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ANGLIAN REGION

STAGE 2 MODELLING OF WATER STORAGE AND TRANSFERS IN THE ANGLIAN REGION

Steve Cook

Supporting Documentation for the
Regional Water Resources Strategy

August 1993

This is the fourth report in a series of supporting documents for the Anglian Region Water Resources Strategy. Documents in the series are:

1 **Preliminary modelling of water storage and transfers in the Anglian Region**

Steve Cook, Glenn Watts & Nigel Fawthrop May 1993

This report describes the models used in the yield analysis of the Trent-Witham-Ancholme system, the Ely Ouse - Essex system, and Rutland Water and Grafham Water. Results are presented for a variety of options for operation, including the possibility of connecting all of the systems to allow augmentation from the Trent.

2 **Reconstruction of historic Witham flows**

Glenn Watts July 1993

This report describes the methods used to extend flow records for the River Witham back to 1933, together with an analysis of the errors associated with the extended flow records. The long flow records can be used in the analysis of the effect of transfers from the River Trent to the Trent-Witham-Ancholme system and from there to the Ely Ouse - Essex system.

3 **Extending Rutland yield analysis to 1933**

Glenn Watts August 1993

This report describes the extension of the records required for Rutland yield analysis back to 1933. The results emphasise the importance of the 1930s drought in assessing the yield of Rutland Water; any analysis which does not consider this period will overestimate Rutland yield.

4 **Stage 2 modelling of water storage and transfers in the Anglian Region**

Steve Cook August 1993

(This report)

CONTENTS

1. INTRODUCTION

Following the Preliminary Modelling Report of May 1993 a number of additional model runs have been specified. These involve developments of previously modelled options and require consideration of factors not previously investigated, the most significant being:

1) extension of flow records back to beyond 1933.

2) consideration of different Trent MRF's and supported Trent.

3) taking all demand from Abberton and Hanningfield, using Great Bradley for support only with no direct supply.

4) transfers to Thames Region using modelled daily requirements.

This report describes the options and presents the results of the model runs. Average quantities pumped for each transfer have been calculated in addition to yield estimates for use in the RESPLAN modelling.

2. DESCRIPTION OF DEVELOPMENTS/ OPTIONS

Figure 1 shows the water resources systems in schematic form.

2.1 Extension of flow records

The starting dates of the flow records for the Trent and Witham has meant that the modelled systems including the Trent transfer option could previously only be simulated from 1972. Previous yields for Rutland and Grafham were based on flow records for the period 1940-92 and 1933-92 respectively. Options involving only the Ely Ouse-Essex system were simulated for the period 1932-92. Two basic sets of yield analysis results were therefore presented in the May 1993 Preliminary Modelling Report based on flow data for a) a short record 1972-92 and where possible b) a long record 1932-92 or 1940-92. The differences between the two sets of results was both large and inconsistent. To enable more reliable estimates of yield to be assessed for all scenarios it has been necessary to extend all flow records back in time to include the 1933-35 drought. Flow records are now available as follows:

Trent	January 1932 to December 1992
Witham	January 1913 to December 1992
Welland	January 1933 to December 1992
Nene	January 1933 to December 1992
Bedford Ouse	January 1933 to December 1992
Ely Ouse	October 1932 to December 1992
Essex Rivers	October 1932 to December 1992

Details of how the flow records were extended with discussion of errors and the quality attached to the records are documented separately in Watts (1993 a); Watts (1993 b); Grimshaw (1993).

2.2 Trent Option

The effect on yields of applying different values for the mrf for the Trent at Torksey has been investigated. Mrf values of 2000, 2500 and 3000 tcmd have been considered. It is understood that the most likely mrf value is 2500 tcmd. The option of supporting the Trent by 'put and take' has also been considered - for the simulations it has been assumed that Trent water would always be available to fully satisfy the demands in the Ancholme and Witham (up to the capacity of the intakes) plus any demand from the Ely Ouse-Essex system and where appropriate, Grafham and Rutland, up to the transfer capacity of 400 tcmd (plus losses). It has been assumed throughout that demands in the Witham and Ancholme have first call on available Trent water.

