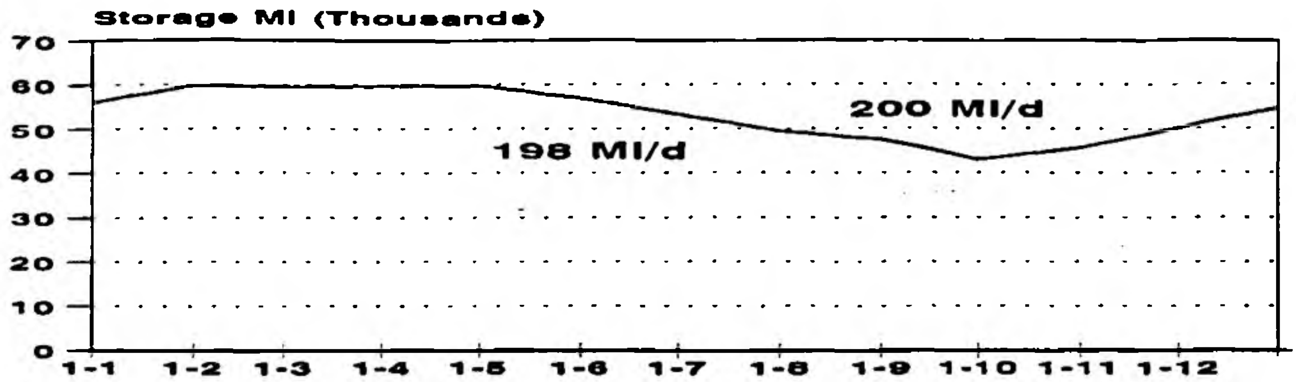


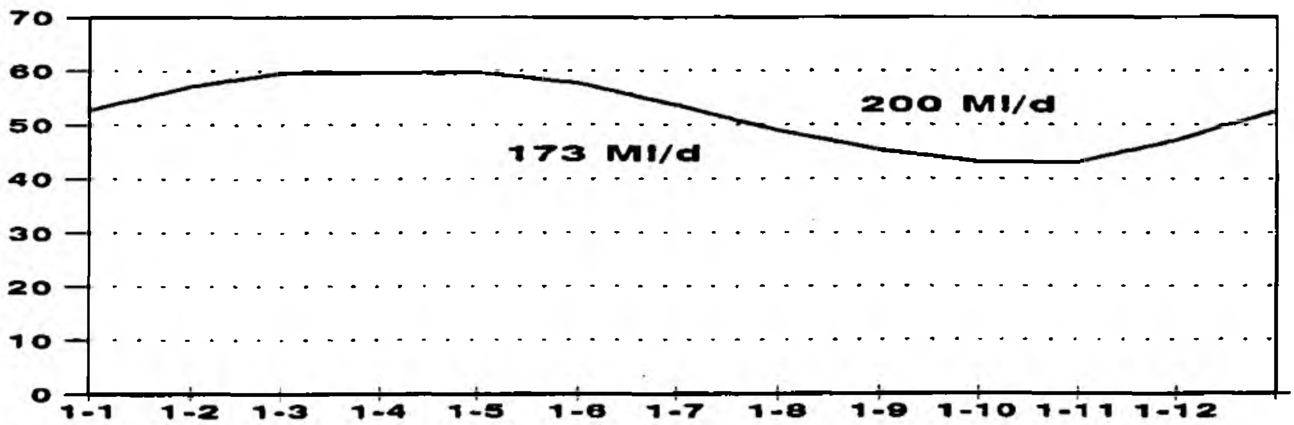
Figure 1 - Simulated Changes in Vyrnwy Volume during 1975-76 for the Base Run, Option 1 and Option 3

L Vyrnwy Redeployment Study - Phase II

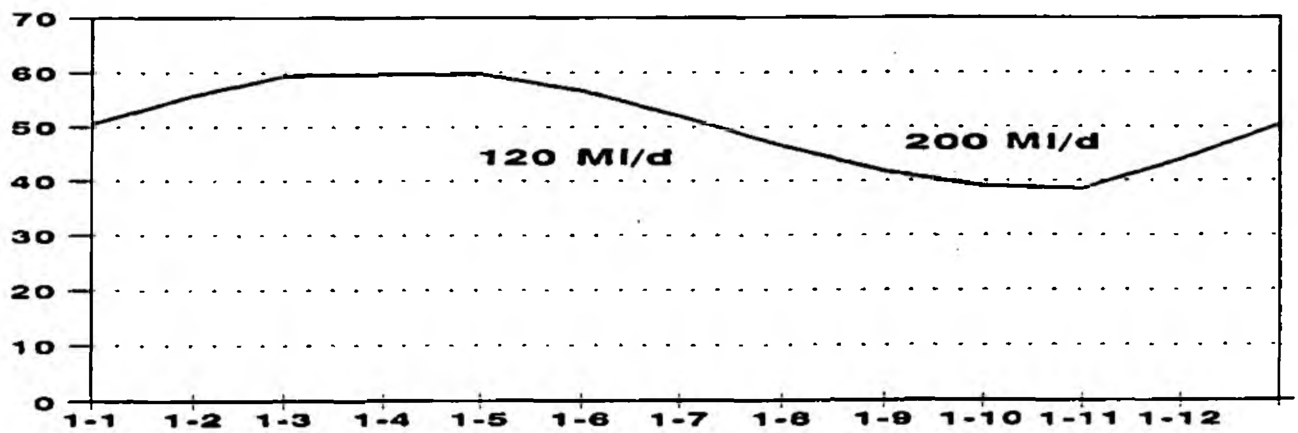
Figure 1



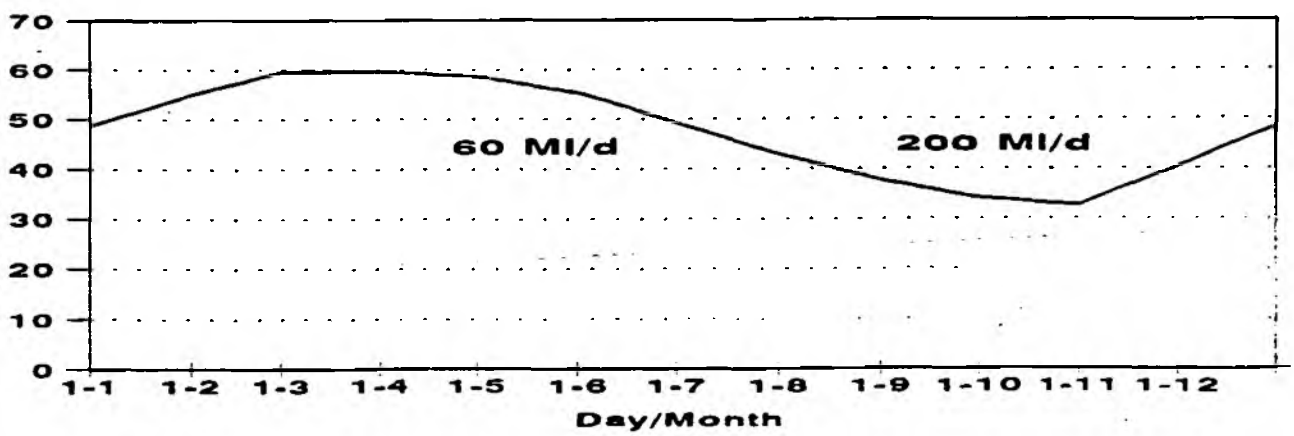
Control Curve NW1



Control Curve NW5



Control Curve NW9



Control Curve NW13

Lake Vyrnwy Redeployment Studies

Total Vyrnwy Supplies

(excluding compensation water)

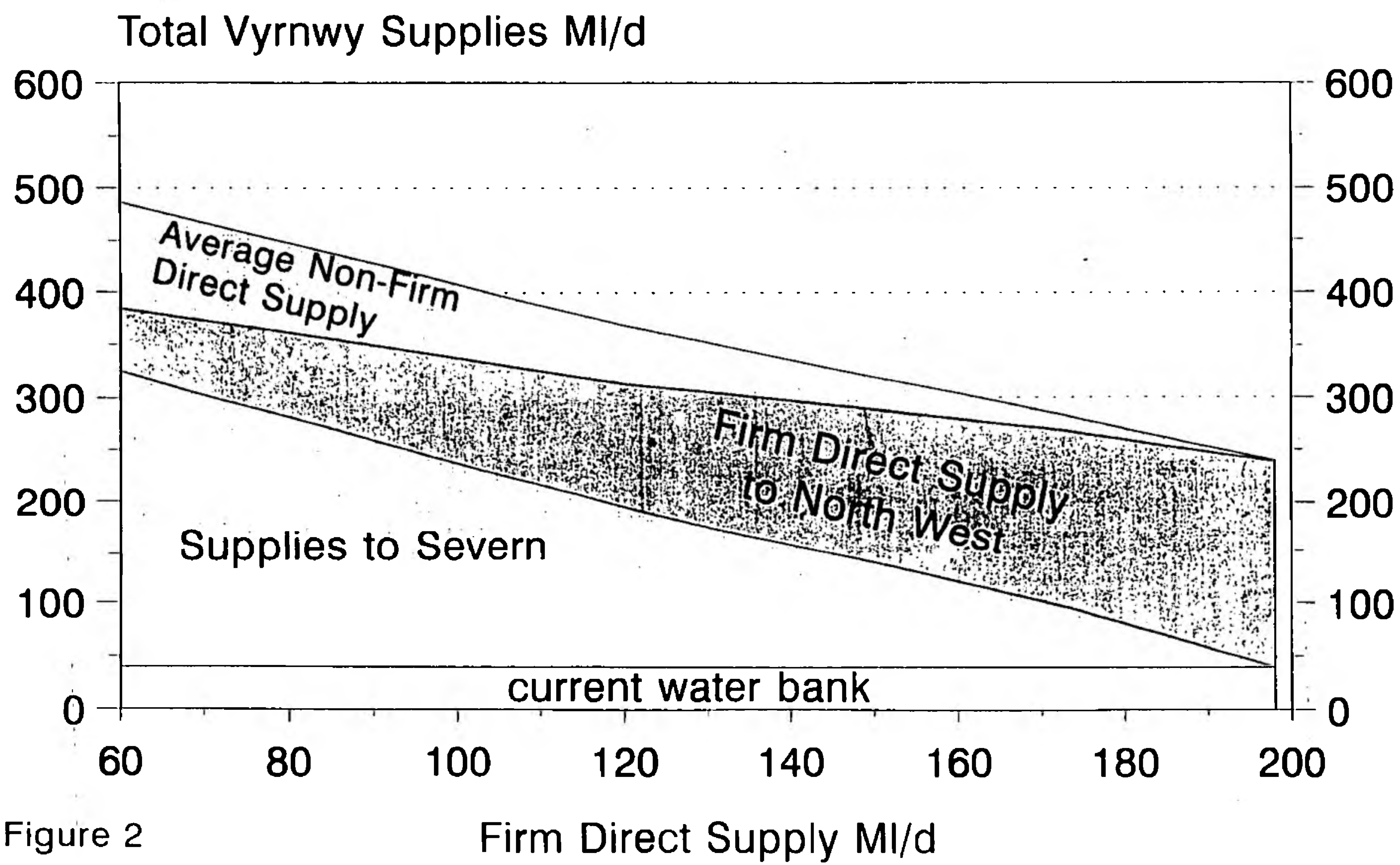


Figure 2

Lake Vyrnwy Redeployment Study

Flow Distribution of Regulation Releases from Lake Vyrnwy
Simulation Period 1932 to 1990

