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PRELIMINARY MODELLING OF WATER STORAGE AND TRANSFERS IN THE ANGLIAN REGION

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Supporting Documentation for the
Regional Water Resources Strategy

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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.

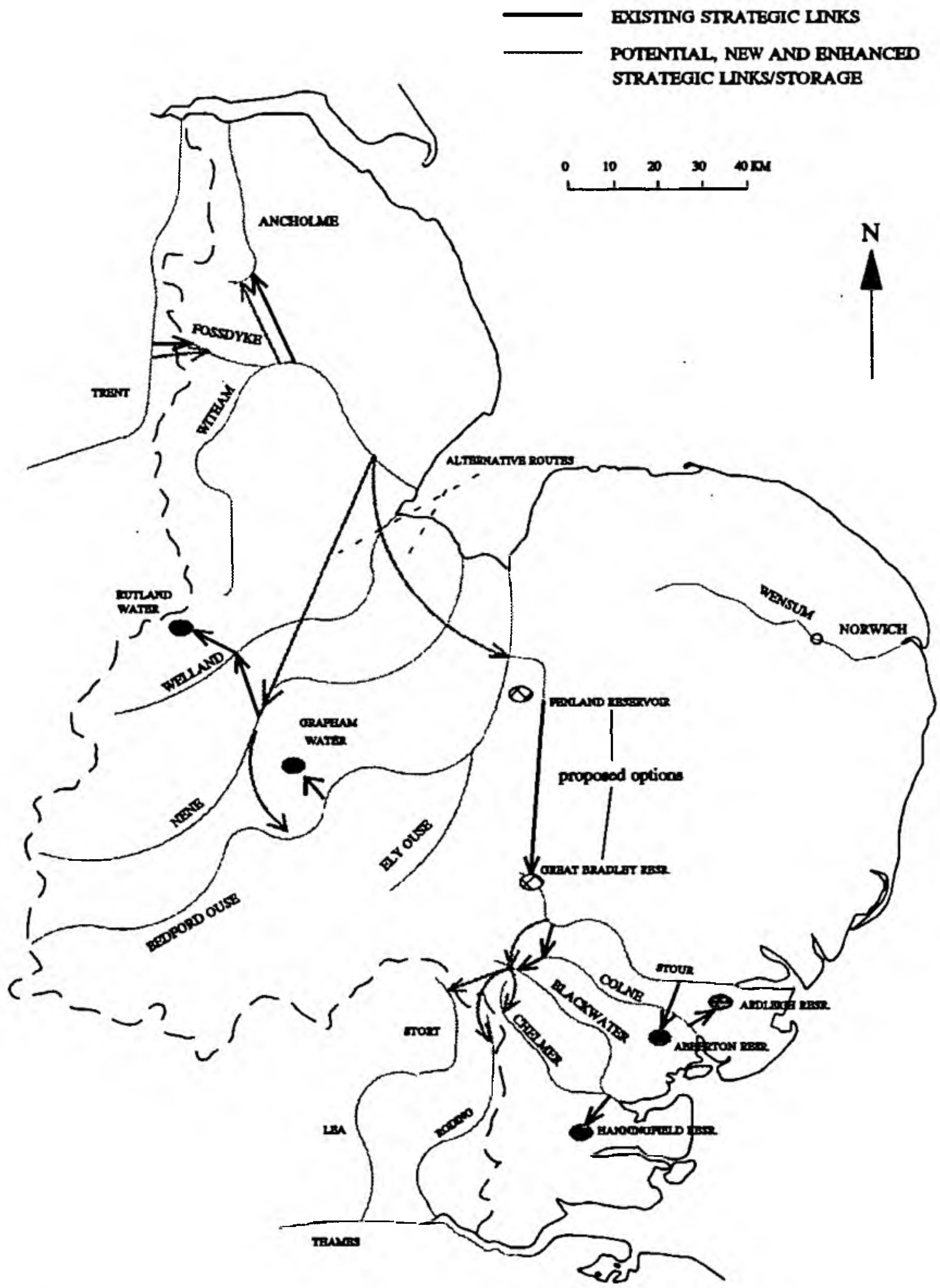


Figure 1:
Strategic transfer links - proposed and existing

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.