A capacity of 400 tcmd has been considered for the direct Witham-Denver transfer - no losses are attached to this link. For the Witham-Wansford-Offord-Denver route a maximum capacity of 400 tcmd has been considered with potential for dropping-off 100 tcmd at Offord and 100 tcmd at Wansford with any remaining up to a maximum 400 tcmd (minus 10 percent losses) made available at Denver.

2.3 Operation of the system

In all previous simulations including the Great Bradley reservoir option Great Bradley was considered to supply a direct demand in addition to its role of supporting the Abberton / Hanningfield systems. Abberton / Hanningfield was assumed to supply the baseline demand only, with the marginal yield being calculated as a direct demand from Great Bradley. Support releases were made from Great Bradley, if required, when the storage level of Abberton plus Hanningfield fell below a predefined control curve. Consideration is now given to taking all demand from the Abberton / Hanningfield systems with no direct supply from Great Bradley. To obtain maximum yield no control curve is used and Great Bradley is allowed to empty without causing system failure. There are a number of consequences in operating the system in this manner:

1) The flow in the Rivers Stour and Blackwater would increase dramatically as larger releases from Great Bradley would be required to support the demand.

2) The intake capacities to the Abberton/ Hanningfield systems would need to be increased above the maximum sizes currently perceived to obtain the full benefit of certain options. This is particularly significant when the Trent plus Great Bradley options are considered together.

3) If releases from Great Bradley to the Stour/ Blackwater are subject to a loss factor the total system yield can be expected to be lower than that calculated with a direct supply from Great Bradley as no losses are attached to the direct supply.

2.4 Intake capacities

The size of the intake capacities for the Essex rivers have previously been based on figures provided by Essex Water Company. When the system was simulated with all demand taken from Abberton/Hanningfield it was found that if the Trent plus Great Bradley options were considered together the calculated yield was restricted to the system intake capacity. Trent water was available over the critical period to maintain substantial storage in Great Bradley but the maximum support to Abberton/Hanningfield was limited to the intake capacity. In this situation the maximum constant demand that can be supplied is the maximum intake rate plus a small quantity which causes Abberton and Hanningfield reservoirs to empty over the simulation period. The system failed while Great Bradley was still substantially full.

The intake capacities on the Stour and Blackwater were therefore increased by increments to determine the optimum size at which the yield was no longer restricted. The results of this investigation for a selected option (Run 4 as referenced in Section 3) are illustrated in Table 1. The optimum size in intake capacity increases as more water becomes available to the system i.e. as the Trent mrf is reduced. Capacities were increased in 10 percent intervals for Stratford St.Mary and Cattawade on the R.Stour, Langford No.1 intake on the Blackwater and the Langford to Hanningfield link. A 10 percent increase in these capacities is equivalent to an 8.3 percent increase in overall system intake capacity. The overall system intake capacity, shown in Table 1-column 3, is the sum of Langham, Stratford St.Mary, Cattawade, Roman River, Langford Mill and the Langford to Hanningfield link. To obtain unrestricted yield for this option the intake capacity needs to be increased by the percentage factor shown in Table 1-column 2 corresponding to the highlighted yield values. (When restricted, the yields in columns 4 to 7 are slightly below capacities in column 3 due to complications caused by monthly demand factors.) The yields highlighted in Table 1 are presented in the results (Appendix 1, Tables A1.1 to A1.4) as Run 4.

Increase in selected intake capacities (percent)	Increase in System intake capacity (percent)	Ab/Ha system intake capacity (tcmd)	Calculated Yields (tcmd) for given Trent MRF (tcmd) (Run No. 4 - Section 3)			
			Supported Trent	mrf=2000	mrf=2500	mrf=3000
0	0	674	671	671	671	671
10	8	730	727	727	727	725
20	18	786	784	783	781	749
30	25	843	840	828	791	750
40	33	900	878	832	791	750
50	42	956	880	833	791	750

Table 1: Yields for increased intake capacities.