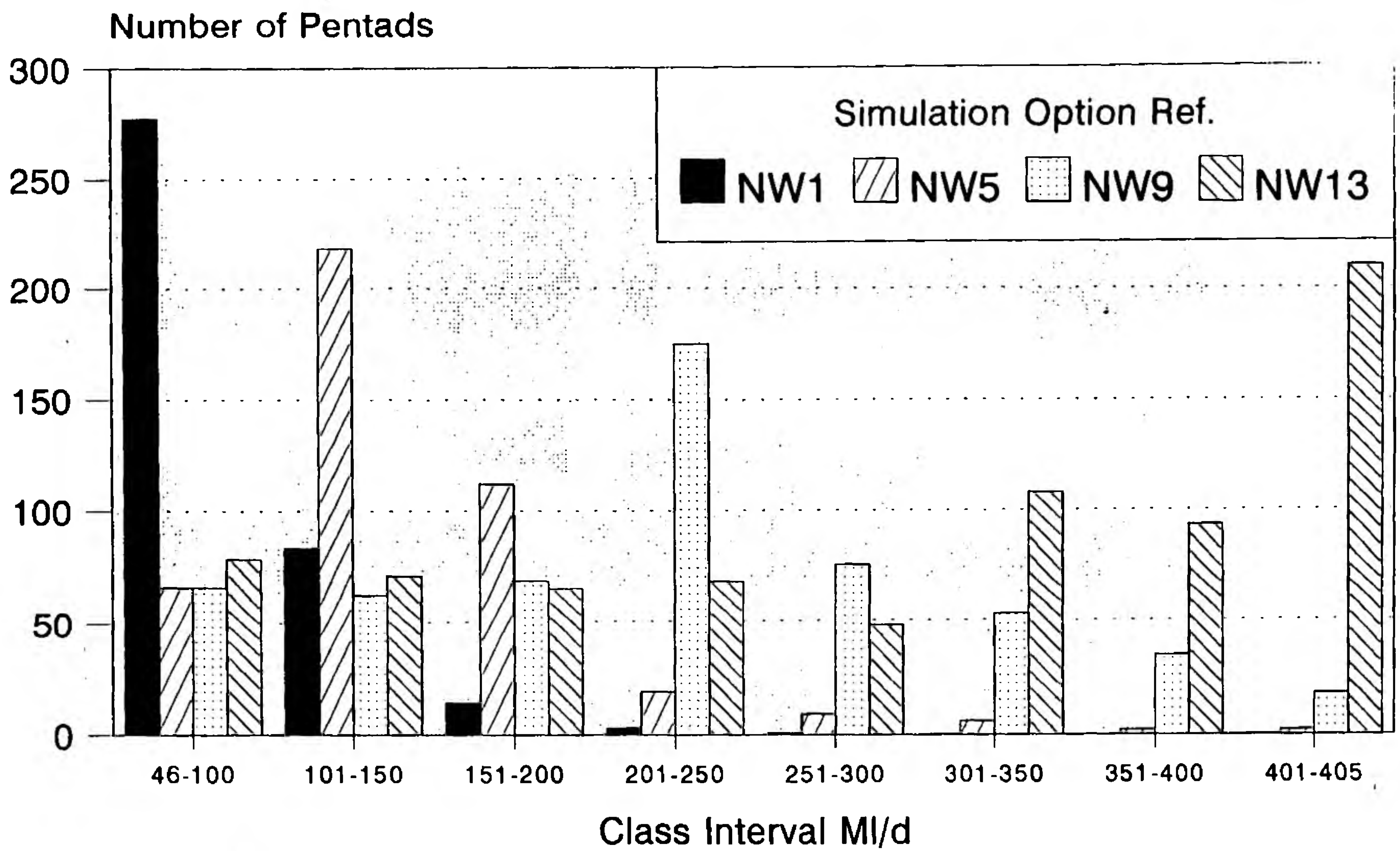


Figure 3

L Vyrnwy Redeployment Study
Simulated R Vyrnwy Flows 1975-76

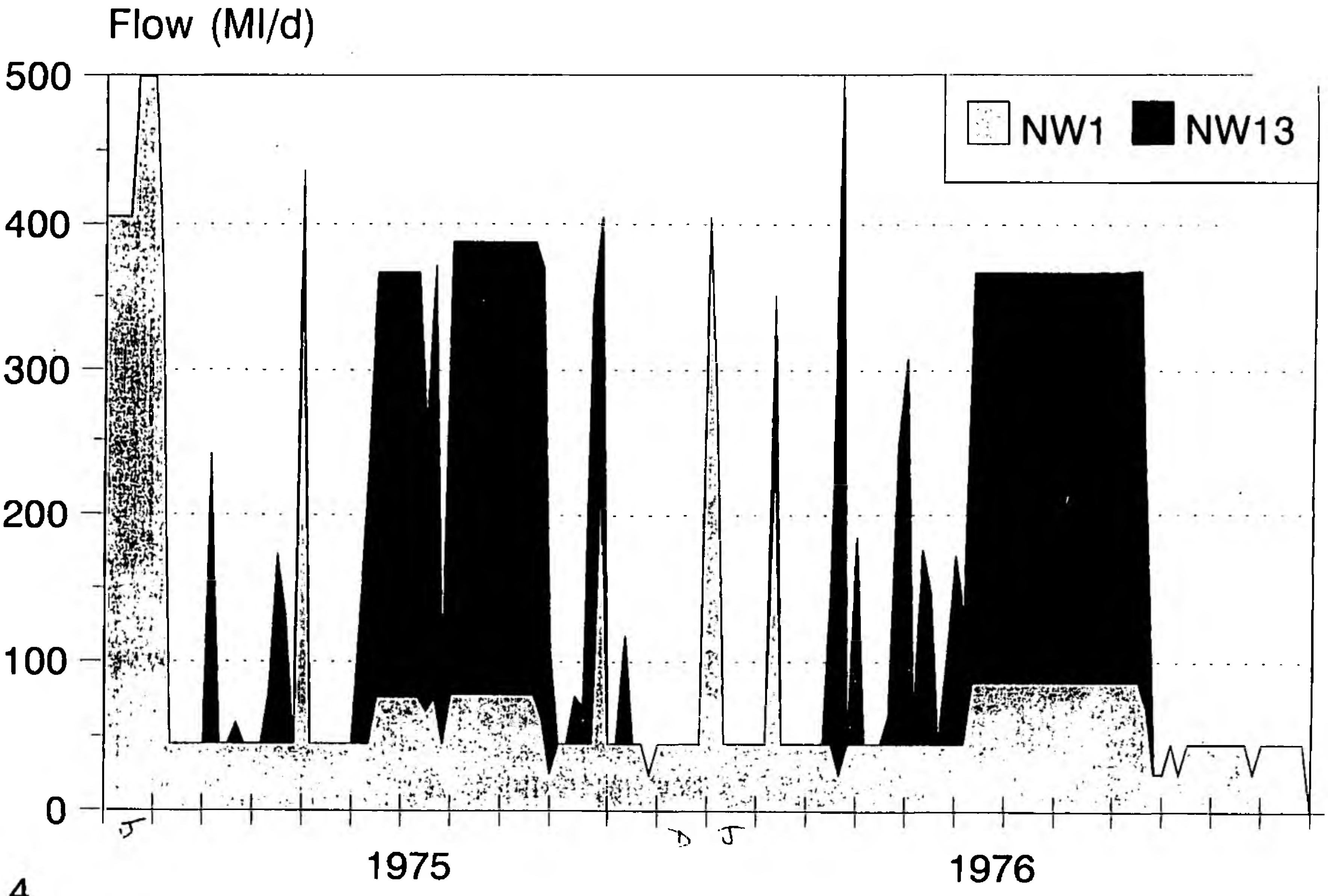
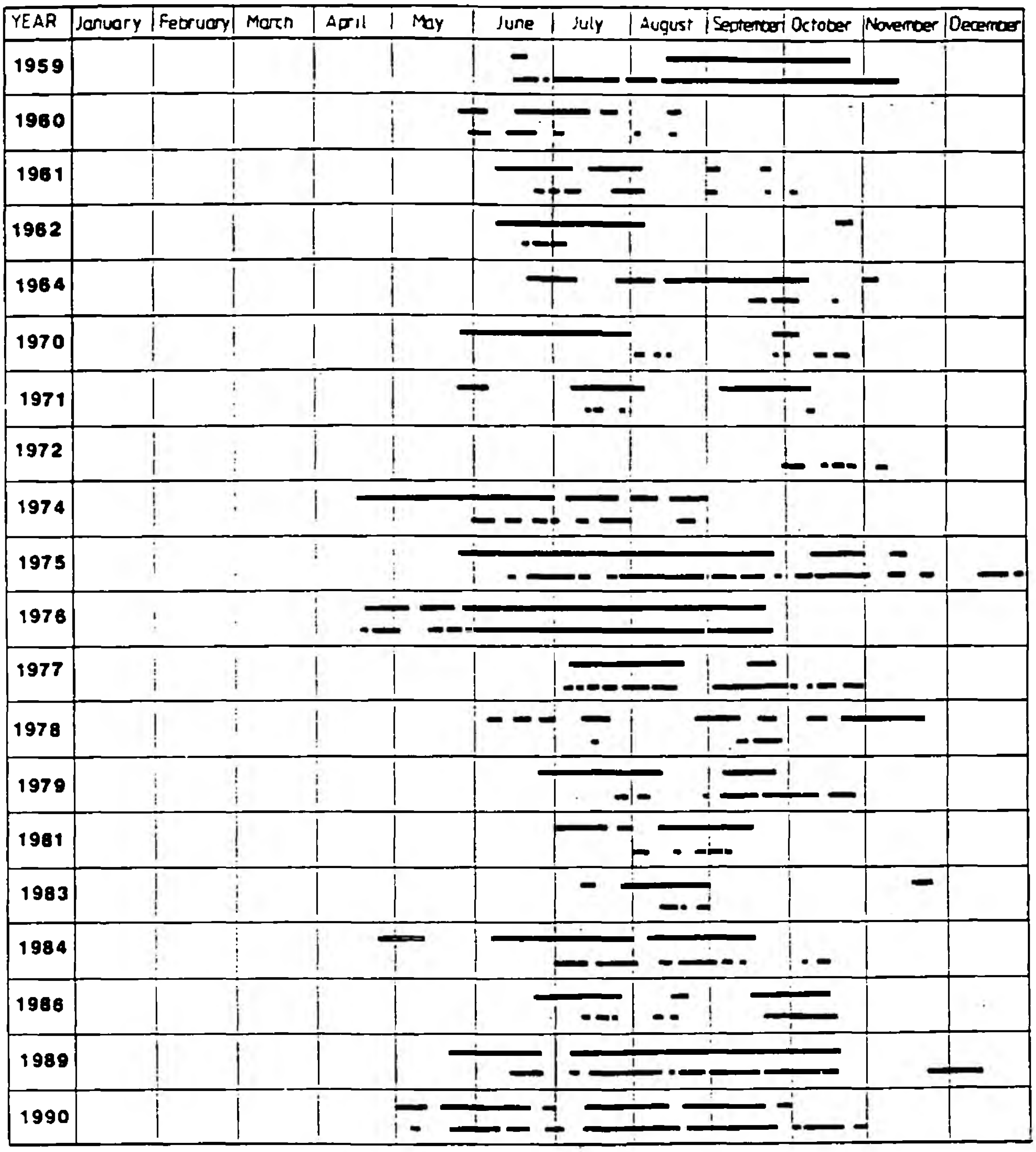


Figure 4



LEGEND

——— PERIOD WHEN TRENT WOULD REQUIRE AUGMENTATION

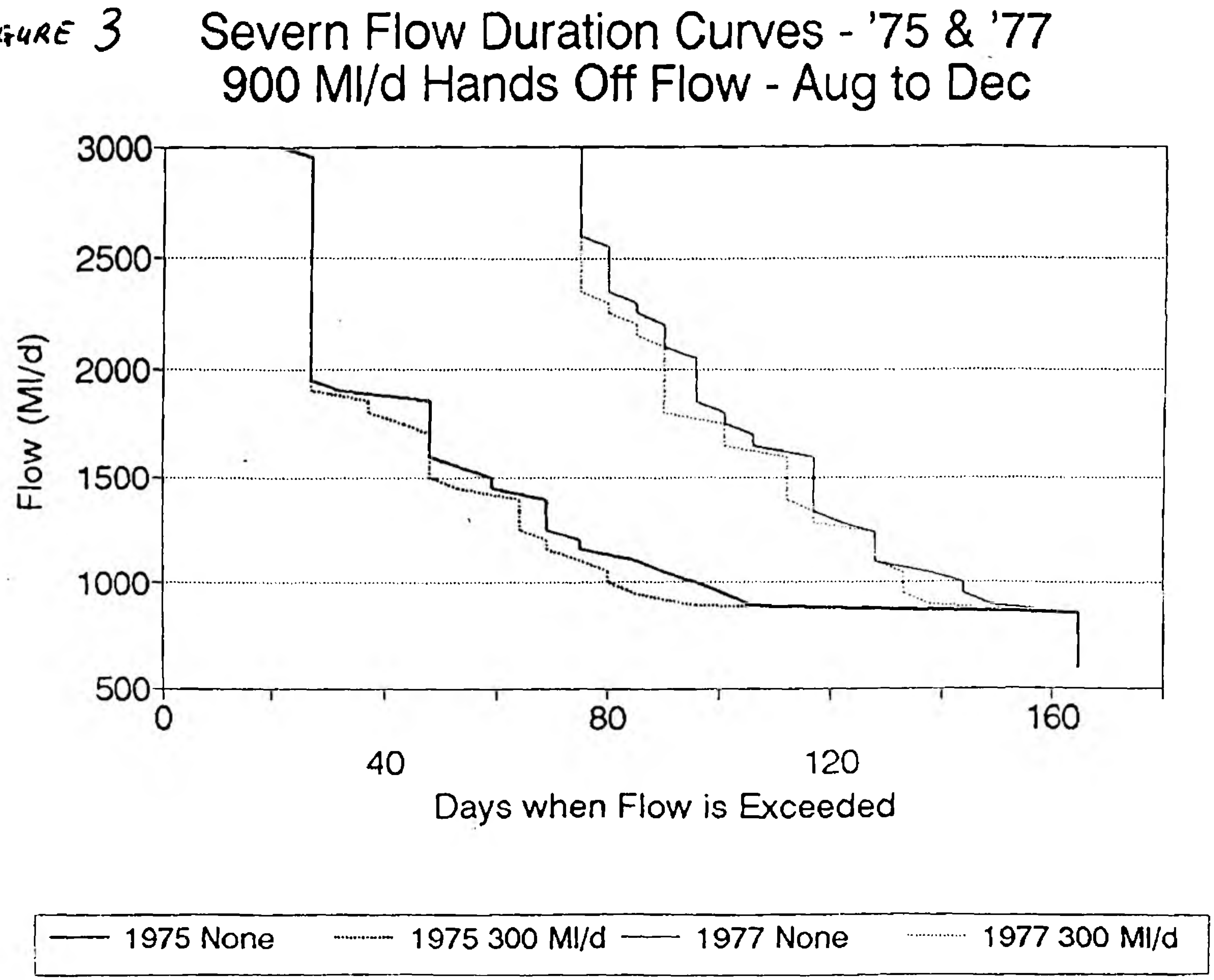
——— PERIOD WHEN SEVERN FALLS BELOW ITS PRESCRIBED FLOW

WS Atkins

AUGMENTATION PERIODS FOR THE TRENT AND THE SEVERN

FIGURE 2

FIGURE 3

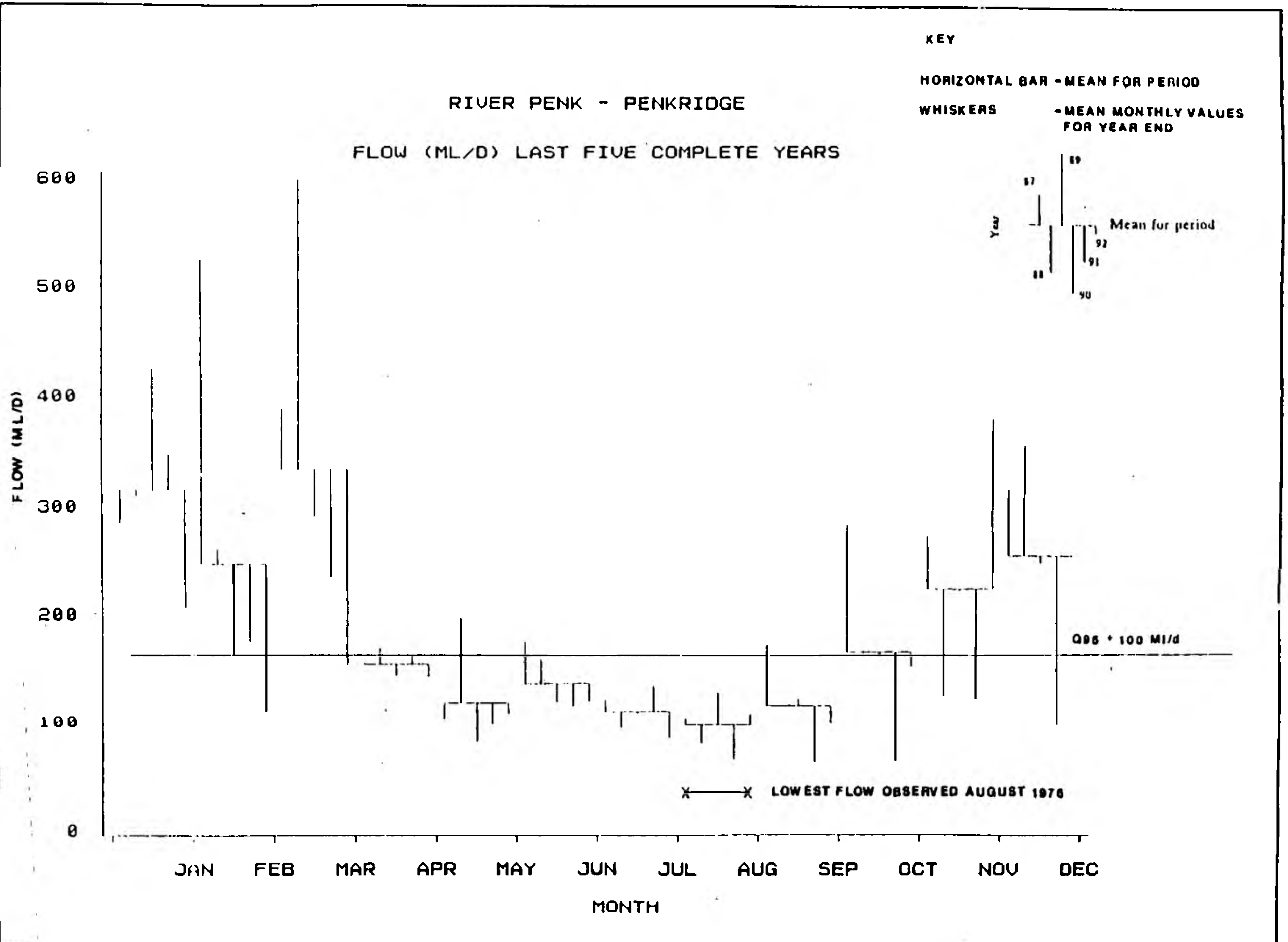


Severn Flow Duration Curves - '75 & '77
900 Ml/d Hands Off Flow - Aug to Dec
3000
2500
2000
1500
1000
500
Flow (Ml/d)
0
40
80
120
160
Days when Flow is Exceeded
1975 None
1975 300 Ml/d
1977 None
1977 300 Ml/d