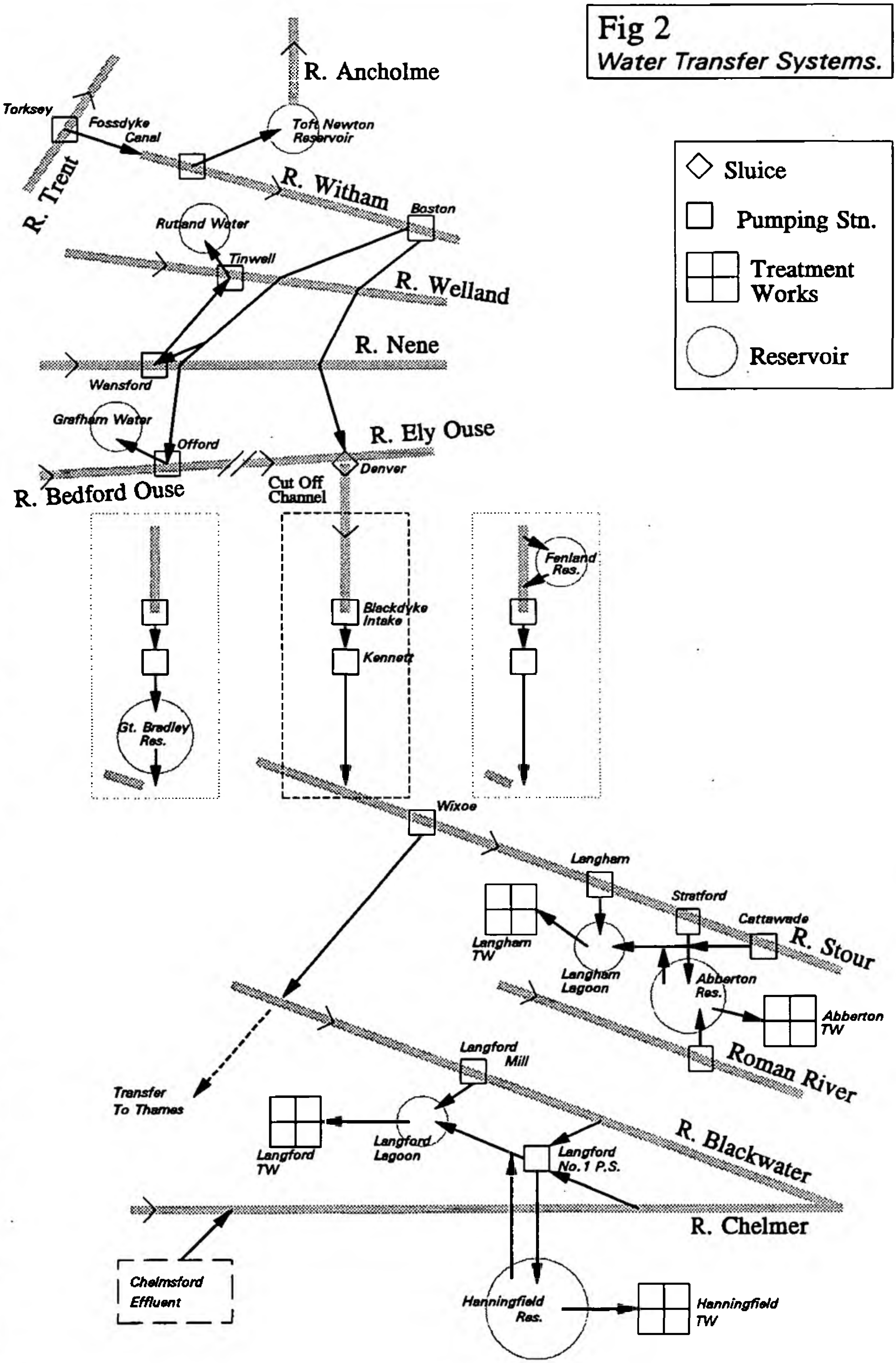


Fig 2
Water Transfer Systems.
Sluice
Pumping Stn.
Treatment Works
Reservoir
R. Ancholme
Torksey
Fossdyke Canal
Toft Newton Reservoir
R. Trent
R. Witham
Boston
Rutland Water
Tinwell
R. Welland
R. Nene
Wansford
Grafham Water
Offord
R. Ely Ouse
Denver
R. Bedford Ouse
Cut Off Channel
Fenland Res.
Blackdyke Intake
Kennett
Gt. Bradley Res.
Wixoe
Langham
Stratford
Cattawade
R. Stour
Langham TW
Langham Lagoon
Abberton Res.
Abberton TW
Roman River
Langford Mill
Transfer To Thames
Langford TW
Langford Lagoon
Langford No.1 P.S.
R. Blackwater
R. Chelmer
Chelmsford Effluent
Hanningfield Res.
Hanningfield TW

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 svstem

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.

REFERENCES

W.S. Atkins (1993) **Options for the Transfer of Water from the River Trent and Reservoir Storage at Great Bradley. Feasibility Reports ; Vol.1 Transfer Systems ; Vol.2 Great Bradley Reservoir.** Report for NRA Anglian Region.

Clarke K F, C Page and J S Brew (1980) Reliability of Water Resources. **Journal of the Institution of Water Engineers and Scientists** 34(1), 71-73.

Institute of Hydrology and Binnie and Partners (1993) **Naturalised river flow records of the Essex Region. Phase II draft final report.** Report for NRA Anglian Region.

NRA Anglian Region (1993) **Water Resources Strategy Consultation Draft.**

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 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 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
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'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
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 dema nd	Wit-Den direc t 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	opti on	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 Stor-age	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

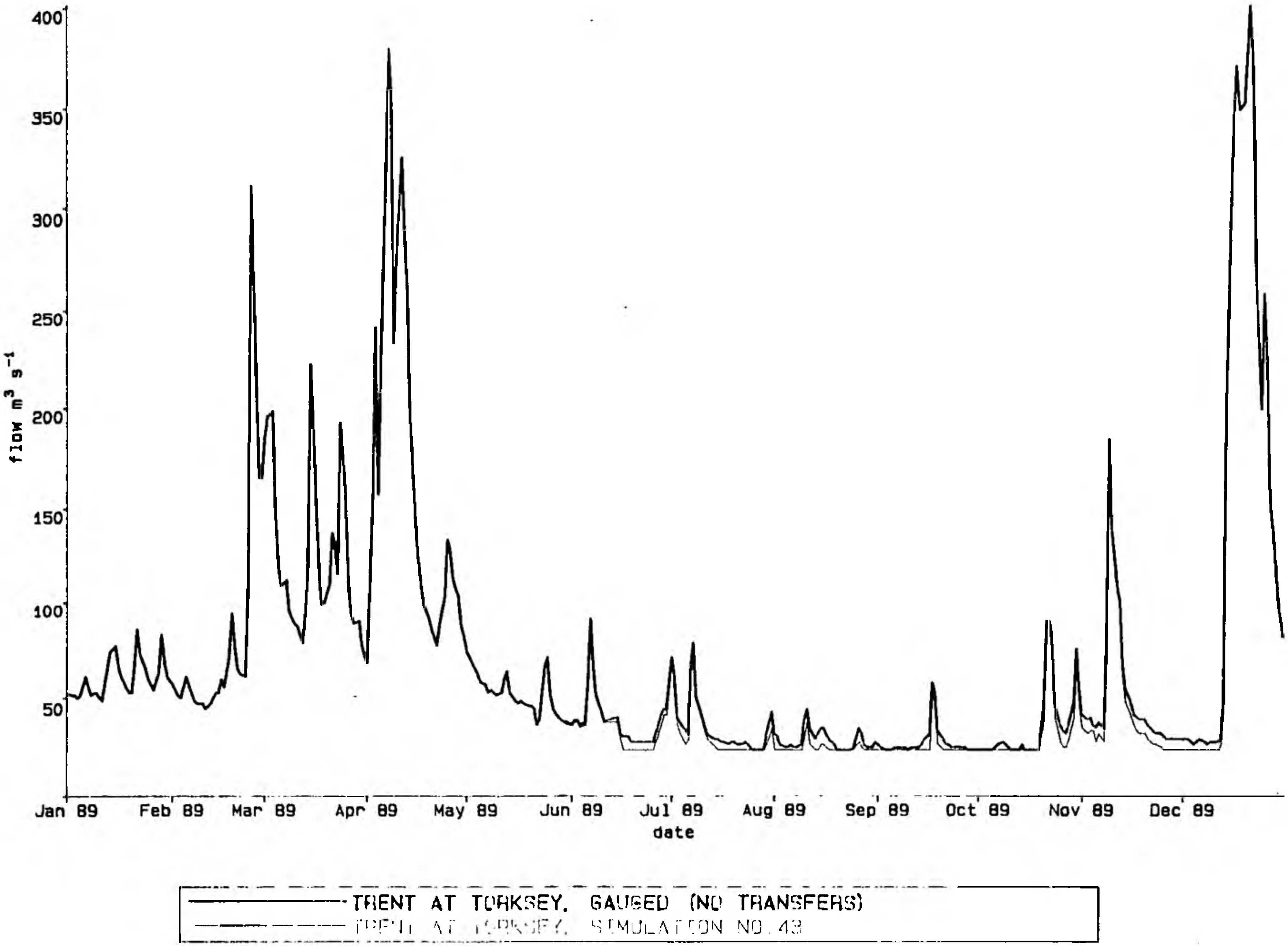
Table A.2.2 Results for simulations 1932-1992