2.5 Losses

In all simulations to date 15 percent losses have been applied to Ely Ouse - Essex transfers. This is simulated by reducing quantities of water discharged into the R.Stour either directly from the Ely Ouse or as a release from Great Bradley by 15 percent before it reaches the intakes. The loss has been included to represent operational inefficiencies and losses in transit, evaporation and leakage. Further investigations are required to determine whether this figure is reliable. Selected options have been simulated with both 15 percent and zero losses in order to determine the significance in terms of system yield.

2.6 Transfers to Thames Region

Thames Region have provided daily transfer requirements for the period 1920-91 for two cases: 1) when 100 tcmd could be used and 2) when 200 tcmd could be used. The transfer is assumed to take place only on the days required at the maximum rate being considered (100 or 200 tcmd). The data supplied for 1990 was repeated for 1992 to enable simulations to be made for 1932-92.

The transfer was simulated effectively as a variable direct demand from Great Bradley which was given priority over the support to the Abberton/ Hanningfield systems. To prevent Great Bradley from emptying prematurely causing system failure, support releases were limited if necessary for this option to keep Great Bradley at equal risk of emptying as Abberton and Hanningfield.

2.7 Direct Trent to Rutland transfer

Consideration has been given to a direct transfer from the Trent to Rutland Water. These simulations only involved the Rutland simulation model - the Witham-Ancholme demands were not considered. The flow record for the Trent at Colwick/ Trent Bridge was used (i.e. not scaled up for flow at Torksey) in the assumption that such a transfer would take place over the shortest distance. The same mrf values were used as for Torksey and the supported Trent option was also considered assuming either 100 or 200 tcmd to be always available. Zero losses were assumed for the transfer.

3 ADDITIONAL MODEL RUNS

Eleven system configurations have been specified for model simulation. These are outlined below.

3.1 Description of runs

0 New Baseline case (assumed to include Chelmsford Effluent at 40 tcmd and Denver mrf at 114 tcmd) - this corresponds to Run 18 of the May 1993 Modelling Report.
1 With Great Bradley - this corresponds to Run 20 of the May 1993 Modelling Report but with all demand taken from the Abberton/ Hanningfield systems.
2 With Trent.
3 With Trent plus increased Kennett pumps.
4 With Great Bradley plus Trent plus increased Kennett pumps.
5 With Trent plus drop-offs at Offord (100 tcmd) and Wansford (100 tcmd).
6 With Great Bradley plus Trent plus increased Kennett pumps plus drop-offs at Offord (100 tcmd) and Wansford (100 tcmd).
7 With Great Bradley but supporting a demand of 100 tcmd in Thames Region.
8 With Great Bradley but supporting a demand of 200 tcmd in Thames Region.
9 With a direct Trent to Rutland transfer of capacity 100 tcmd.
10 With a direct Trent to Rutland transfer of capacity 200 tcmd.

4 RESULTS

The main results are presented in Appendix 1, Tables A1.1 to A1.4. Table A1.1 shows results for all of the 11 runs with those including the Trent option assuming the Trent to be supported. Tables A1.2, A1.3 and A1.4 show results again for all runs but with mrf values of 2000, 2500 and 3000 respectively for the Trent option (non-Trent options are repeated for easy comparison). The average Trent-Anglian transfer presented for the baseline case (Run 0) is the transfer utilised for the Witham and Ancholme demands only. All results are based on flow records for the period 10/32 to 12/92 except those including Grafham or Rutland which are based on 1/33 to 12/92. The demand year used was 2001.

The necessity to increase intake capacity in order to prevent restricted yield of the Ely Ouse-Essex system was described earlier in Section 2.4. The yields presented for both of Runs 4 and 6 in Tables A1.1 to A1.4 are based on the increased intake capacities as deduced for Run 4 and described in Section 2.4.

4.1 Average Transfers

The average transfer figures shown in Tables A1.1 to A1.4 are average daily quantities pumped over the simulation period 10/32 - 12/92 (1/33-12/92 where drop-offs to Offord and Wansford are considered).

1) Trent-Anglian : this is total abstraction from the Trent at Torksey for the Witham-Ancholme demands plus onward transfer to Grafham/ Rutland/ Denver.

2) Witham-Denver : quantities are made up of Trent plus Witham water as abstracted at Boston.