WS Atkins

RIVER PENK - PENKRIDGE
FLOW (ML/D) LAST FIVE COMPLETE YEARS

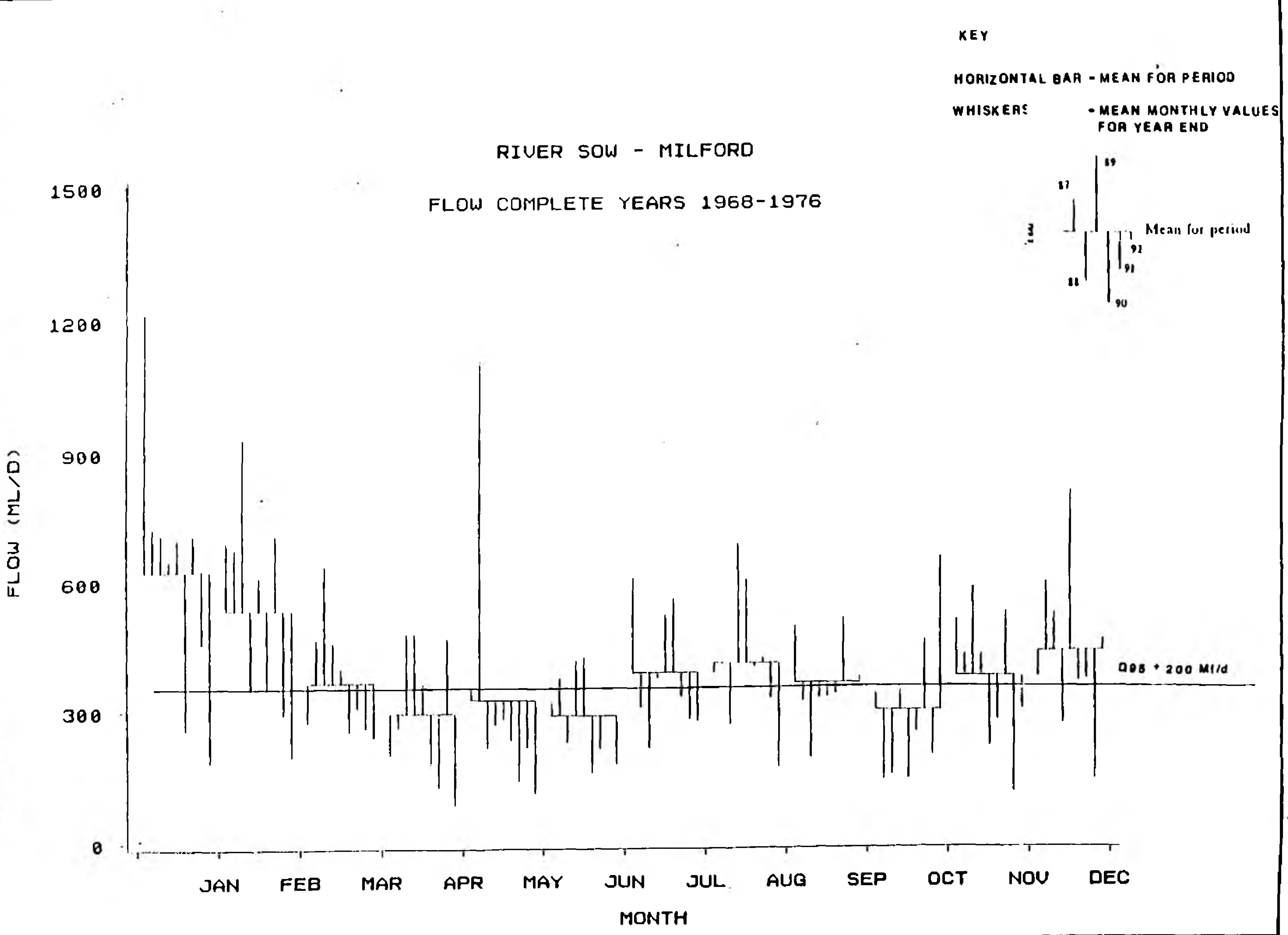
Figure 4



RIVER SOW - MILFORD

FLOW COMPLETE YEARS 1968 - 1976

Figure 5

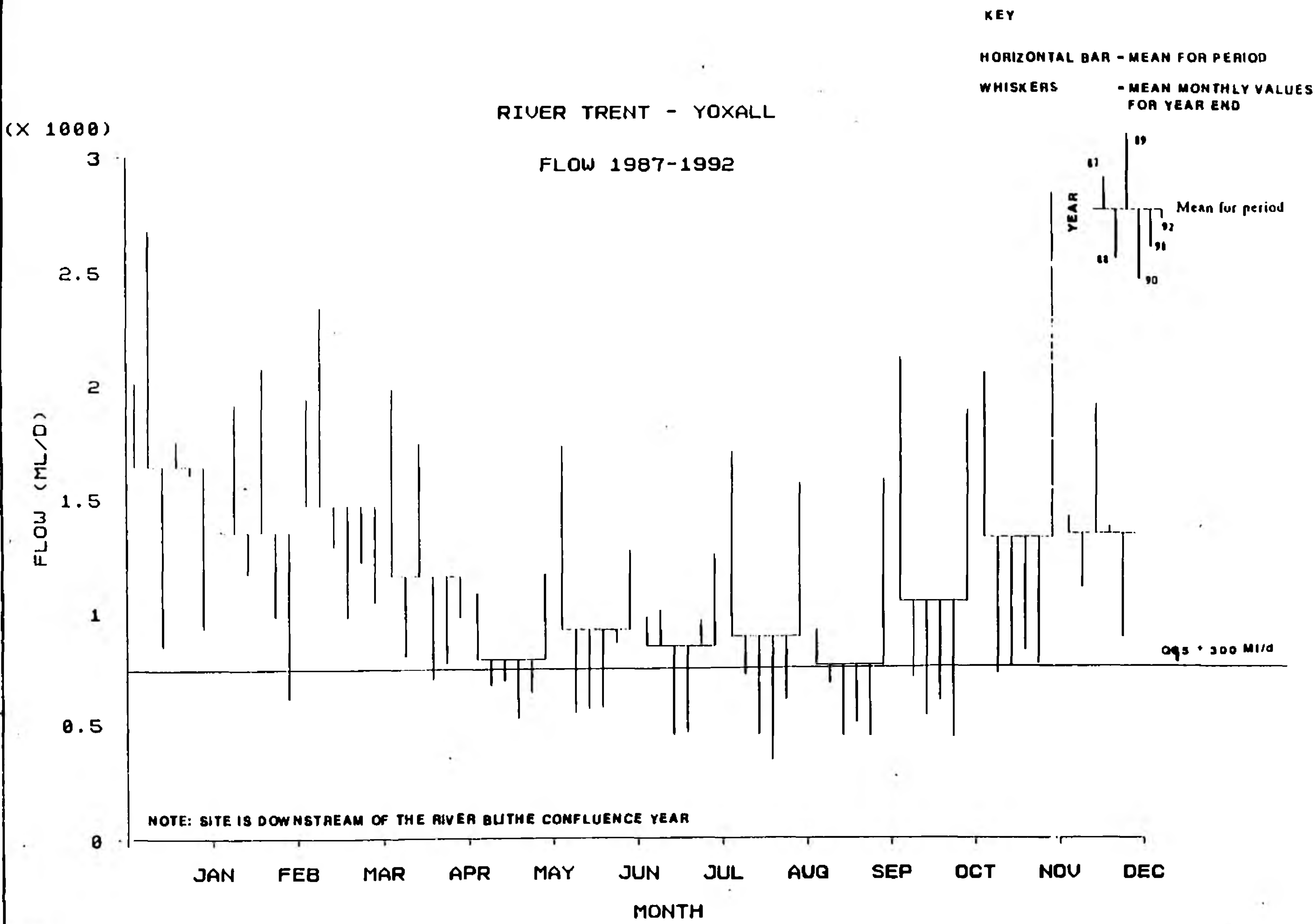


WS Atkins

RIVER TRENT - YOXALL

FLOW 1987 - 1992

Figure 6



Appendix B2

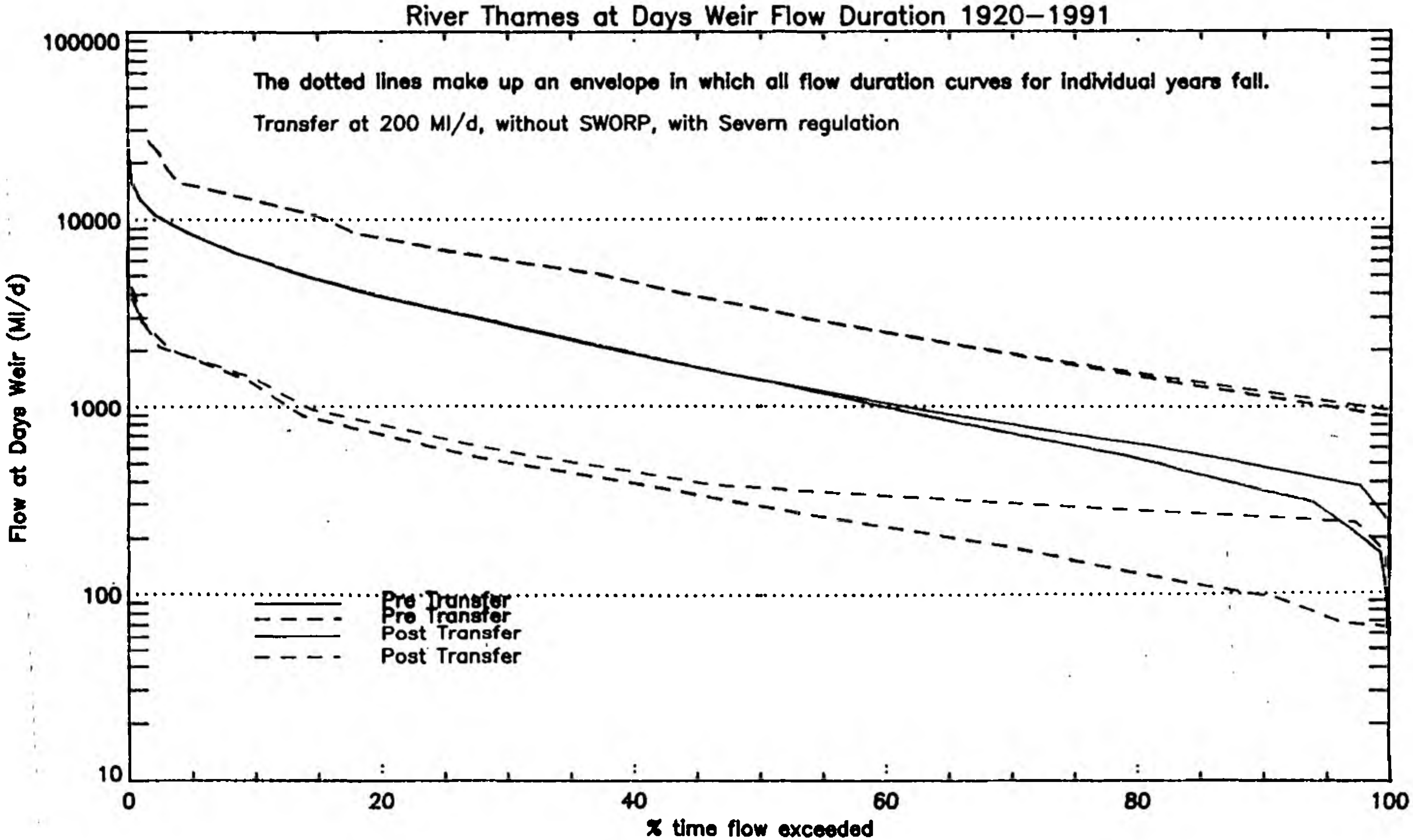
NRA THAMES

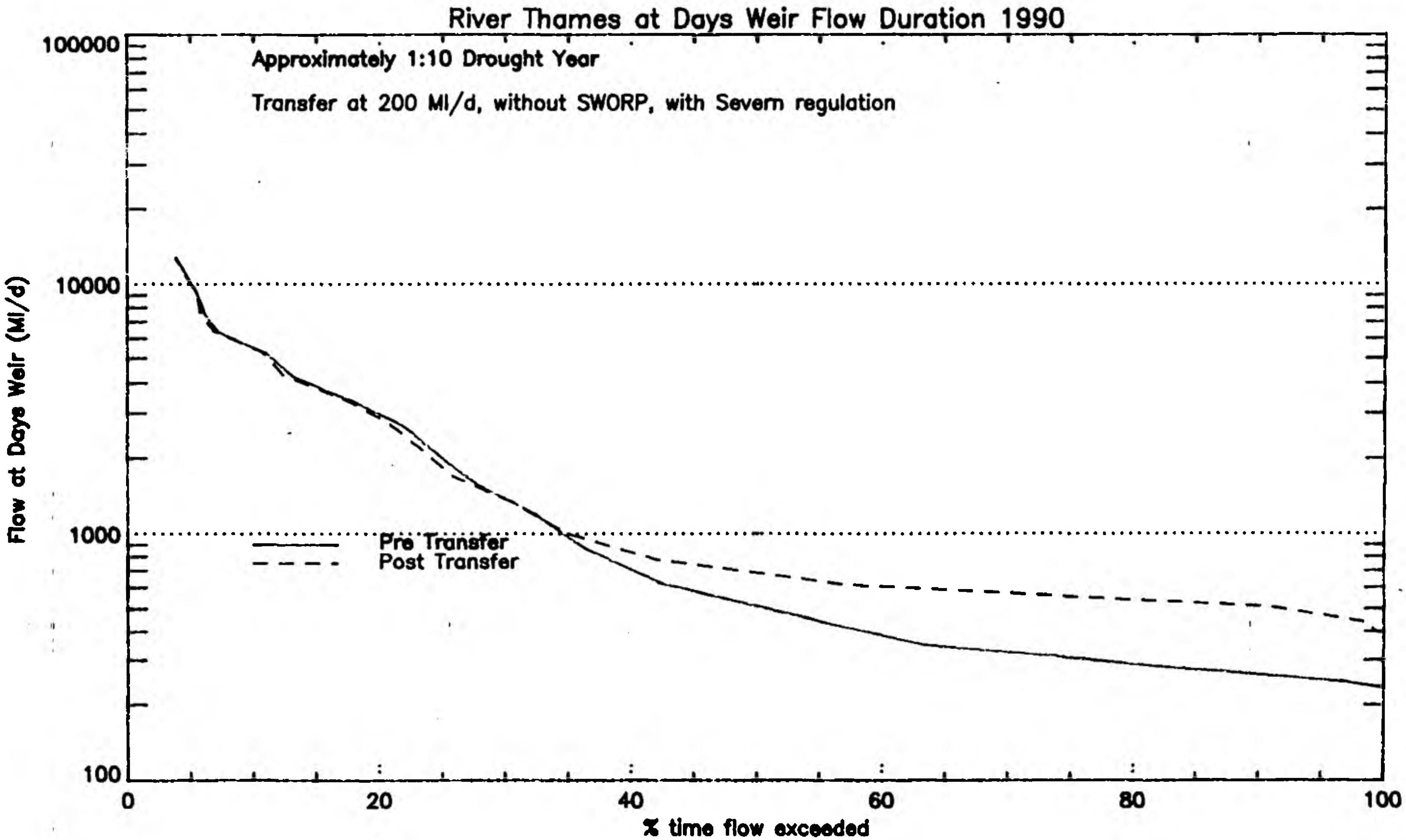
River Thames, flow at Days Weir 1920-1991
Transfer at 200 Ml/d, without SWORP, with Severn Regulation

Figures in Ml/d	Pre Transfer	Post Transfer
Mean Flow	2459.011	2473.822
Mean Annual Flood	12940.62	12861.07
Mean Annual Min 7-day	394.5232	482.0264
Year	Annual Minimum 7-day Flow	
1920	629	613
1921	138	267
1922	376	450
1923	348	399
1924	979	1064
1925	384	462
1926	311	397
1927	543	629
1928	326	413
1929	182	272
1930	451	537
1931	793	878
1932	786	874
1933	256	519
1934	164	336
1935	314	440
1936	456	545
1937	364	451
1938	233	260
1939	413	499
1940	246	324
1941	607	693
1942	332	419
1943	246	430
1944	189	357

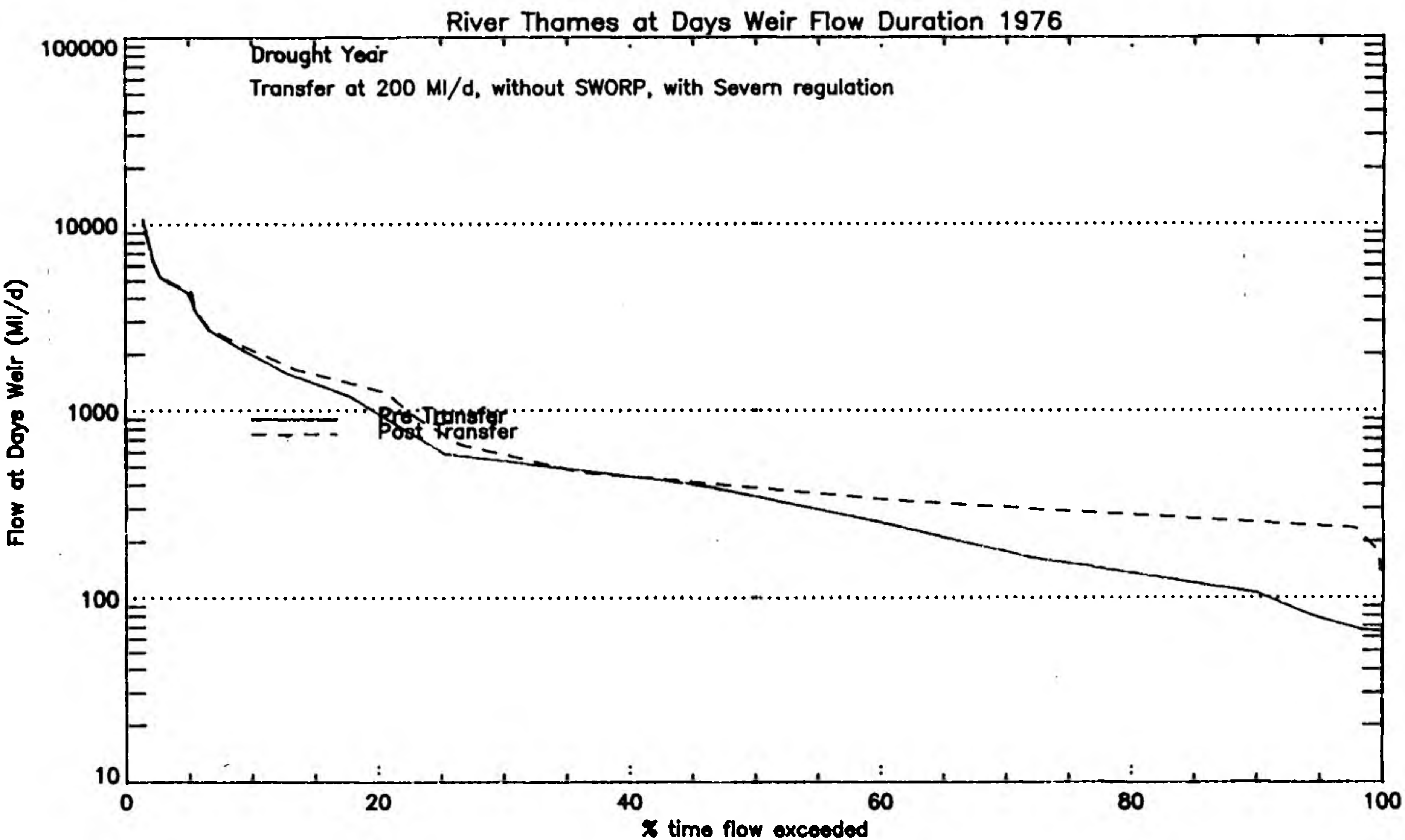
1945	259	524
1946	428	516
1947	290	377
1948	352	411
1949	210	344
1950	473	558
1951	568	674
1952	356	443
1953	335	495
1954	713	573
1955	256	344
1956	340	373
1957	464	502
1958	740	826
1959	239	307
1960	541	532
1961	347	433
1962	273	301
1963	521	608
1964	312	397
1965	389	470
1966	433	521
1967	425	510
1968	601	586
1969	386	473
1970	399	487
1971	508	595
1972	329	417
1973	337	330
1974	336	437
1975	287	362
1976	65	219
1977	662	758
1978	304	352