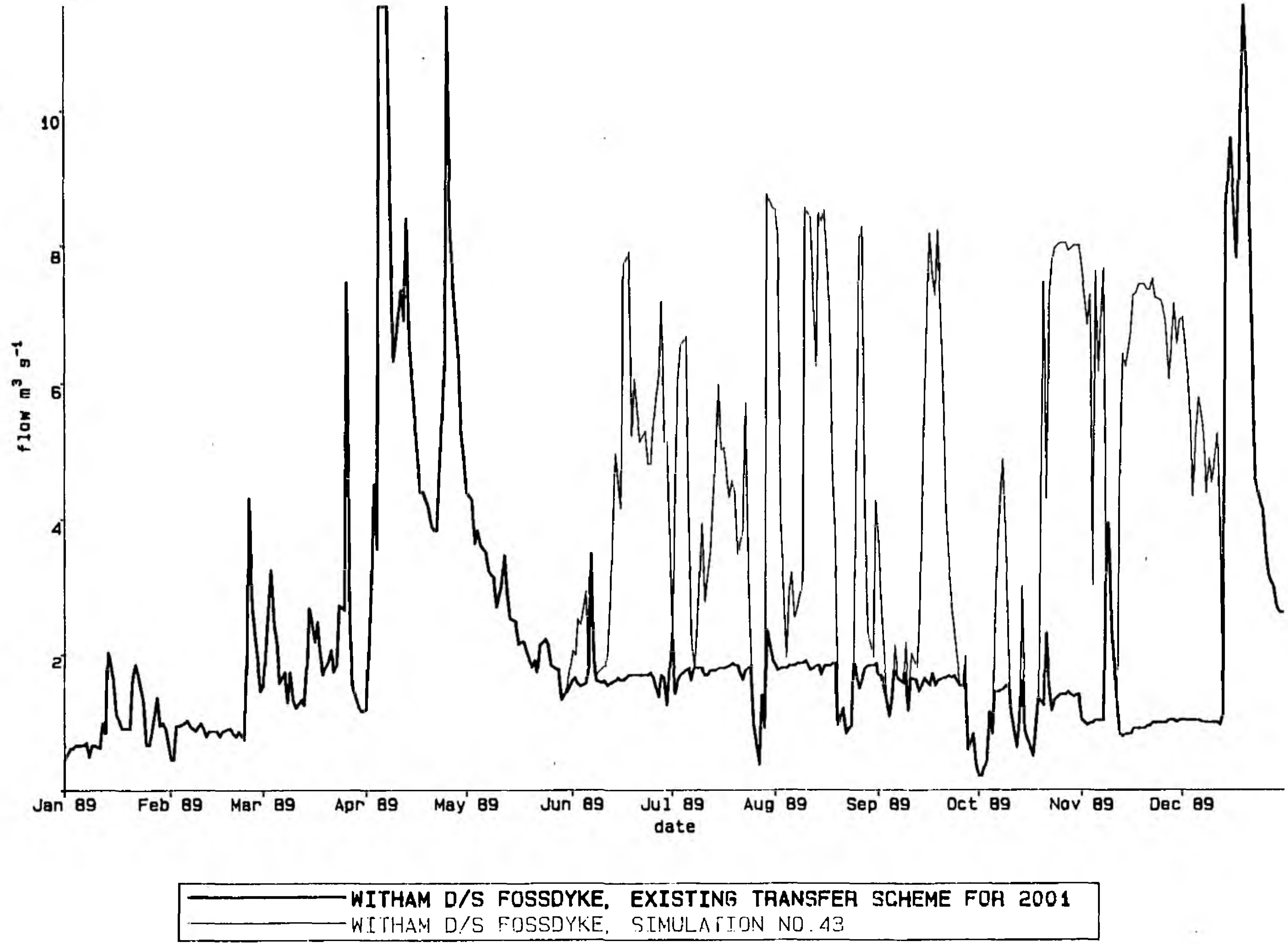
	Trent Tran ?	Chelm Eff	Great Brad Store	Kenn. Pump Size	Wixoe pump size	Black water int. cap	Chelm int. cap	Lang Hann. link cap	Denv mrf	Tran to Thames	Fen Resv Stor-age	EOE yield
	y / n	tcmd	$m^3 * 10^6$	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	$m^3 * 10^6$	tcmd
21	n	40	106	334	341	305	205	300	50			576
22	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