3) Ely Ouse-Essex : quantities are made up of Ely Ouse plus Trent plus Witham water as abstracted at Denver.

5 DISCUSSION

5.1 Baseline Yields

Run 0

The Ely Ouse-Essex yield of 398 has been calculated for the 'new' baseline case and is as presented for Run 18 in the May 1993 Preliminary Modelling Report. The Grafham yield of 269 tcmd is also as previously presented. The Rutland yield has now been calculated as 199 tcmd which is lower than the value previously presented. The main reason for the lower value is that the current figure is based on the extended flow record 1933-92 whereas previously it was based on the 1940-92 record; a less significant contributing factor is that corrections to the analysis program have been made since the original figure was calculated. The revised yield analysis for Rutland is fully documented in an NRA report (reference Watts (1993 b)).

5.2 Non Trent options

Run 1

The yield obtained for Run no.1 with all Great Bradley routed through Abberton/ Hanningfield is 558 tcmd. This compares with 566 tcmd obtained for Run no. 20 of the May 1993 Preliminary Modelling Report in which the baseline demand only was taken from Abberton/ Hanningfield. The lower yield is due to the 15 percent losses incurred on the additional releases required from Great Bradley as support to the Essex reservoirs. When simulated with no losses, a yield of 606 tcmd is obtained (Section 5.6).

Runs 7 and 8

To support an intermittent transfer to Thames Region of 100 tcmd the Ely Ouse-Essex yield is reduced by 52 tcmd from 558 to 506 tcmd. To support a 200 tcmd transfer the yield is reduced by 118 tcmd from 558 to 440 tcmd. In a typical year the transfer is required on most days from May/June to November/December.

5.3 Trent options

The results for simulations involving the Trent option are not directly comparable with earlier results. Yields are now based on the long flow record (1932-92) whereas previously they were based on a much shorter record (1972-92). Also the combination of options is different to that simulated previously i.e. a) the Trent option was not previously combined with Chelmsford effluent and reduced Denver mrf and b) the quantities and priority of the drop-offs is different.

Runs 5 and 6

The benefit of the drop-offs to Offord and Wansford in terms of increase in yield of Grafham and Rutland above the baseline are summarised in Table 2.

Trent mrf (tcmd)	Increase in yield (tcmd)	
	Grafham	Rutland
Supported	101	124
2000	84	111
2500	69	90
3000	53	77

Table 2: Yield increases for Grafham and Rutland.

Runs 9 and 10

Considering yields for the direct Trent-Rutland transfer option: for the supported Trent case the Rutland yields for Run 9 and Run 5/6 are the same as both runs consider 100 tcmd of Trent water to be always available at Wansford albeit by different routes. As the mrf increases from 2000 to 3000 the Rutland yield is reduced as expected as the maximum transfer becomes less reliable. However the Rutland yield with the direct transfer is higher than with the 'drop-off' route in all cases where an mrf is imposed. This is as expected as the direct transfer should be more reliable than the long route which gives priority to Witham-Ancholme demands and the Offord drop-off.

Runs 2 to 6

Transferring water via the long Witham-Wansford-Offord-Denver route, dropping water off at Wansford and Offord, leaves less of the capacity 400 tcmd for Denver than with the direct Witham-Denver transfer route hence the Ely Ouse-Essex yields are lower. There is however substantially greater benefit to the **total** system yield (EO-E plus Grafham plus Rutland) using the long route. The increases in total system yield from the baseline case are summarised in Table 3.

Trent mrf (tcmd)	Increase in total system yield (tcmd) with Trent transfers				
	Witham-Denver direct route			Witham-Wansford-Offord-Denver route	
	Small Kennett	Big Kennett	With Gt.Bradley	Small Kennett	With Gt.Bradley
Supported	146	237	480	320	610
2000	105	179	430	260	550
2500	71	105	393	201	491
3000	47	58	351	152	442

Table 3: Increases in total system yield.