1979	435	521
1980	426	512
1981	455	542
1982	337	424
1983	423	474
1984	253	334
1985	590	676
1986	436	523
1987	351	438
1988	395	482
1989	255	398
1990	239	448
1991	268	355

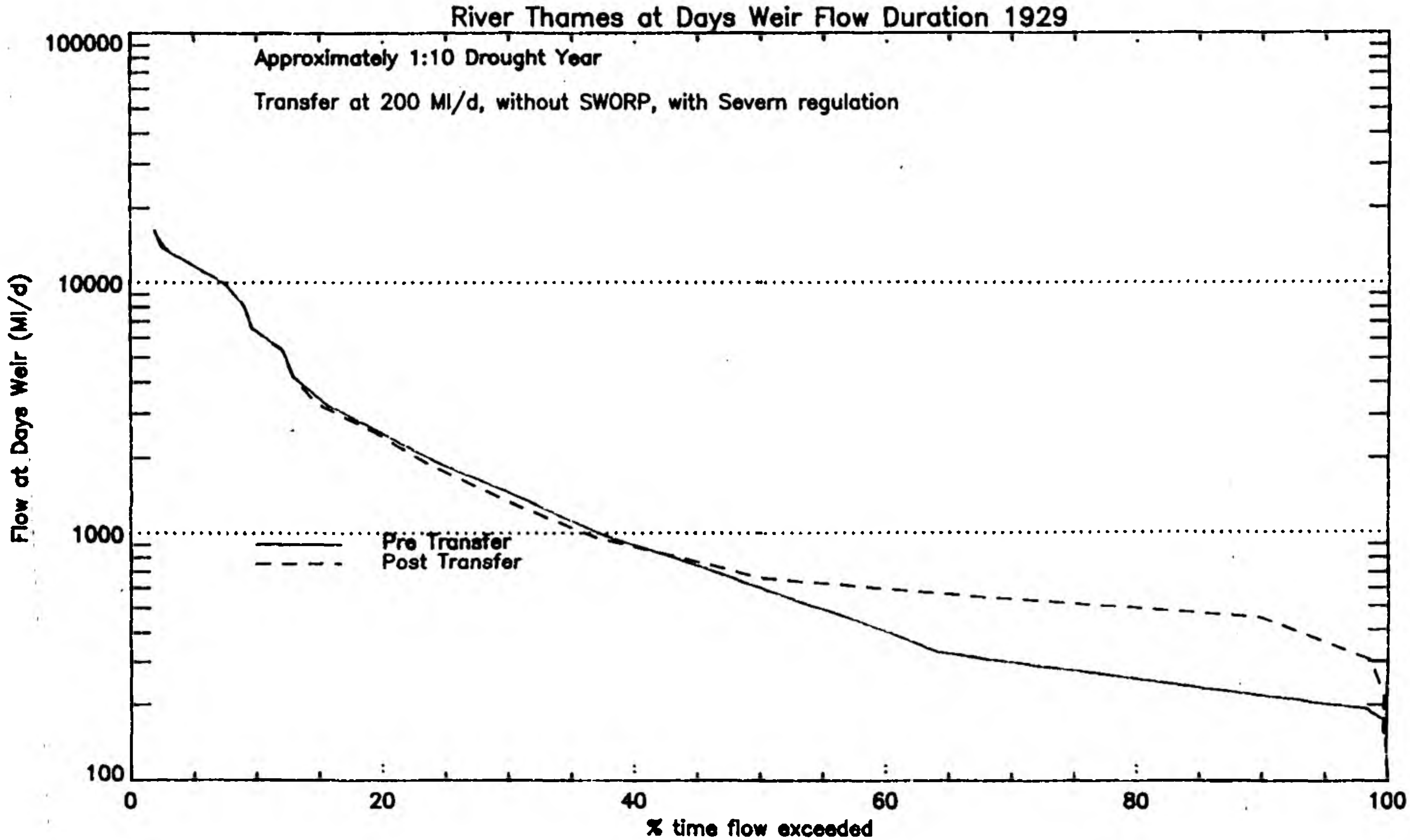

River Thames at Days Weir Flow Duration 1920–1991
The dotted lines make up an envelope in which all flow duration curves for individual years fall.
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Flow at Days Weir (Ml/d)
100000
10000
1000
100
10
0
20
40
60
80
100
% time flow exceeded
Pre Transfer
Pre Transfer
Post Transfer
Post Transfer



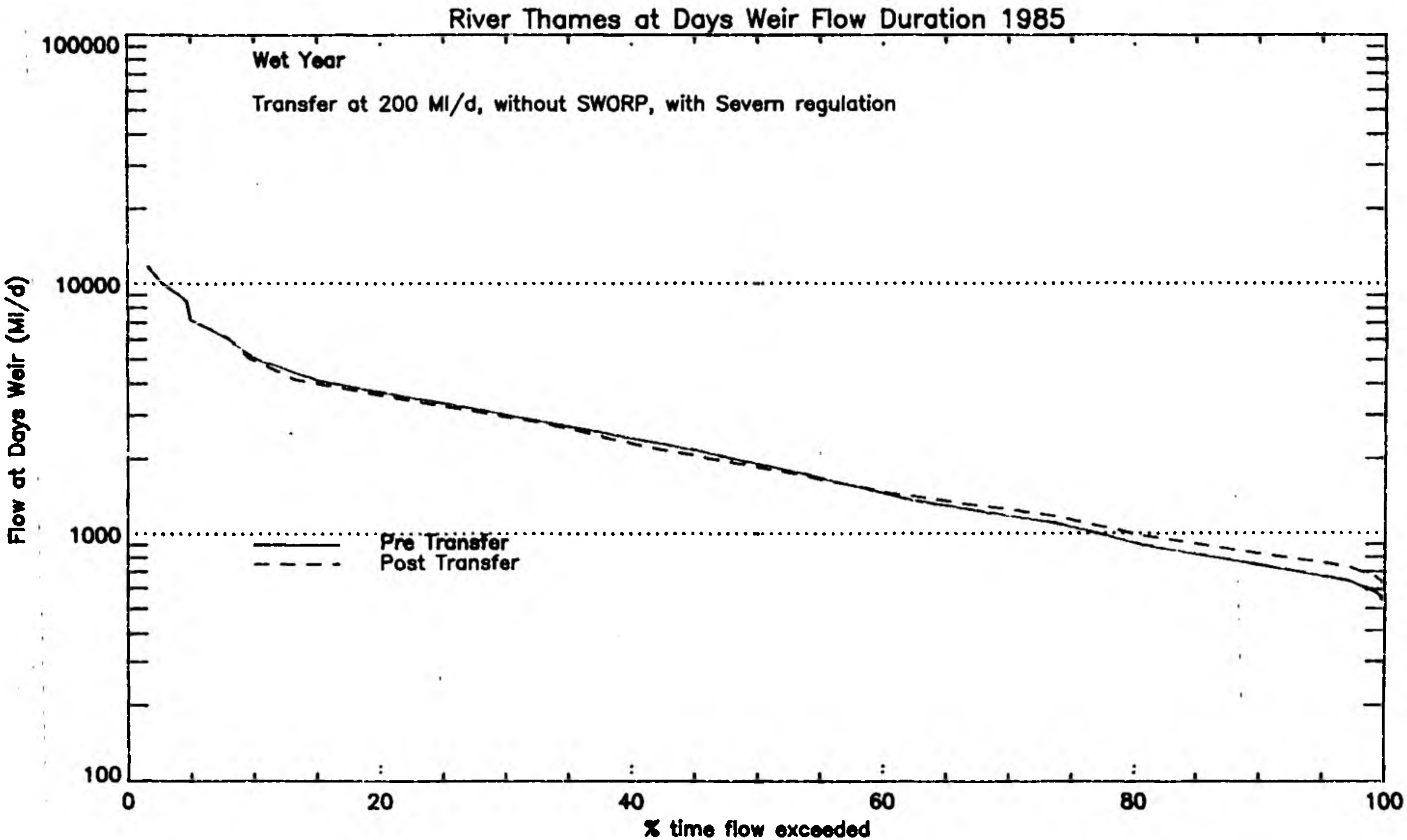
River Thames at Days Weir Flow Duration 1990
Approximately 1:10 Drought Year
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Flow at Days Weir (Ml/d)
100000
10000
1000
100
Pre Transfer
Post Transfer
0
20
40
60
80
100
% time flow exceeded

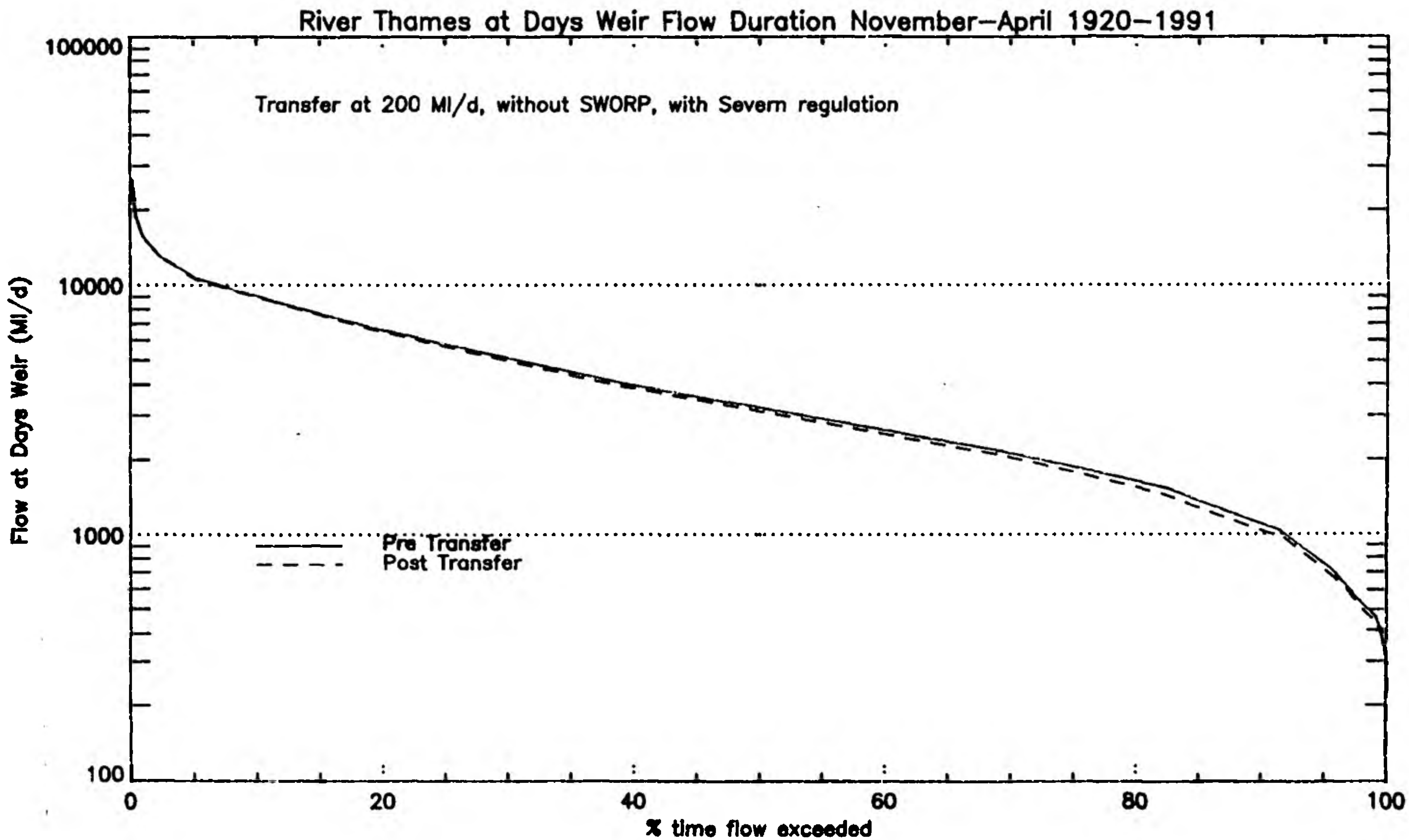


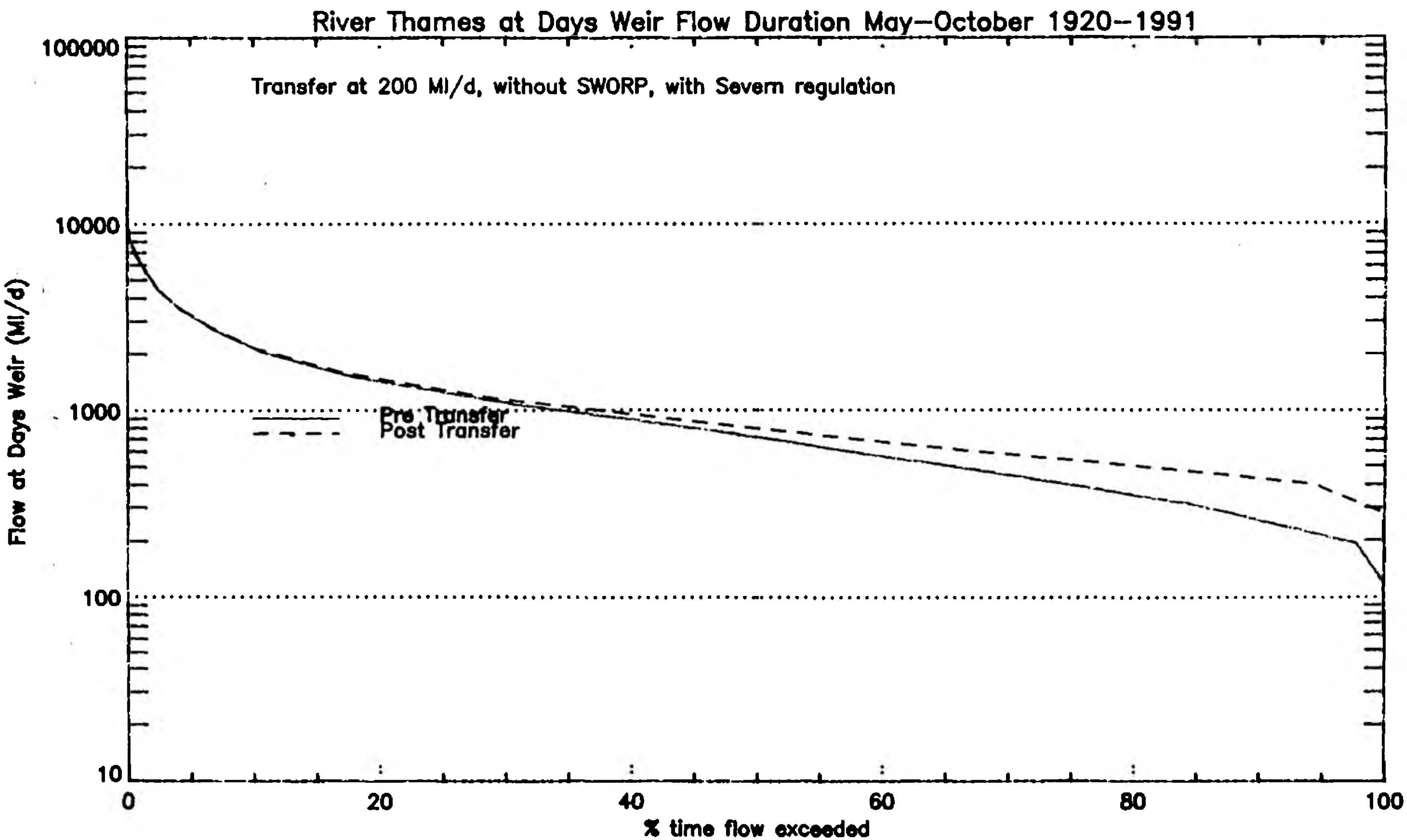
River Thames at Days Weir Flow Duration 1976
Drought Year
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Pre Transfer
Post Transfer
100000
10000
1000
100
10
Flow at Days Weir (Ml/d)
0
20
40
60
80
100
% time flow exceeded