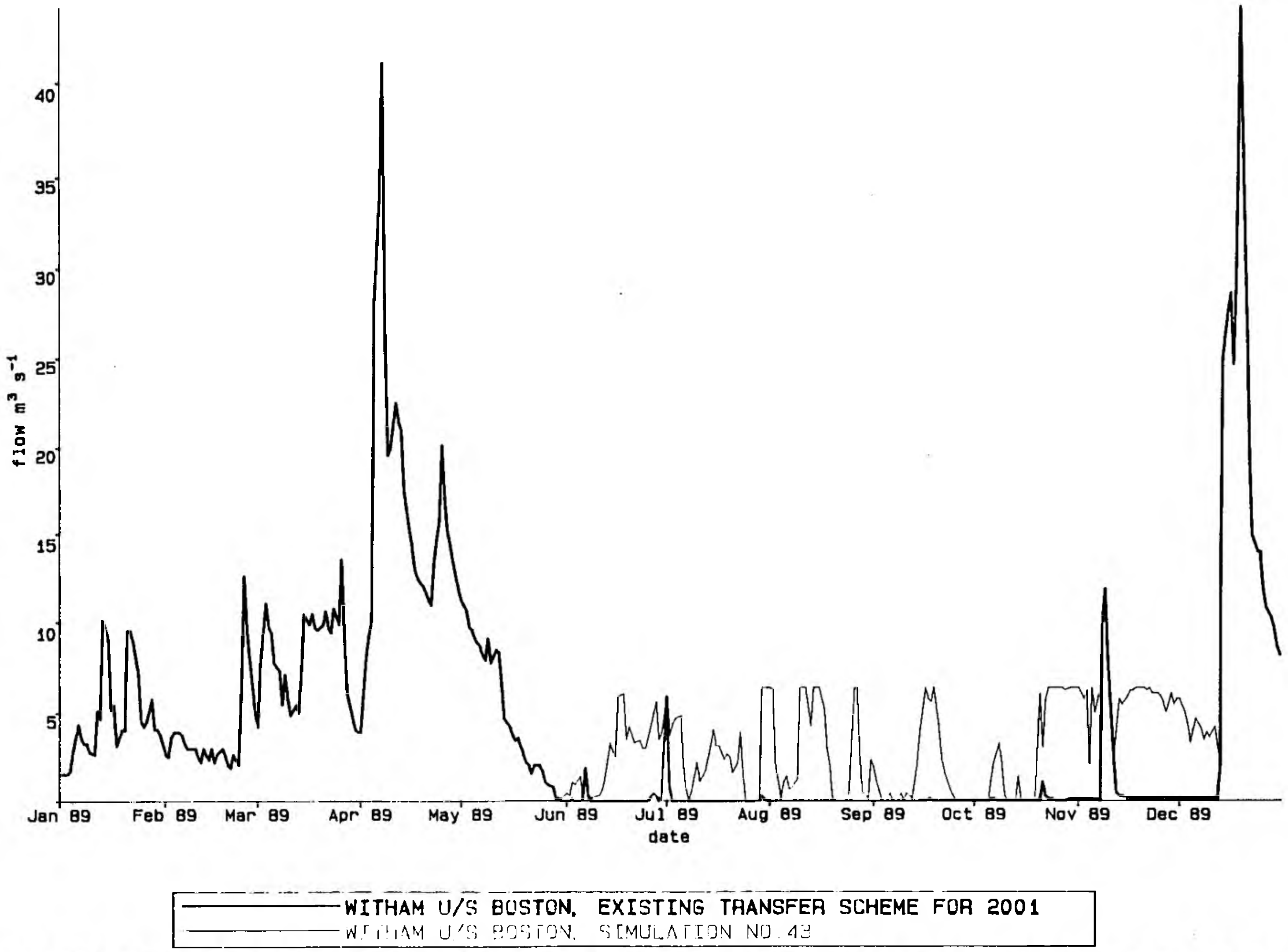
APPENDIX 3: SIMULATION OF DOWNSTREAM FLOWS

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.

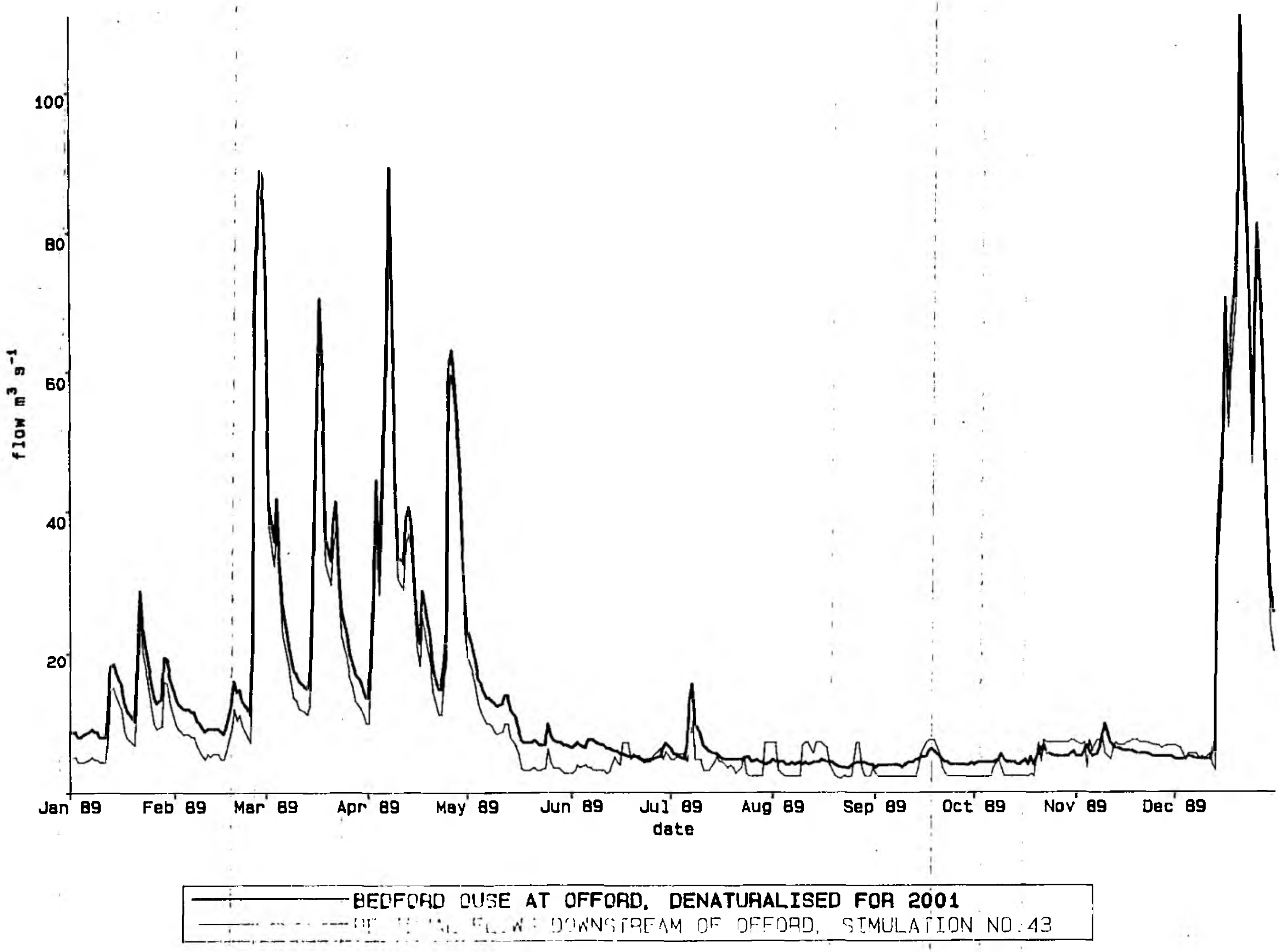

400
350
300
250
200
150
100
50
flow m^3 s^{-1}
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
TRENT AT TORKSEY, GAUGED (NO TRANSFERS)