5.4 Witham-Ancholme demands

The supported Trent option assumes that Witham-Ancholme demands are fully satisfied in addition to the required quantities being made available at Boston for onward transfer to Grafham/Rutland/Denver. When the Trent is unsupported with an imposed mrf at Torksey there are periods when the Witham-Ancholme demands cannot be met. The number of years when shortfalls occur and total shortfall quantity increases as the mrf becomes more strict. In these periods no Trent water is available for transfer to Grafham/Rutland/Denver-Essex. A summary of the shortfall quantities is given in Table 4.

Trent mrf (tcmd)	Shortfall in Witham-Ancholme demand 1933-92		Maximum shortfall	
	No.of years	tcmd*1000	Year	tcmd*1000
2000	16	53.6	1976	15.6
2500	36	162.3	1976	19.2
3000	52	310.5	1976	23.5

Table 4: Shortfall in Witham-Ancholme demands.

5.5 System operation

Figure 2 shows the simulated reservoir storages for Abberton, Hanningfield and Great Bradley reservoirs over the period 10/32-12/35 for Run no. 1. Operating the system with no direct demand on Great Bradley allows Great Bradley storage to fall to zero without failure of the system - this situation can occur for prolonged periods. Failure occurs when either Abberton or Hanningfield storage falls to zero. As can be seen Abberton/ Hanningfield storage only falls when Great Bradley is empty as any storage in Great Bradley can be released to fill Abberton and Hanningfield.

When Great Bradley is considered with the Trent option the very high yields calculated for runs 4 and 6 are very close to the intake capacity (refer to Table 1-Section 2.4). This indicates that Abberton and Hanningfield storage becomes relatively insignificant with this combination of options and operating strategy. A demand of 878 tcmd (Table A1.1, Run no. 4) would only approximate to 50 days storage in the Abberton/ Hanningfield system.

If Abberton and Hanningfield were to supply all of the demand equivalent to the calculated yields, the environmental impact on the Rivers Stour and Blackwater could be significant. Flows to the intakes would be significantly higher than indicated in the May 1993 Preliminary Modelling Report. The maximum yield calculated from the current simulations is 878 tcmd for Run no. 4 which includes Great Bradley plus supported Trent options. The increase in flow is illustrated in Figure 3 for the Stour at Langham for a selected year.

5.6 Losses

All results presented assume 15 percent losses for the Ely Ouse/ Great Bradley to Essex transfer. For selected options the yield of the Ely Ouse - Essex system was also calculated with no losses on this transfer. The system yields are compared in Table 5.

Run No.	Yield in tcmd Supported Trent (Runs 2,3 and 4)			Yield in tcmd Trent mrf = 2500 tcmd (Runs 2,3 and 4)		
	15% loss	No loss	Increase	15% loss	No loss	Increase
0	398	405	7			
1	558	606	48			
2	544	586	42	469	501	32
3	635	657	22	503	513	10
4	878	982	104	791	879	88
7	506	543	37			
8	440	471	31			

Table 5: Ely Ouse-Essex yields assuming different loss factors.

N.B. For Run 4 the total intake capacity on the Abberton/ Hanningfield system was increased as follows:
a) for the 'no loss' case the increase was 50 percent for the supported Trent option and 33

percent for the 2500 tcmd mrf option;
b) for the '15 percent loss' case the increase was 33 percent for the supported Trent option and 25 percent for the 2500 tcmd mrf option.

5.7 Flow records

It should be stressed that the extended flow records for the Trent for the period 1932 to 1958 supplied by Severn-Trent Region are provisional. Grimshaw (1993) notes that the pre 1937 record seems particularly suspect. Further quality control and validation is continuing. With regard to the Trent, for simulations under consideration here, flows below approximately 3600 tcmd (42 m^3/s) become significant. i.e.

maximum Trent transfer required for Witham-Ancholme demands = 200 tcmd approx.

maximum Trent transfer required for Boston onwards	= 400 tcmd
plus losses	= 21 tcmd
maximum mrf at Torksey considered	=3000 tcmd
Trent may be limiting if flow is below total	=3621 tcmd

6 CONCLUSIONS

Yields and average transfers have been calculated for the Ely Ouse-Essex system, Rutland and Grafham for 11 system configurations. All yields presented are based on flow records starting in 1932/33. Reservations to various degrees are held concerning the quality of the extended flow records. It must be appreciated that the records were extended with the best methods available in a very short timescale and any interpretation of the results presented should bear this in mind.