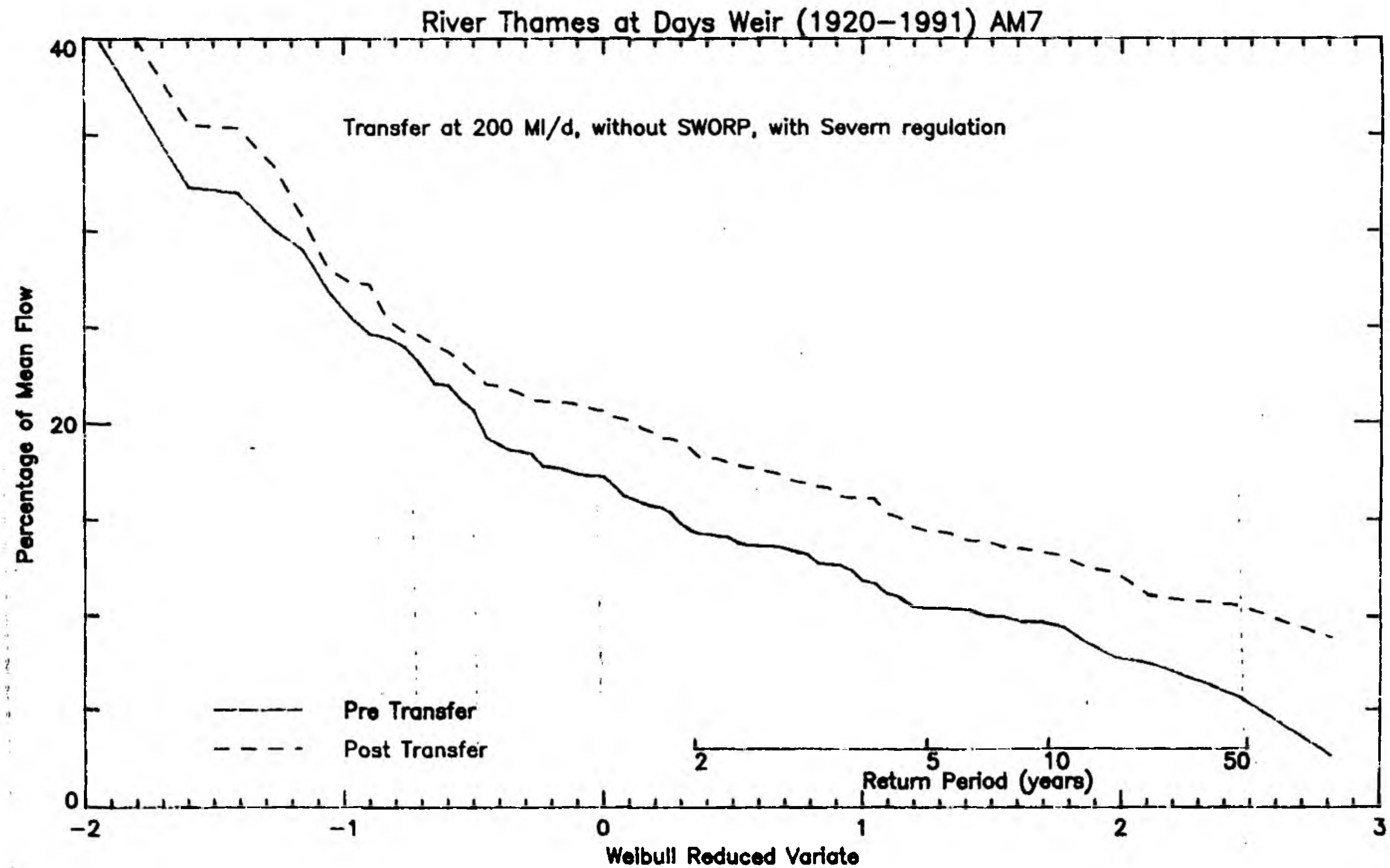


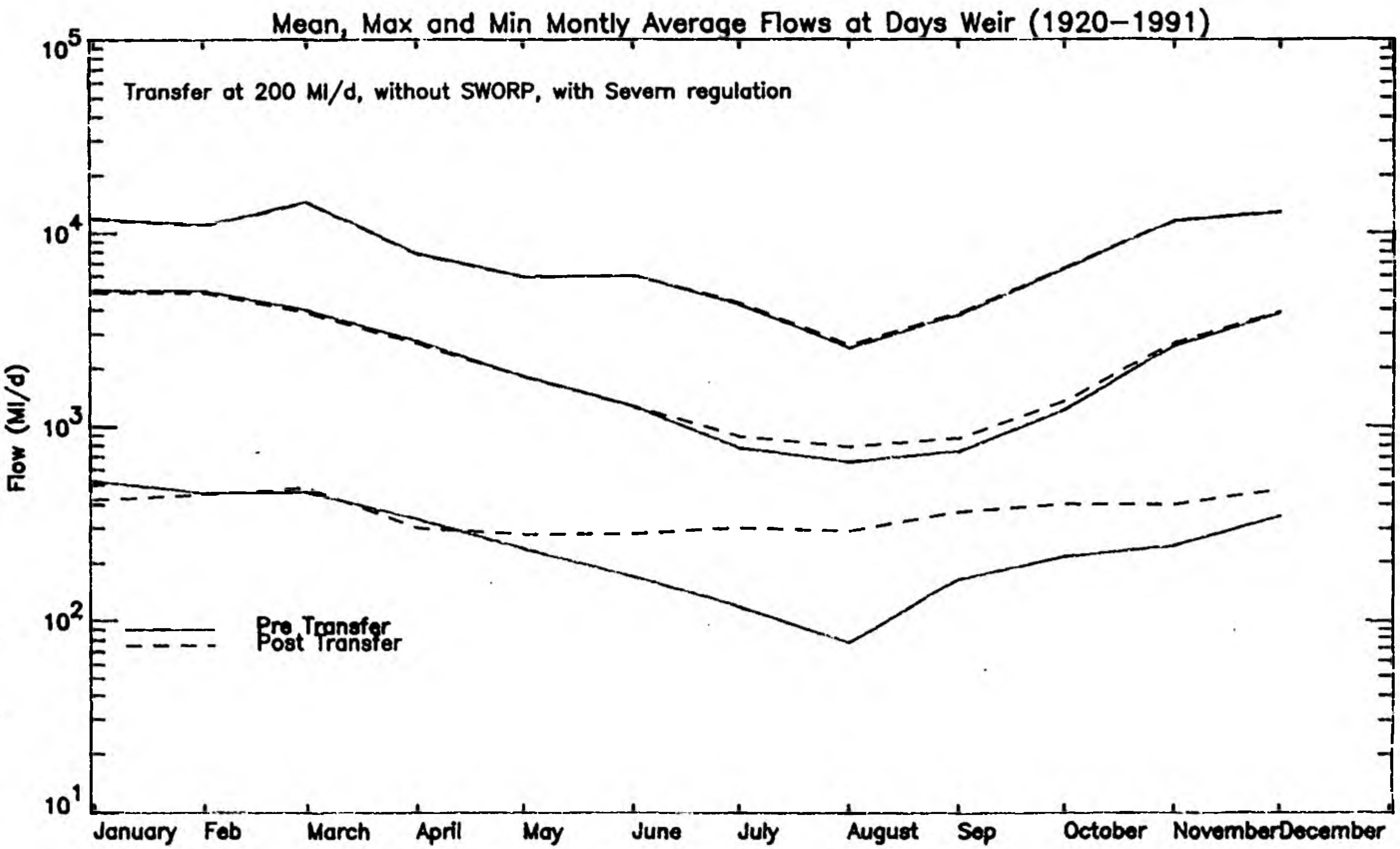
River Thames at Days Weir Flow Duration 1929
Approximately 1:10 Drought Year
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Pre Transfer
Post Transfer
Flow at Days Weir (Ml/d)
100000
10000
1000
100
0
20
40
60
80
100
% time flow exceeded


River Thames at Days Weir Flow Duration 1985
Wet Year
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Flow at Days Weir (Ml/d)
100000
10000
1000
100
0
20
40
60
80
100
% time flow exceeded
Pre Transfer
Post Transfer


River Thames at Days Weir Flow Duration November–April 1920–1991
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Pre Transfer
Post Transfer
Flow at Days Weir (Ml/d)
100000
10000
1000
100
0
20
40
60
80
100
% time flow exceeded


River Thames at Days Weir Flow Duration May–October 1920–1991
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Pre Transfer
Post Transfer
Flow at Days Weir (Ml/d)
% time flow exceeded
100000
10000
1000
100
10
0
20
40
60
80
100

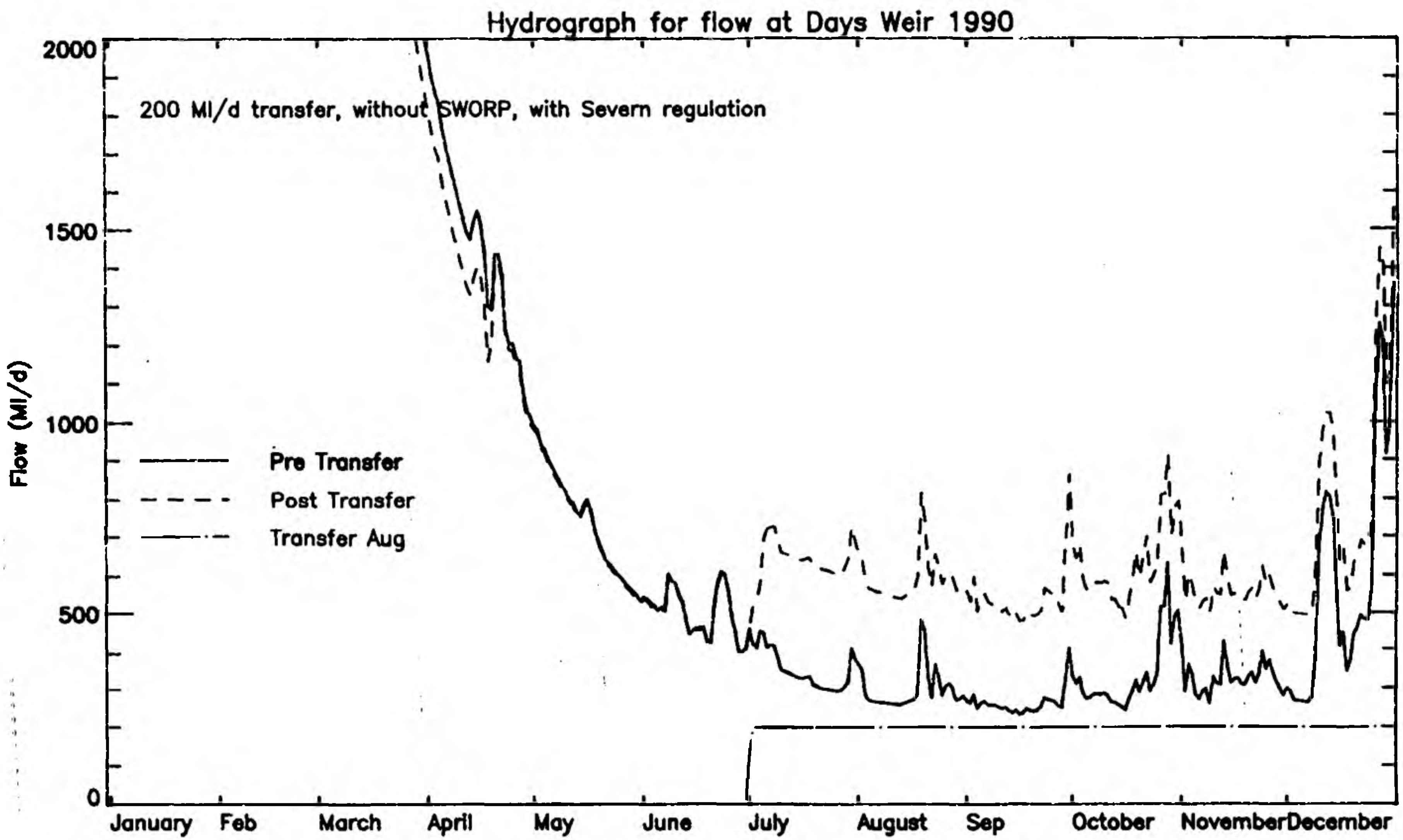

River Thames at Days Weir (1920–1991) AM7
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Percentage of Mean Flow
40
20
0
Pre Transfer
Post Transfer
2
5
10
50
Return Period (years)
–2
–1
0
1
2
3
Weibull Reduced Variate



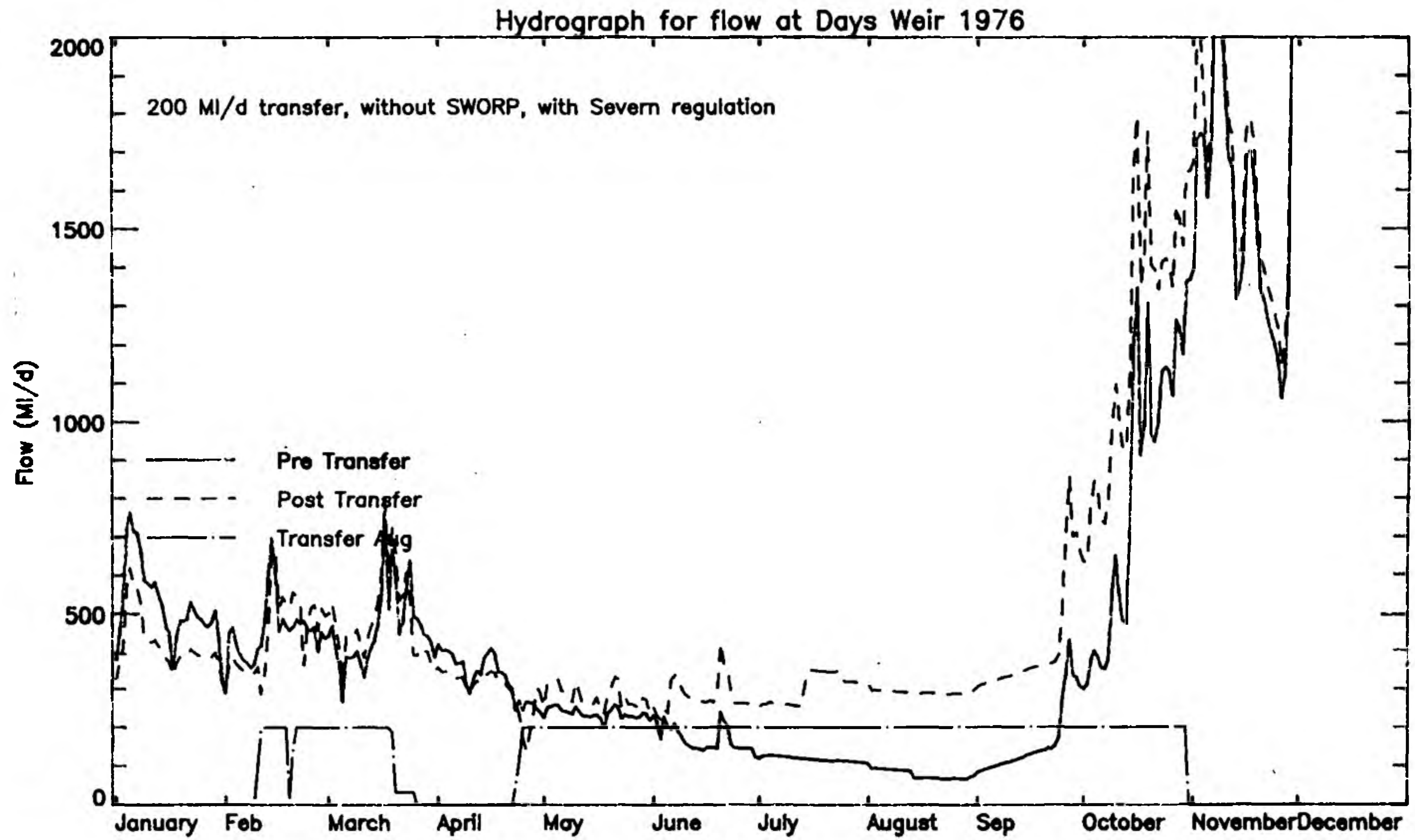
Mean, Max and Min Montly Average Flows at Days Weir (1920–1991)
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Flow (Ml/d)
10^5
10^4
10^3
10^2
10^1
Pre Transfer
Post Transfer
January
Feb
March
April
May
June
July
August
Sep
October
November
December

YEAR	TOTAL QUANTITY (ML)	DAYS USE
1921	43721	219
1922	43206	219
1923	8294	83
1929	33347	167
1933	31572	159
1934	62749	331
1935	14260	81
1938	27203	164
1940	9069	56
1942	176	11
1943	37481	188
1944	55697	305
1945	38152	195
1946	315	3
1947	13760	70
1948	22348	112
1949	27258	143
1953	13114	101
1956	12002	62
1959	8695	55
1964	4282	31
1965	15662	81
1973	9431	48
1974	200	1
1976	45604	236
1984	6348	92
1989	17674	119
1990	36734	184
1991	10060	65
	YEARS USED	29
TOTAL	648414	3581
MEAN	18012	99