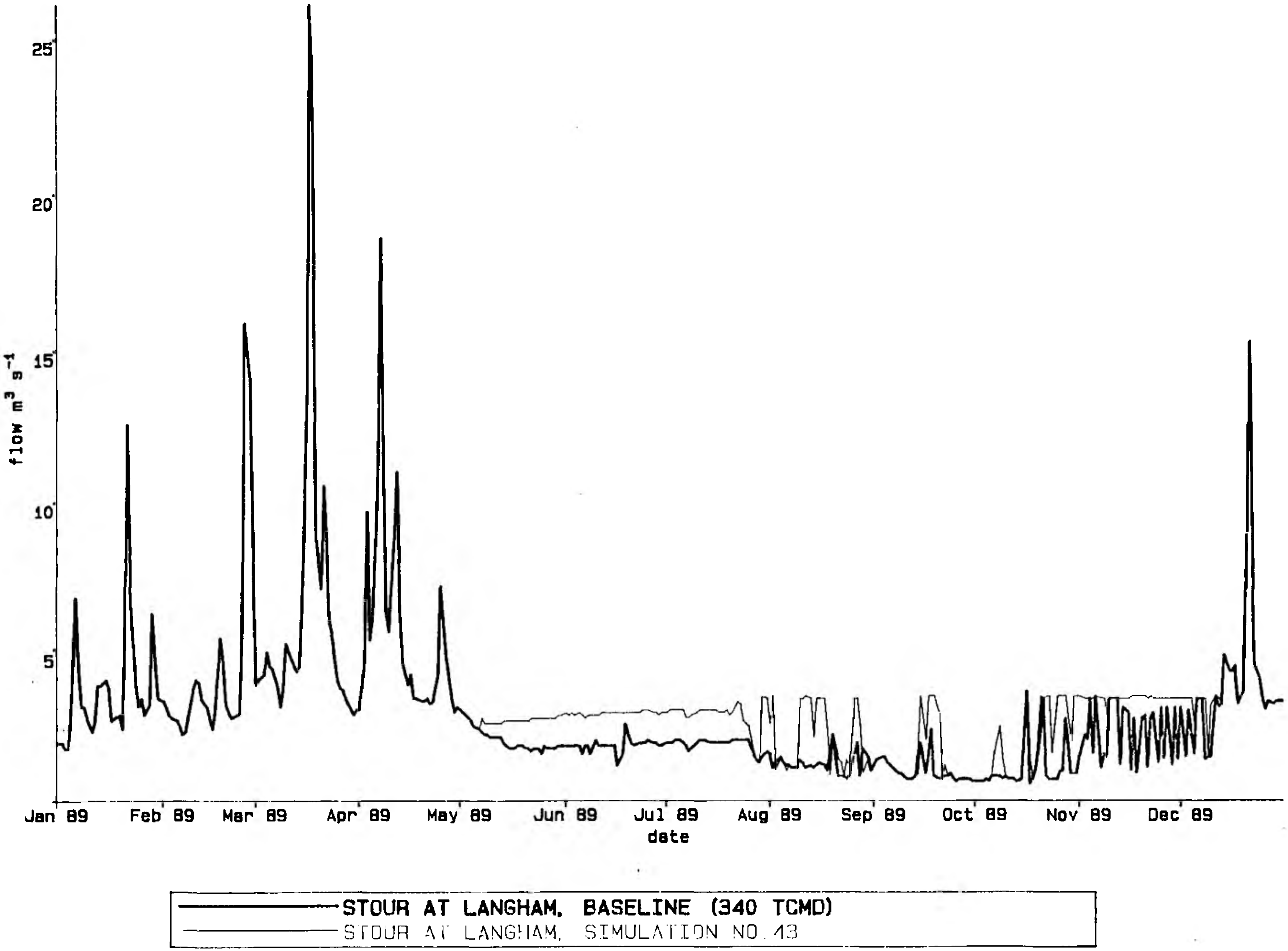
10
8
6
4
2
flow m^3 s^-1
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
WITHAM D/S FOSSDYKE, EXISTING TRANSFER SCHEME FOR 2001
WITHAM D/S FOSSDYKE, SIMULATION NO.43