REFERENCES

Watts G 1993 a. **Reconstruction of historic Witham flows**. NRA Anglian Region.

Watts G 1993 b. **Extending Rutland yield analysis to 1933**. NRA Anglian Region.

Grimshaw D 1993. A letter to N.Fawthrop dated 20/7/93 ref. DLG/32/455/12/JSW with attached notes. NRA Severn Trent Region.

APPENDIX 1: SIMULATION RESULTS

	Trnt mrf	Wit-Den cap	Drop offs in prior-ity order O-W-D	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 Thame s	Trnt -Rut cap	Calculated Yield			Average Transfer		
															EO-E	Graf -ham	Rutl -and	Tr-Ang	Wi-De	EO-E
	tcmd	tcmd	tcmd	tcmd	$m^3 * 10^6$	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd
0				40		334	227	309	205	205	280	114			398	269	199	38.9		98.7
1				40	106	334	341	309	305	205	300	114			558					224.9
2	Supp	400	direct	40		334	341	309	305	205	300	114			544			67.9	28.9	200.2
3	Supp	400	direct	40		681	341	309	305	205	300	114			635			101.7	62.5	287.
4	Supp	400	direct	40	106	681	450	415	409	205	420	114			878			142.2	109.5	532.8
5	Supp	400	100/ 100/ 400	40		334	341	309	305	205	300	114			493	370	323	147.	123.5	165.4
6	Supp	400	100/ 100/ 400	40	106	681	450	415	409	205	420	114			783	370	323	193.3	173.	442.3
7				40	106	334	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	Supp													100			323			
10	Supp													200			447			

Table A1.1: Simulation results- supported Trent.

	Trnt mrf	Wit-Den cap	Drop offs in prior-ity order O-W-D	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
	tcmd	tcmd	tcmd	tcmd	$m^3 * 10^6$	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd
0				40		334	227	309	205	205	280	114			398	269	199	36.5		98.7
1				40	106	334	341	309	305	205	300	114			558					224.9
2	2000	400	direct	40		334	341	309	305	205	300	114			503			58.	21.6	171.4
3	2000	400	direct	40		681	341	309	305	205	300	114			577			80.3	43.8	237.
4	2000	400	direct	40	106	681	400	388	383	205	390	114			828			125.	94.3	481.
5	2000	400	100/ 100/ 400	40		334	341	309	305	205	300	114			463	353	310	130.	107.8	143.1
6	2000	400	100/ 100/ 400	40	106	681	400	388	383	205	390	114			753	353	310	172.8	153.8	413.2
7				40	106	334	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	2000 Supp													100			316			
10	2000 Supp													200			429			

Table A1.2: Simulation results- Trent mrf=2000 tcmd

	Trnt mrf	Wit-Den cap	Drop offs in prior-ity order O-W-D	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
	tcmd	tcmd	tcmd	tcmd	$m^3 * 10^6$	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd
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					224.9
2	2500	400	direct	40		334	341	309	305	205	300	114			469			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	334	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			

Table A1.3: Simulation results- Trent mrf=2500 tcmd.

	Trnt mrf	Wit-Den cap	Drop offs in prior-ity order O-W-D	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
	tcmd	tcmd	tcmd	tcmd	$m^3 * 10^9$	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd	tcmd
0				40		334	227	309	205	205	280	114			398	269	199	24.8		98.7
1				40	106	334	341	309	305	205	300	114			558					224.9
2	3000	400	direct	40		334	341	309	305	205	300	114			445			34.1	9.8	130.3
3	3000	400	direct	40		681	341	309	305	205	300	114			456			38.9	14.6	140.7
4	3000	400	direct	40	106	681	380	362	357	205	360	114			749			74.9	56.7	406.
5	3000	400	100/ 100/ 400	40		334	341	309	305	205	300	114			420	322	276	83.2	72.	114.7
6	3000	400	100/ 100/ 400	40	106	681	380	362	357	205	360	114			710	322	276	111.2	103.8	370.3
7				40	106	334	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	3000 Supp													100			278			
10	3000 Supp													200			354			

Table A1.4: Simulation results- Trent mrf=3000 tcmd.