SUMMARY DATA FOR SEVERN-THAMES TRANSFER AT 200 ML/D, WITHOUT SWORP, WITH SEVERN REGULATION

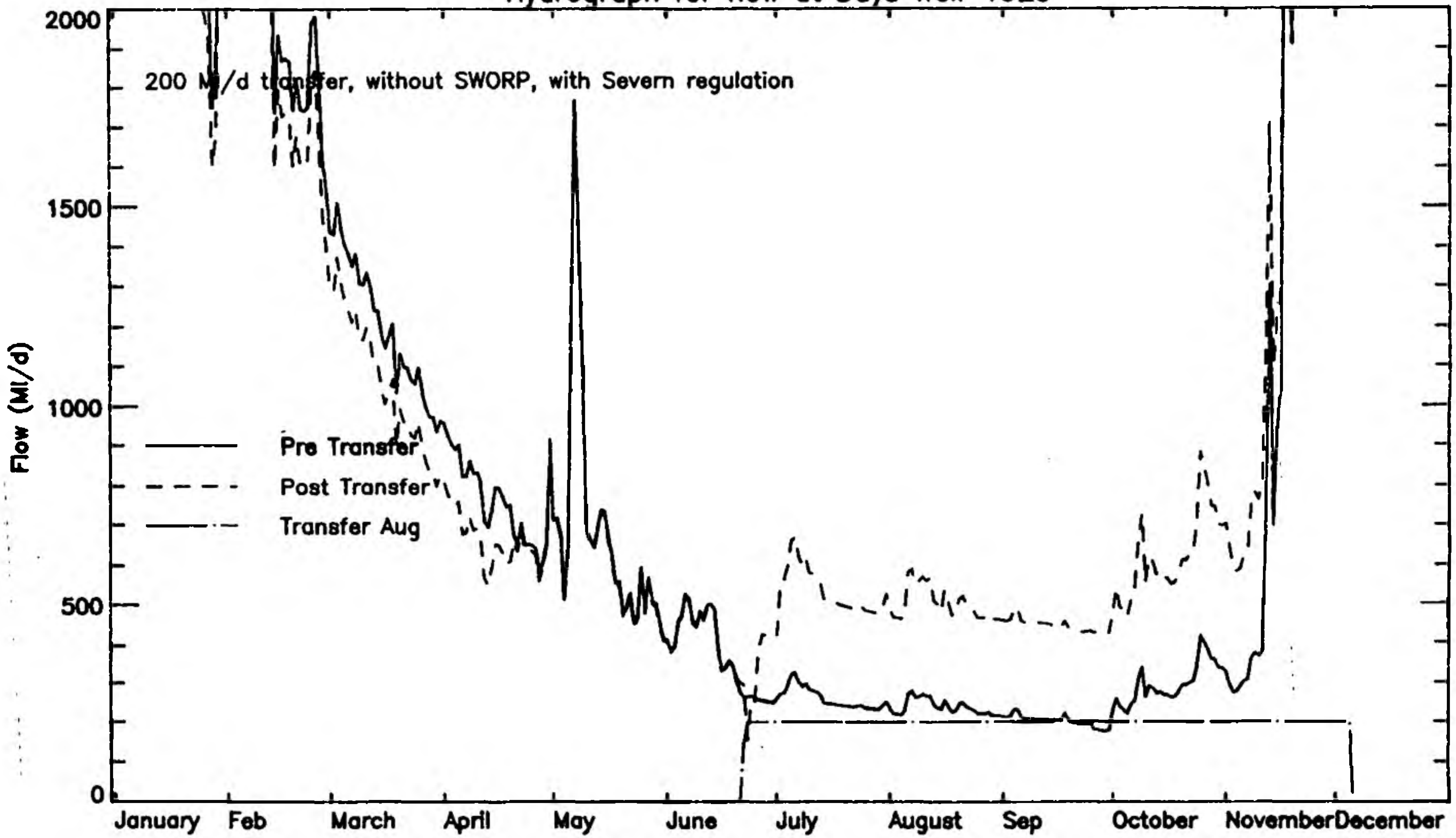


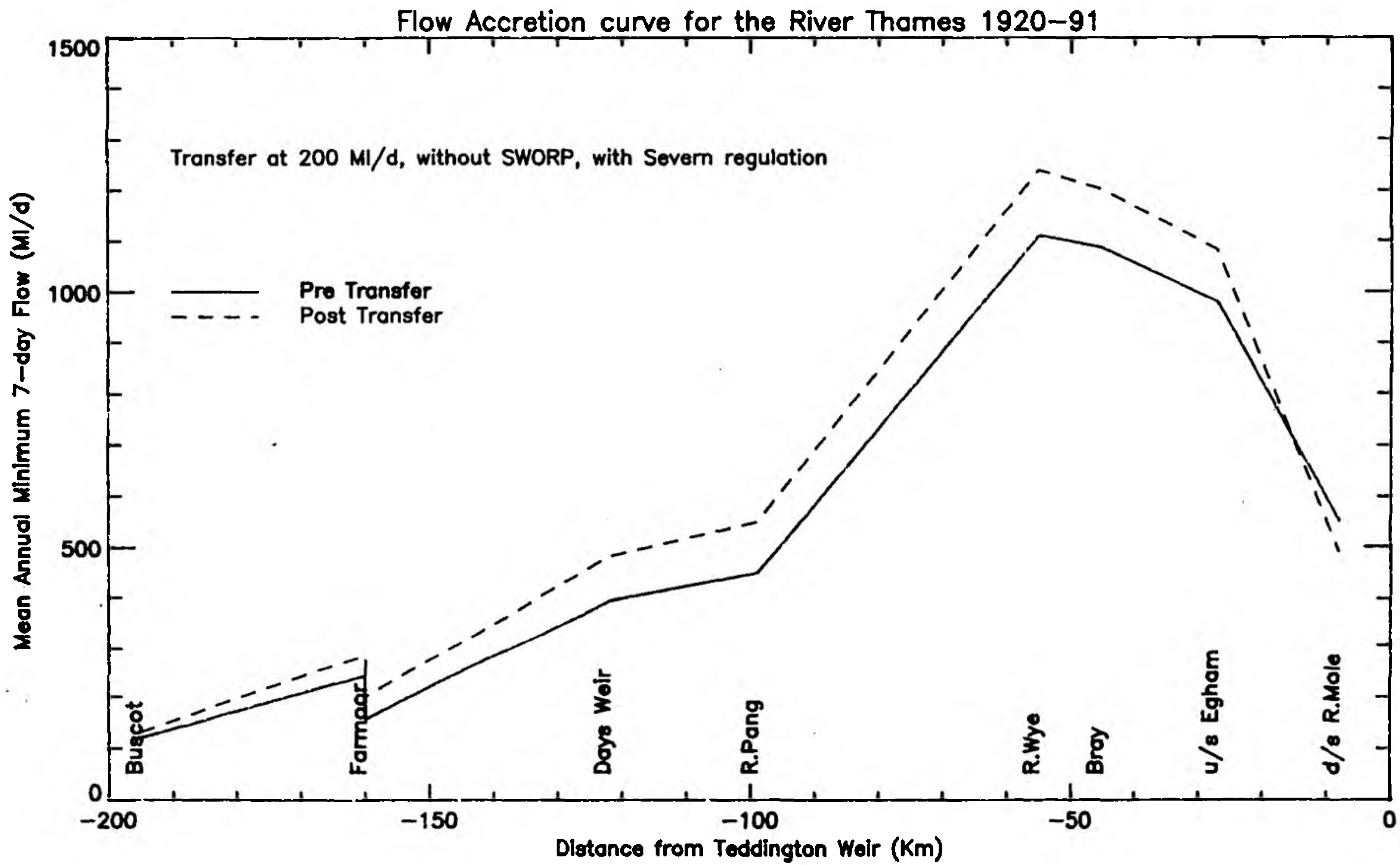
Hydrograph for flow at Days Weir 1990
200 Ml/d transfer, without SWORP, with Severn regulation
Flow (Ml/d)
2000
1500
1000
500
0
Pre Transfer
Post Transfer
Transfer Aug
January
Feb
March
April
May
June
July
August
Sep
October
November
December



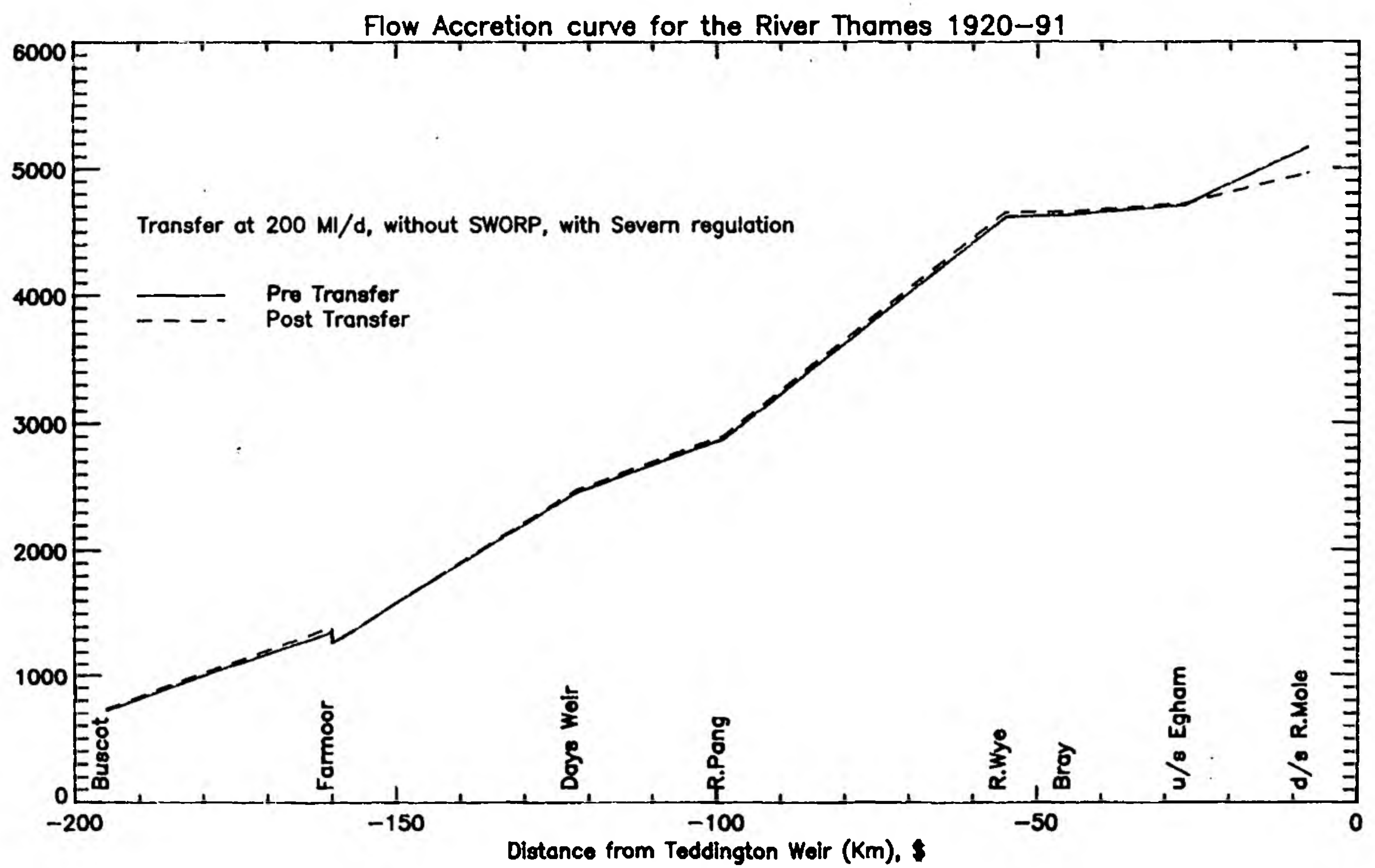
Hydrograph for flow at Days Weir 1976
200 Ml/d transfer, without SWORP, with Severn regulation
Flow (Ml/d)
2000
1500
1000
500
0
Pre Transfer
Post Transfer
Transfer Aug
January
Feb
March
April
May
June
July
August
Sep
October
November
December

Hydrograph for flow at Days Weir 1929





Flow Accretion curve for the River Thames 1920–91
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Pre Transfer
Post Transfer
Mean Annual Minimum 7-day Flow (Ml/d)
1500
1000
500
0
Distance from Teddington Weir (Km)
−200
−150
−100
−50
0
Buscot
Farmoor
Days Weir
R.Pang
R.Wye
Bray
u/s Egham
d/s R.Mole



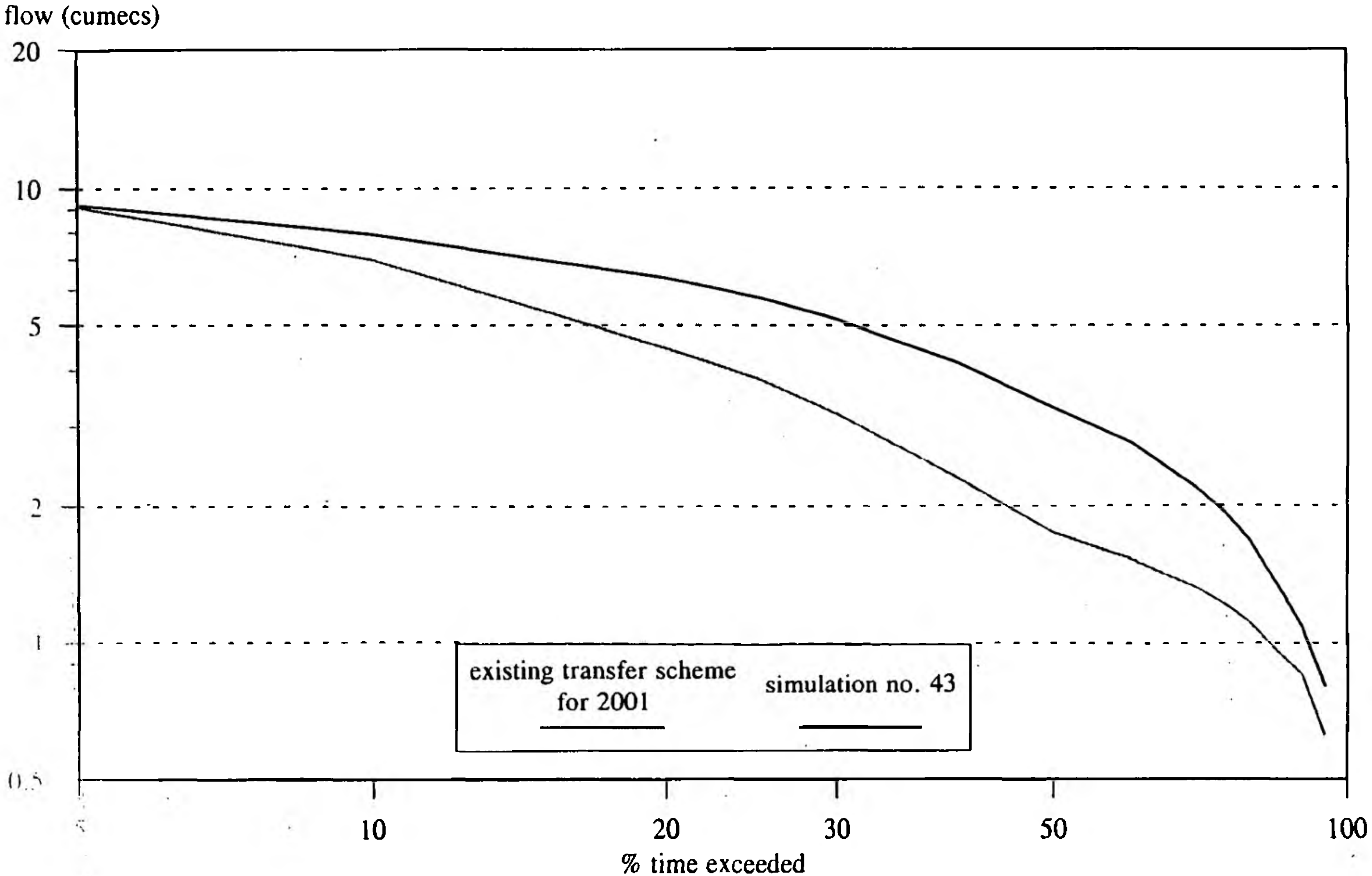
Flow Accretion curve for the River Thames 1920–91
Transfer at 200 Ml/d, without SWORP, with Severn regulation
Pre Transfer
Post Transfer
6000
5000
4000
3000
2000
1000
0
−200
−150
−100
−50
0
Buscot
Farmoor
Days Weir
R.Pang
R.Wye
Bray
u/s Egham
d/s R.Mole
Distance from Teddington Weir (Km), $