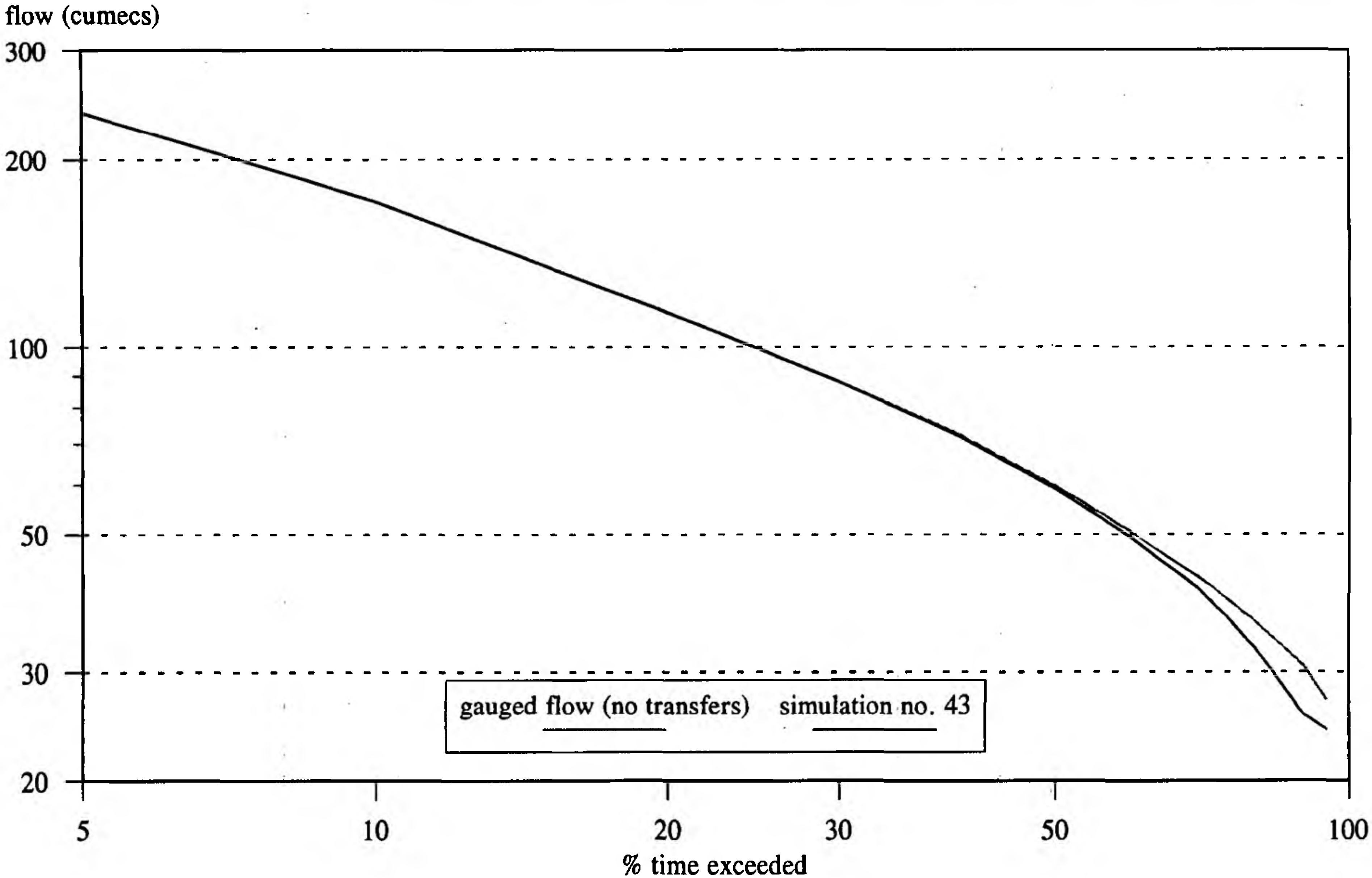
40
35
30
25
20
15
10
5
flow m³ s⁻¹
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
WITHAM U/S BOSTON. EXISTING TRANSFER SCHEME FOR 2001
WITHAM U/S BOSTON. SIMULATION NO.43



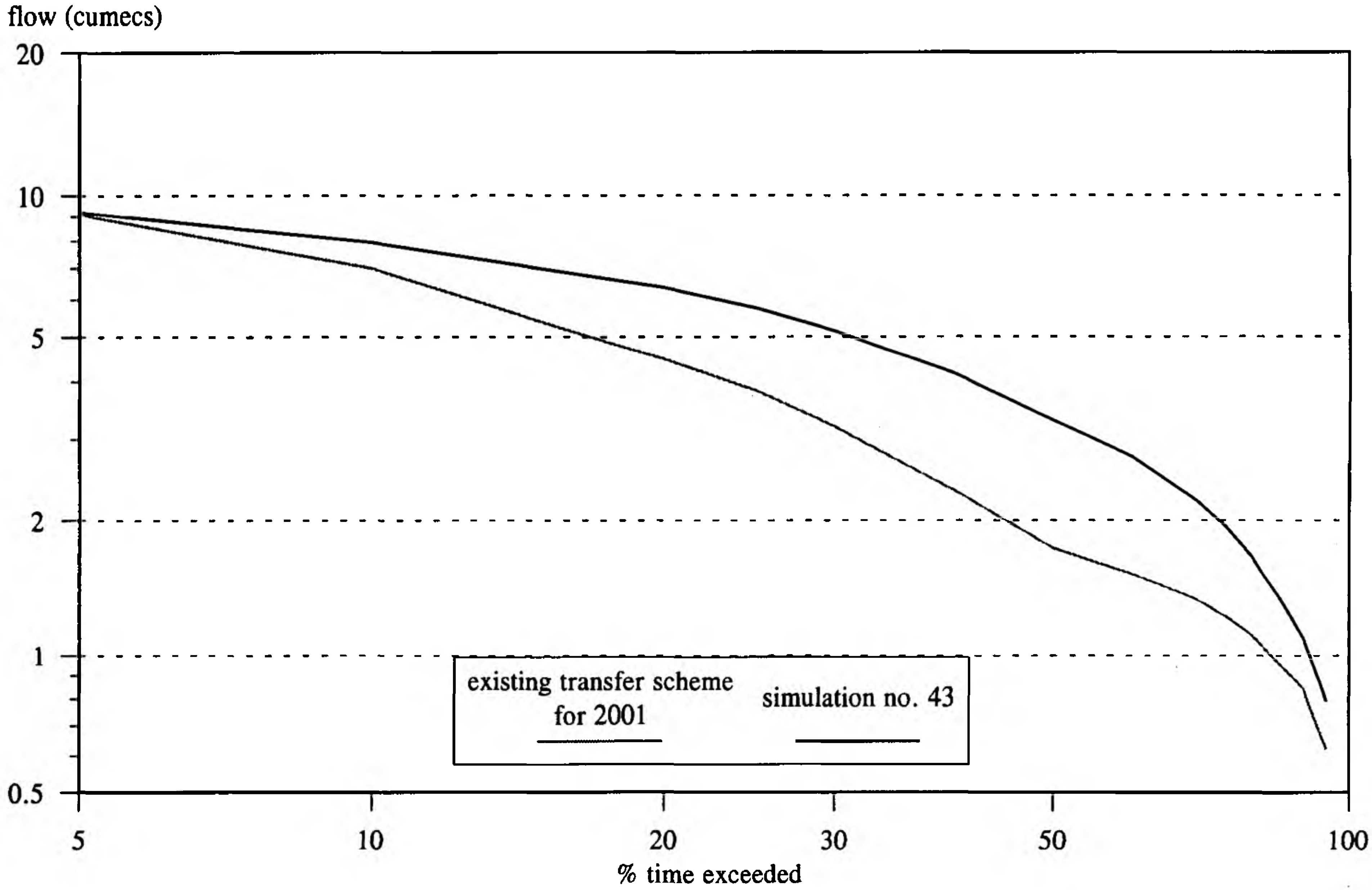
100
80
60
40
20
flow m3 s-1
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
BEDFORD OUSE AT OFFORD, DENATURALISED FOR 2001
DOWNSTREAM OF OFFORD, SIMULATION NO:43