Appendix B3

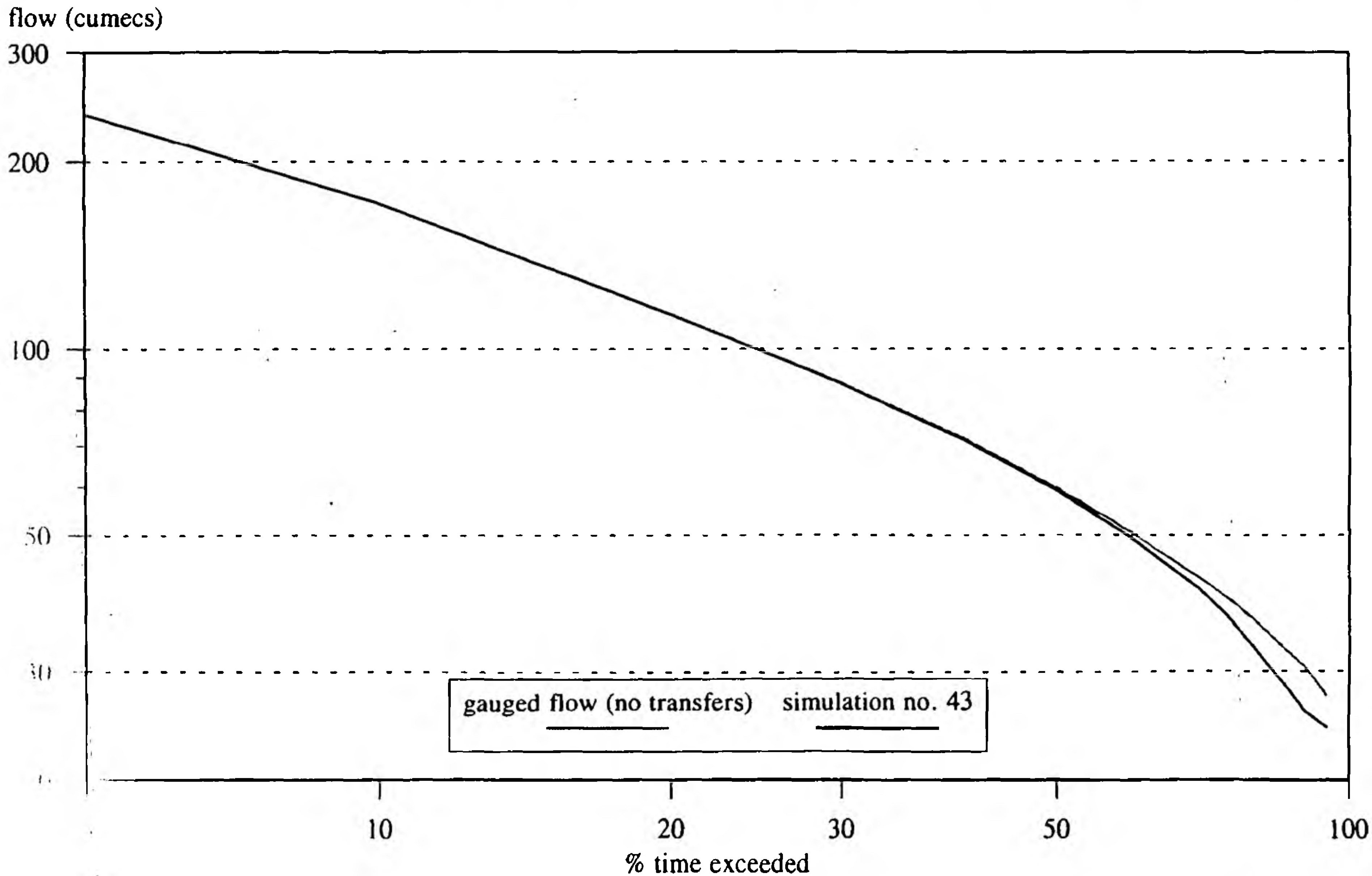
NRA ANGLIAN

APPENDIX 3: SIMULATION OF DOWNSTREAM FLOWS

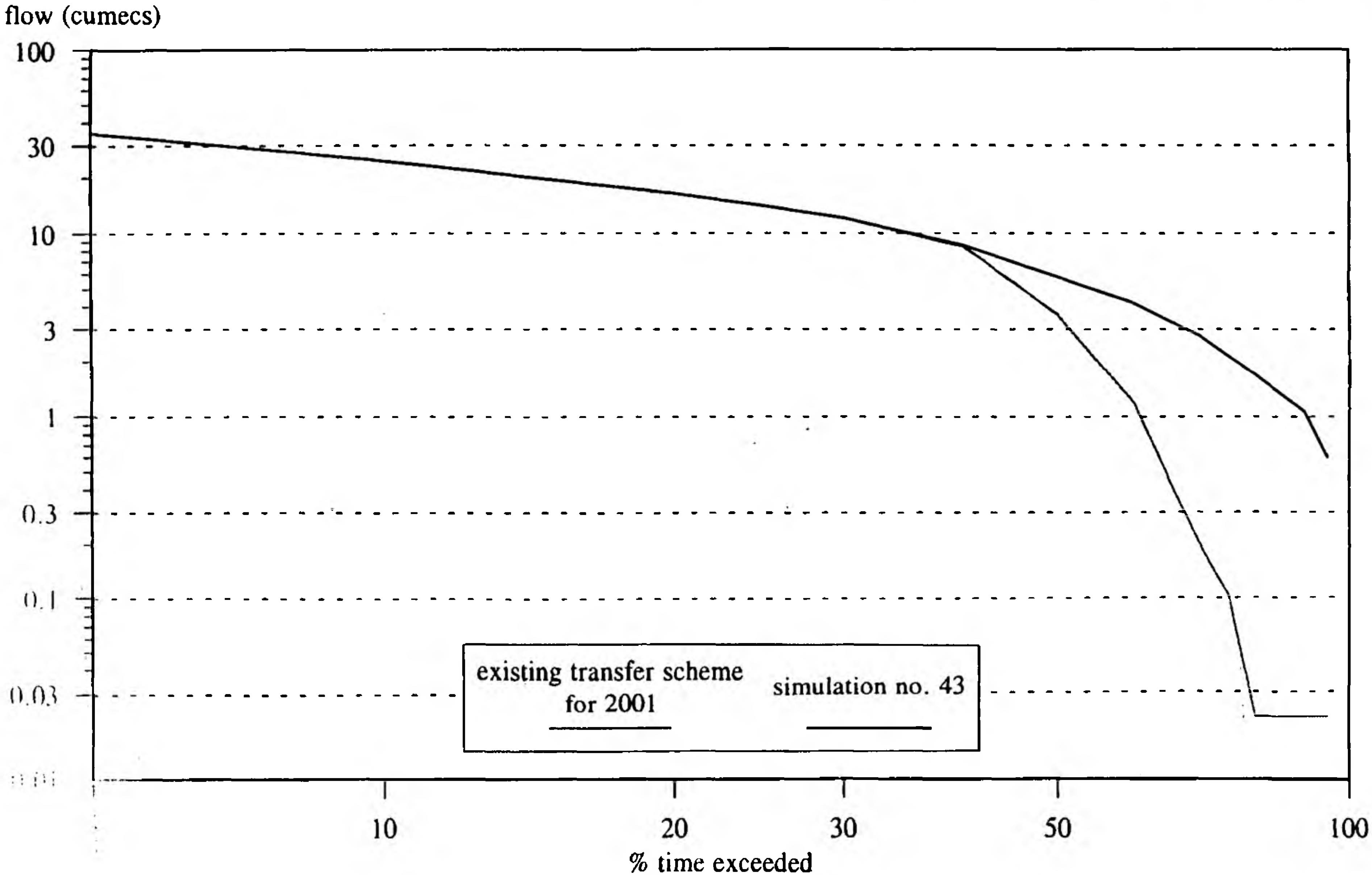
These plots illustrate the type of data which is available for Environmental Impact studies. Flow data may be presented numerically, as summary statistics, as hydrographs or as flow duration curves.



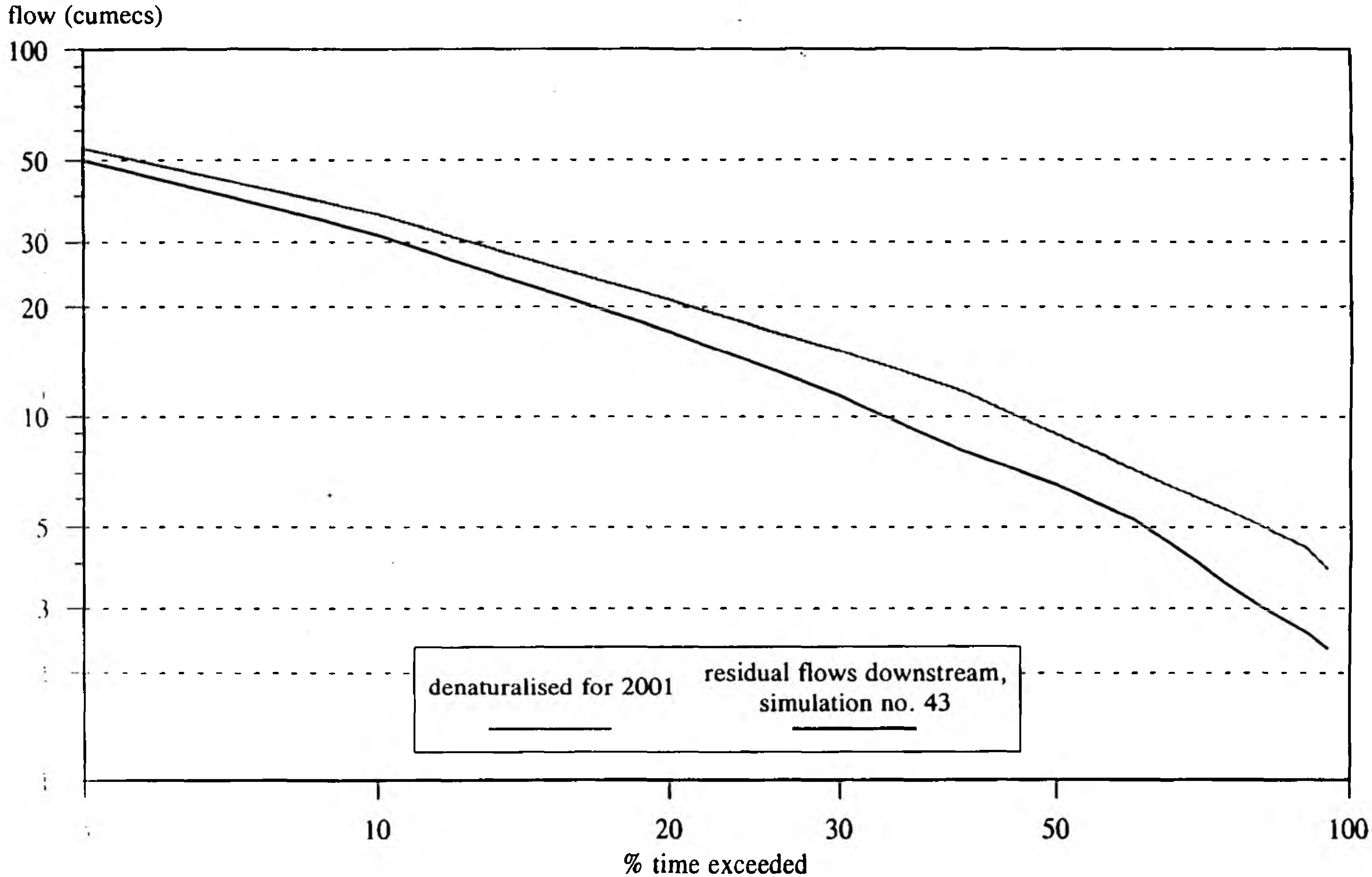
Witham downstream of Fossdyke
Simulated flow duration curves 1972 - 1992



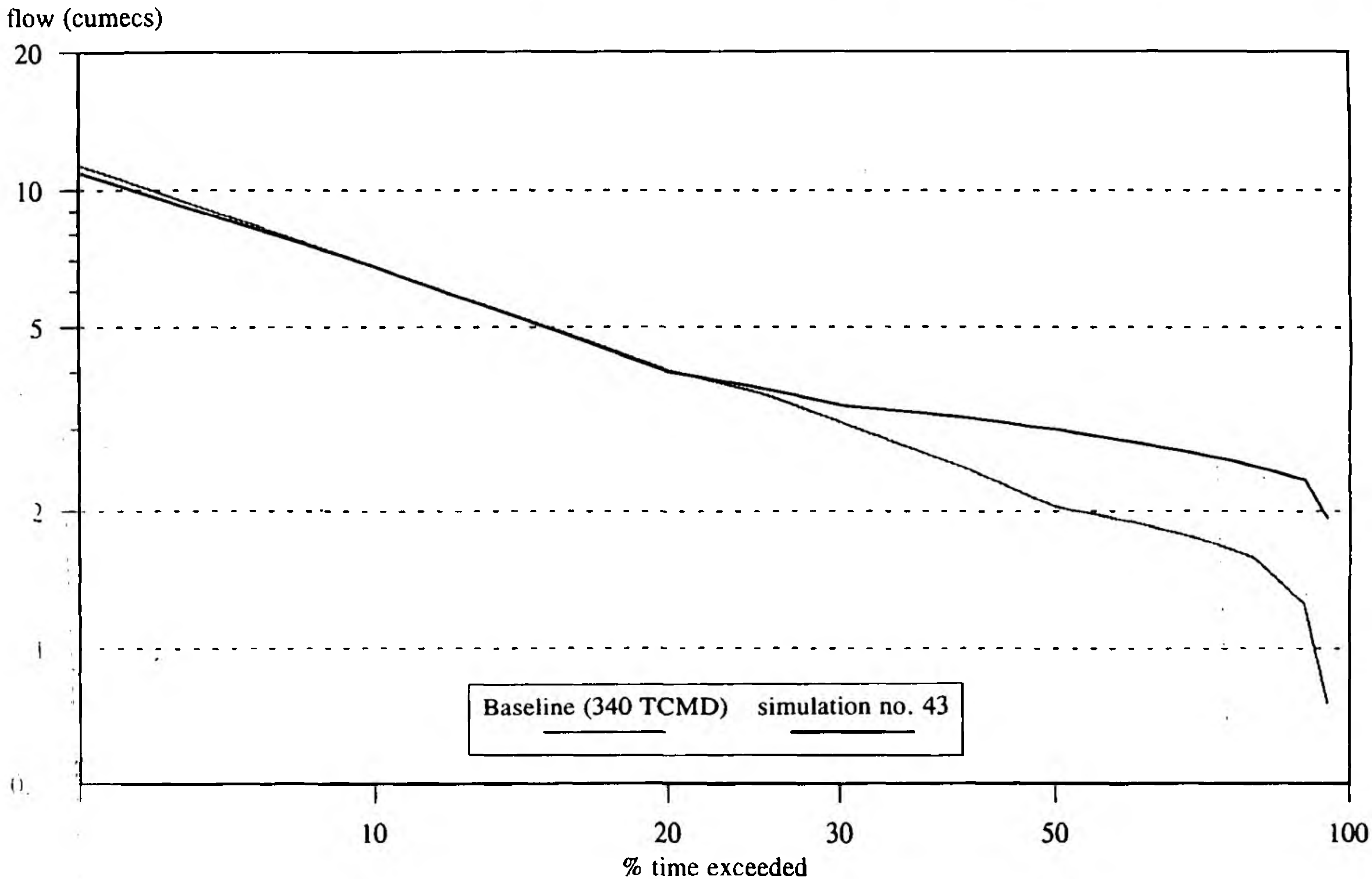
Trent at Torksey
Simulated flow duration curves 1972 - 1992



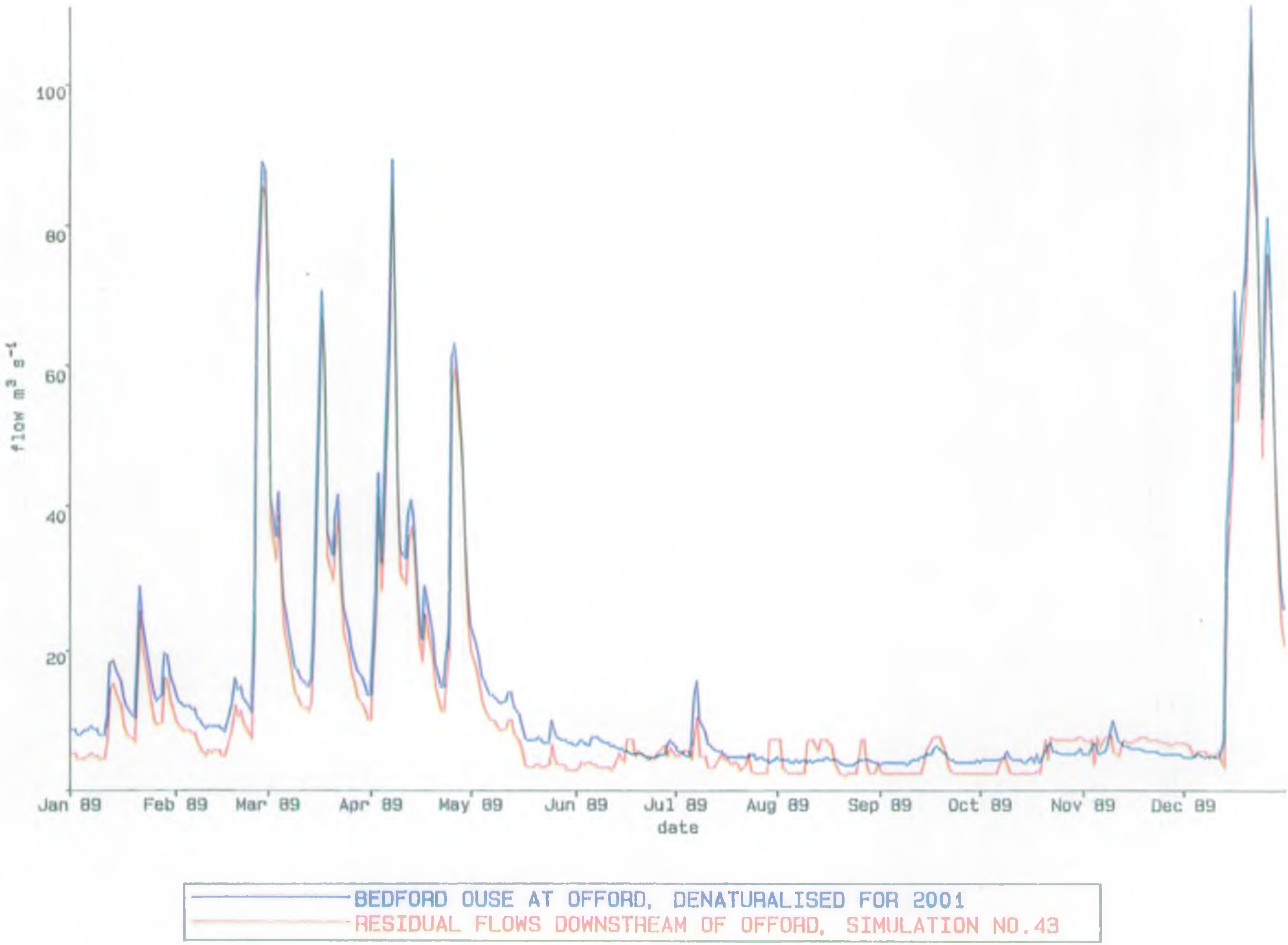
Witham upstream of Boston
Simulated flow duration curves 1972 - 1992



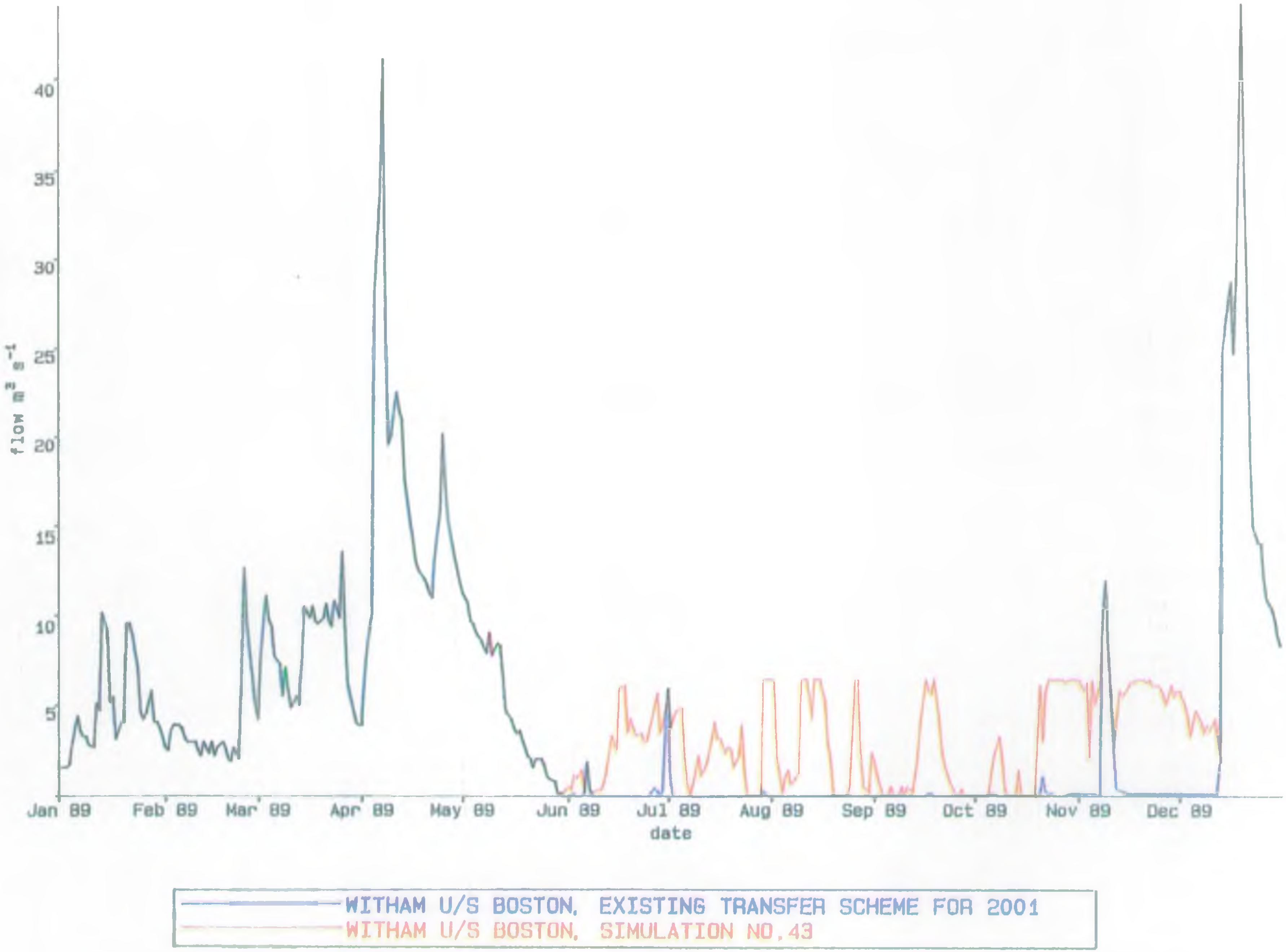
Bedford Ouse at Offord
Simulated flow duration curves 1972 - 1992



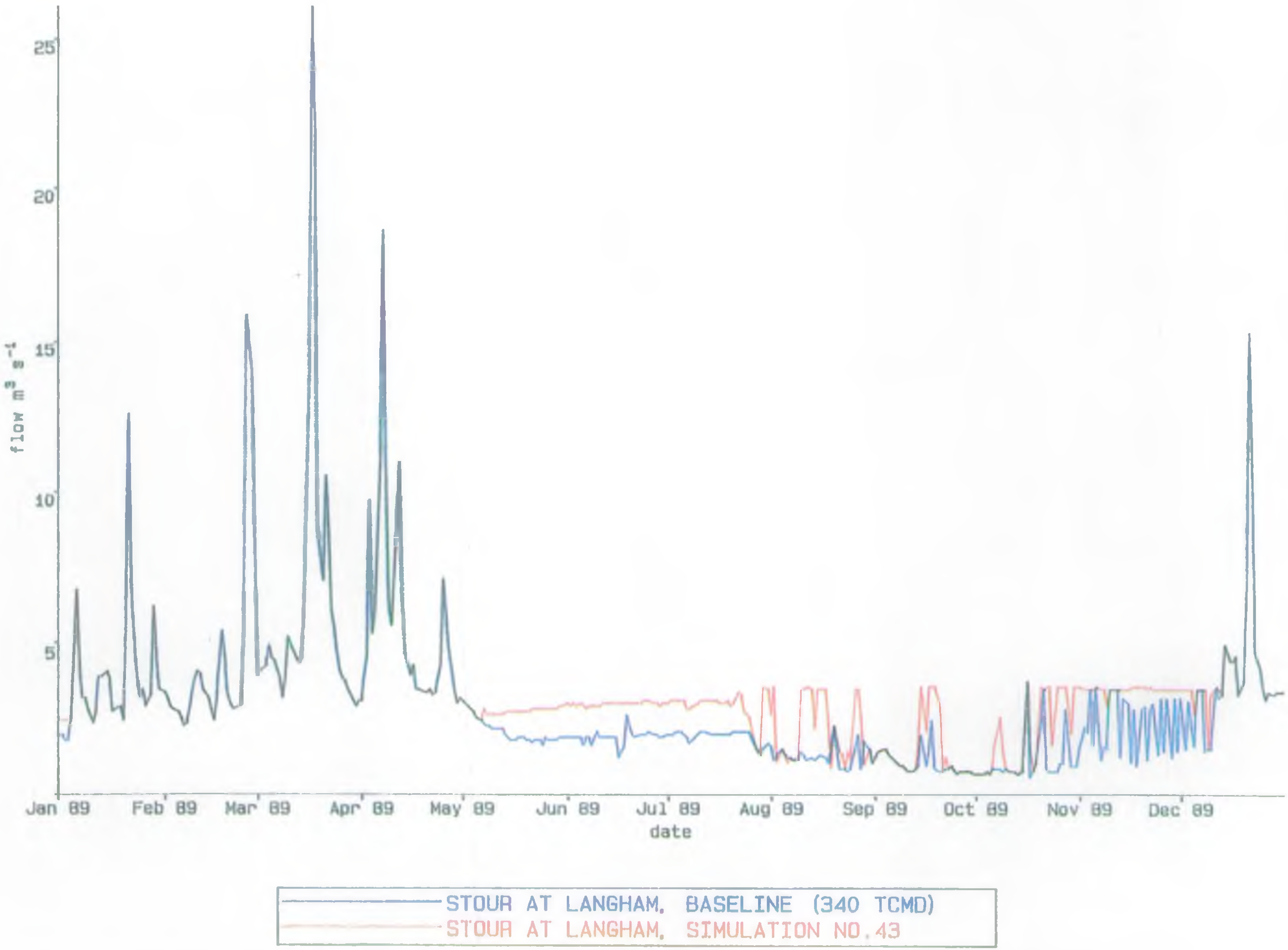
Stour at Langham
Simulated flow duration curves 1972 - 1992



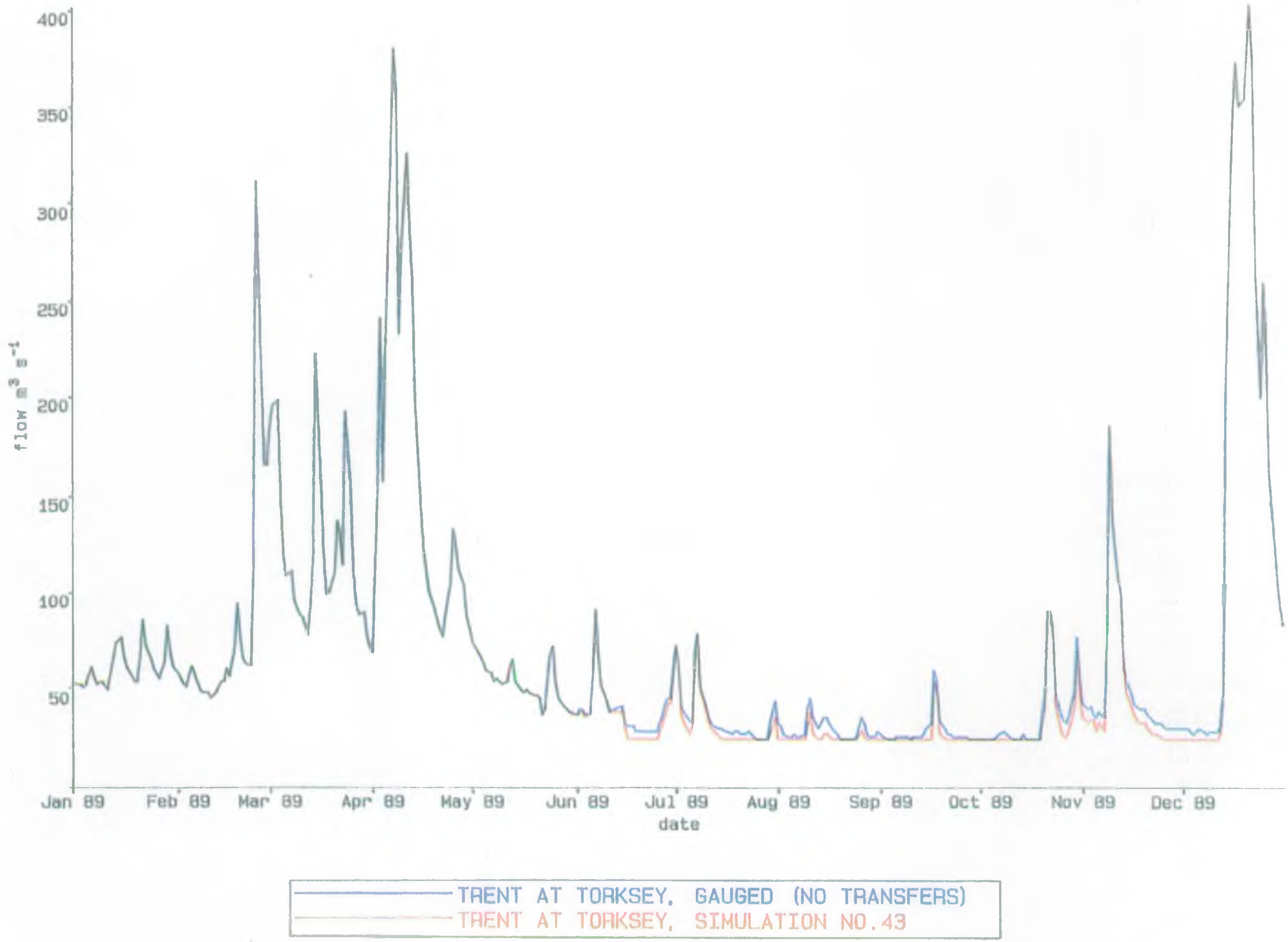
100
80
60
40
20
flow m³ s⁻¹
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
BEDFORD OUSE AT OFFORD, DENATURALISED FOR 2001
RESIDUAL FLOWS DOWNSTREAM OF OFFORD, SIMULATION NO.43

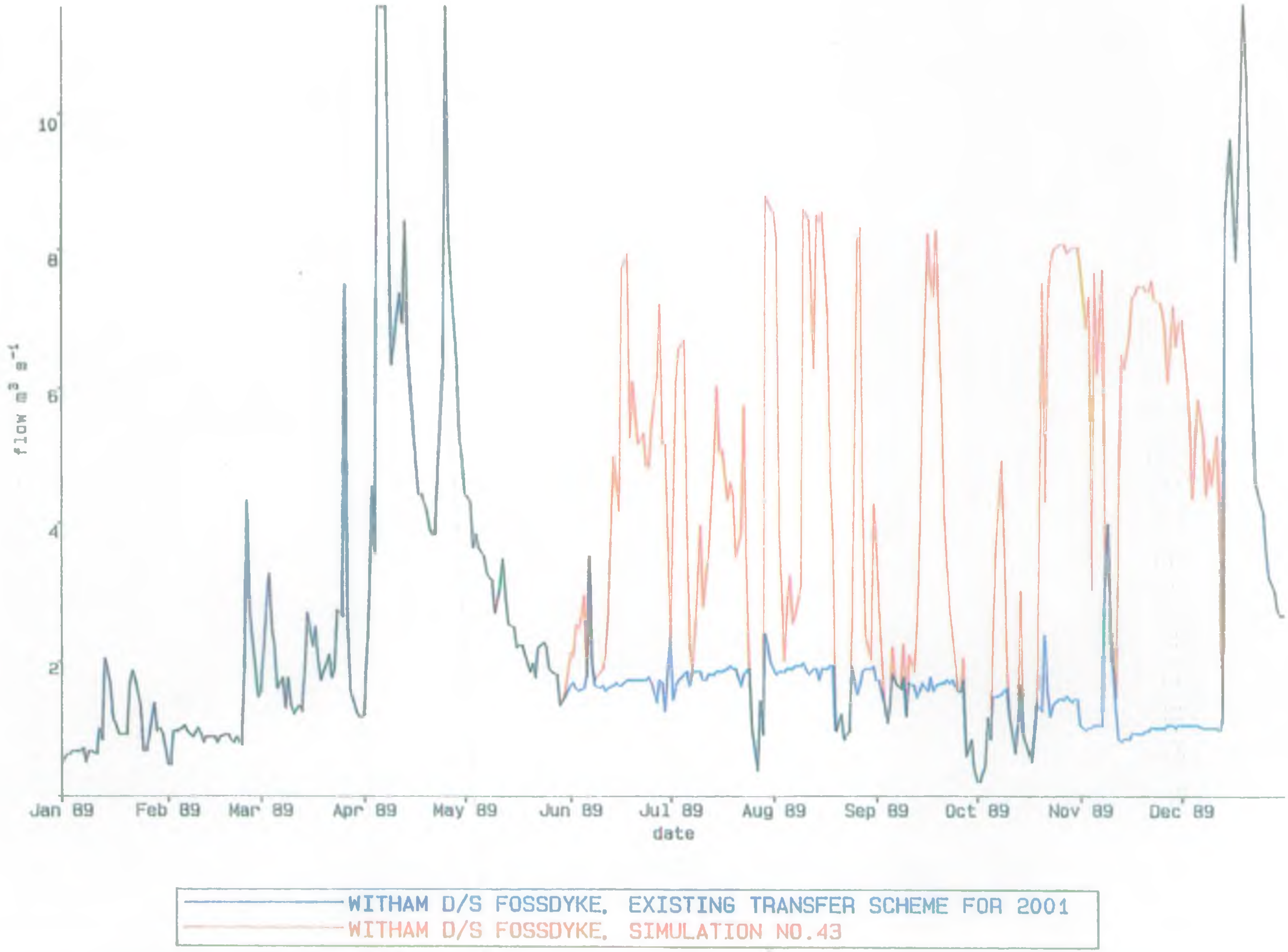


40
35
30
25
20
15
10
5
flow m³ s⁻¹
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
WITHAM U/S BOSTON, EXISTING TRANSFER SCHEME FOR 2001
WITHAM U/S BOSTON, SIMULATION NO.43



25
20
15
10
5
flow m3 s-1
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
STOUR AT LANGHAM, BASELINE (340 TCMD)
STOUR AT LANGHAM, SIMULATION NO.43


400
350
300
250
200
150
100
50
flow m3 s-1
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
TRENT AT TORKSEY, GAUGED (NO TRANSFERS)
TRENT AT TORKSEY, SIMULATION NO.43



flow m3 s-1
10
8
6
4
2
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
WITHAM D/S FOSSDYKE, EXISTING TRANSFER SCHEME FOR 2001
WITHAM D/S FOSSDYKE, SIMULATION NO.43