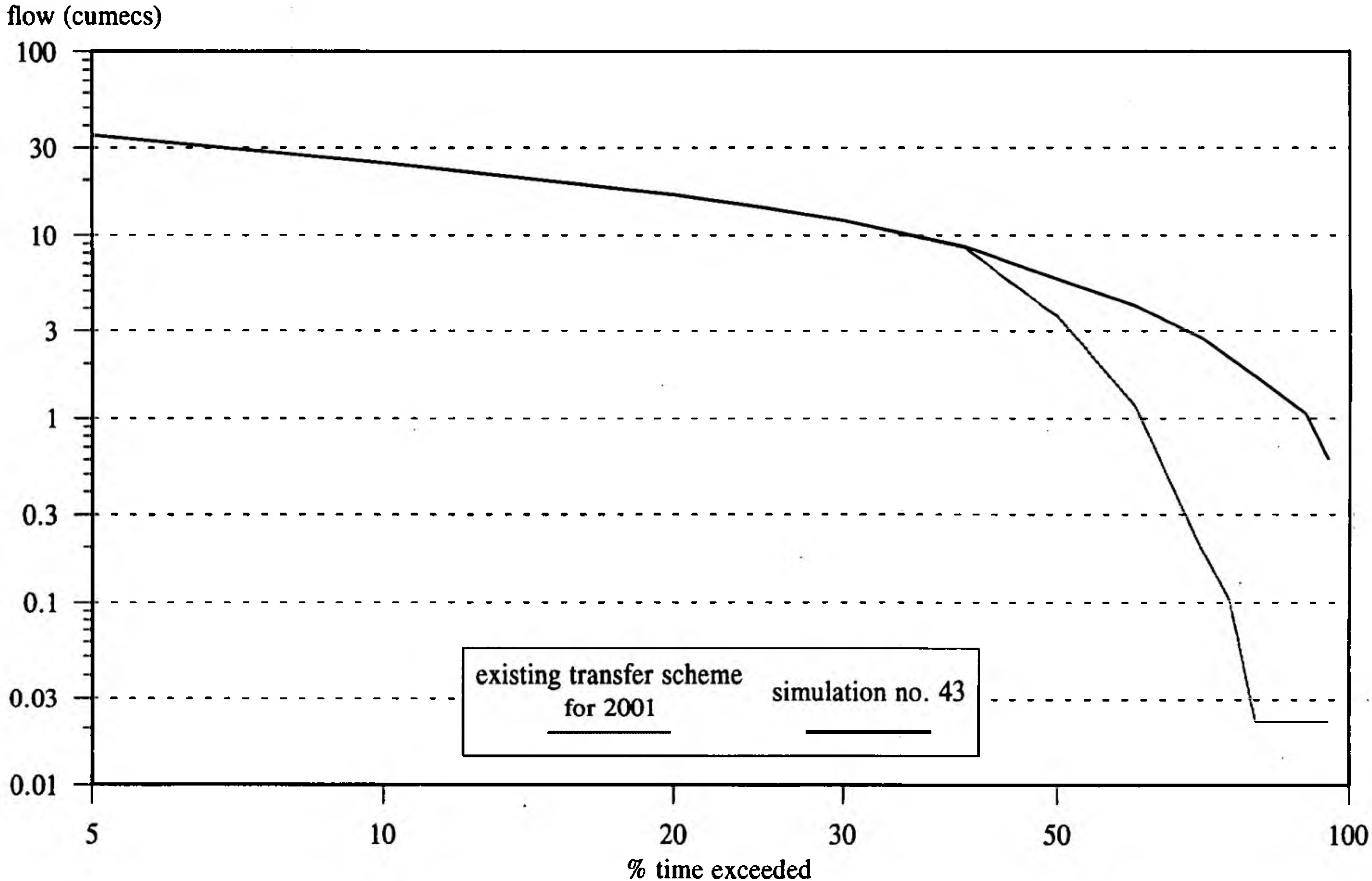
25
20
15
10
5
flow m3 s-1
Jan 89
Feb 89
Mar 89
Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
Dec 89
date
STOUR AT LANGHAM, BASELINE (340 TCMD)
STOUR AT LANGHAM, SIMULATION NO.43



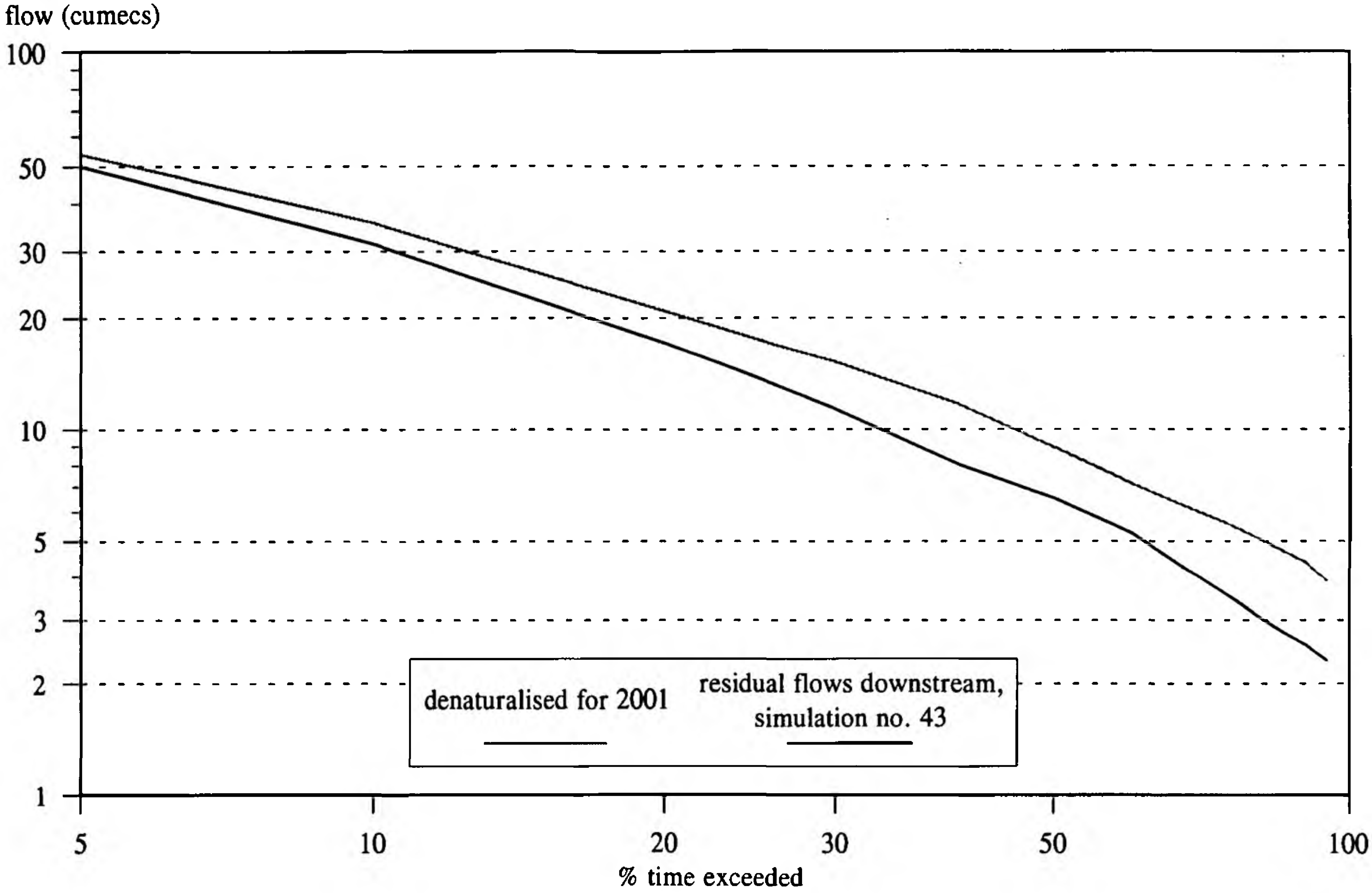
Trent at Torksey
Simulated flow duration curves 1972 - 1992



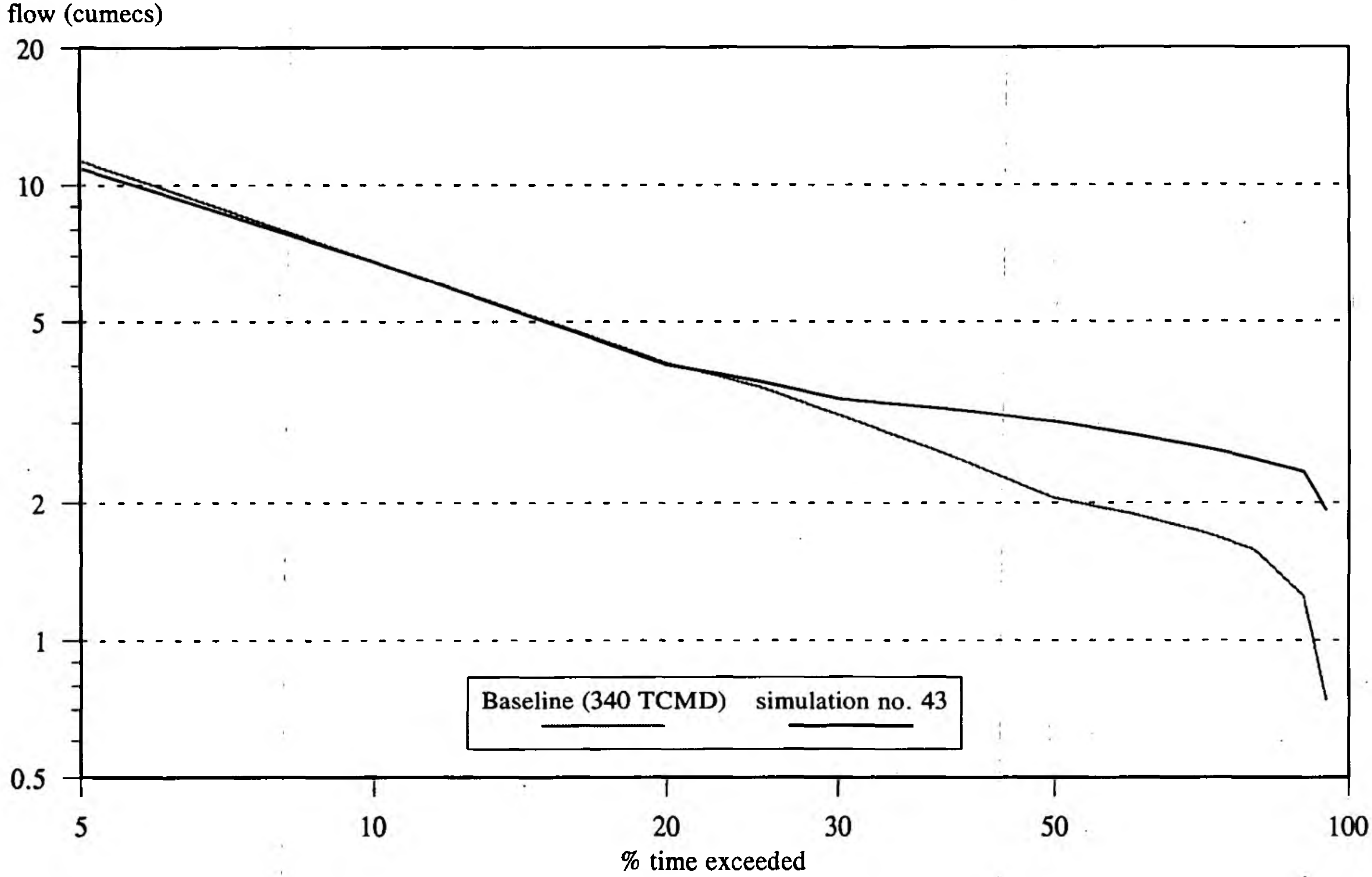
Witham downstream of Fossdyke
Simulated flow duration curves 1972 - 1992



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