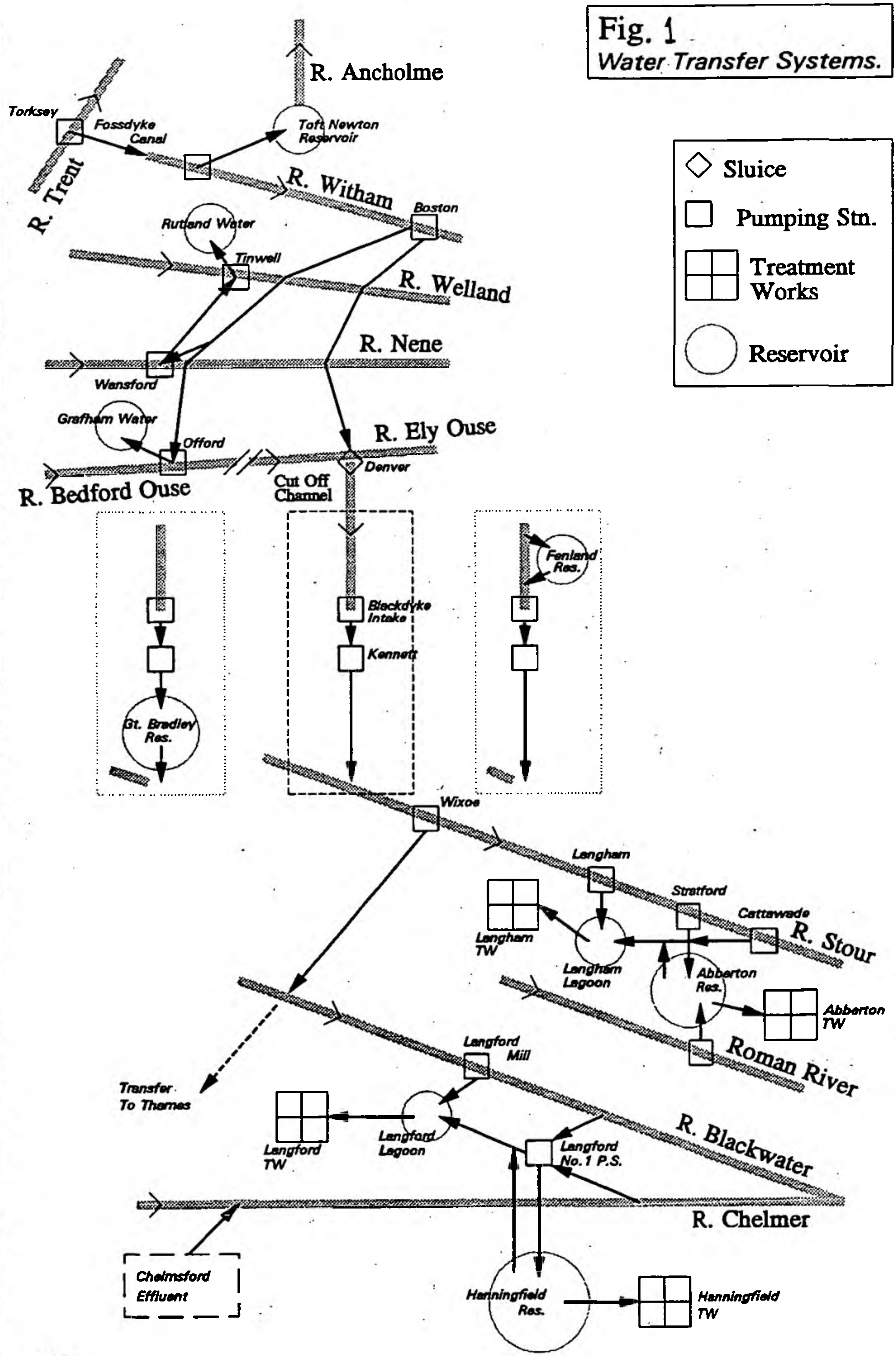
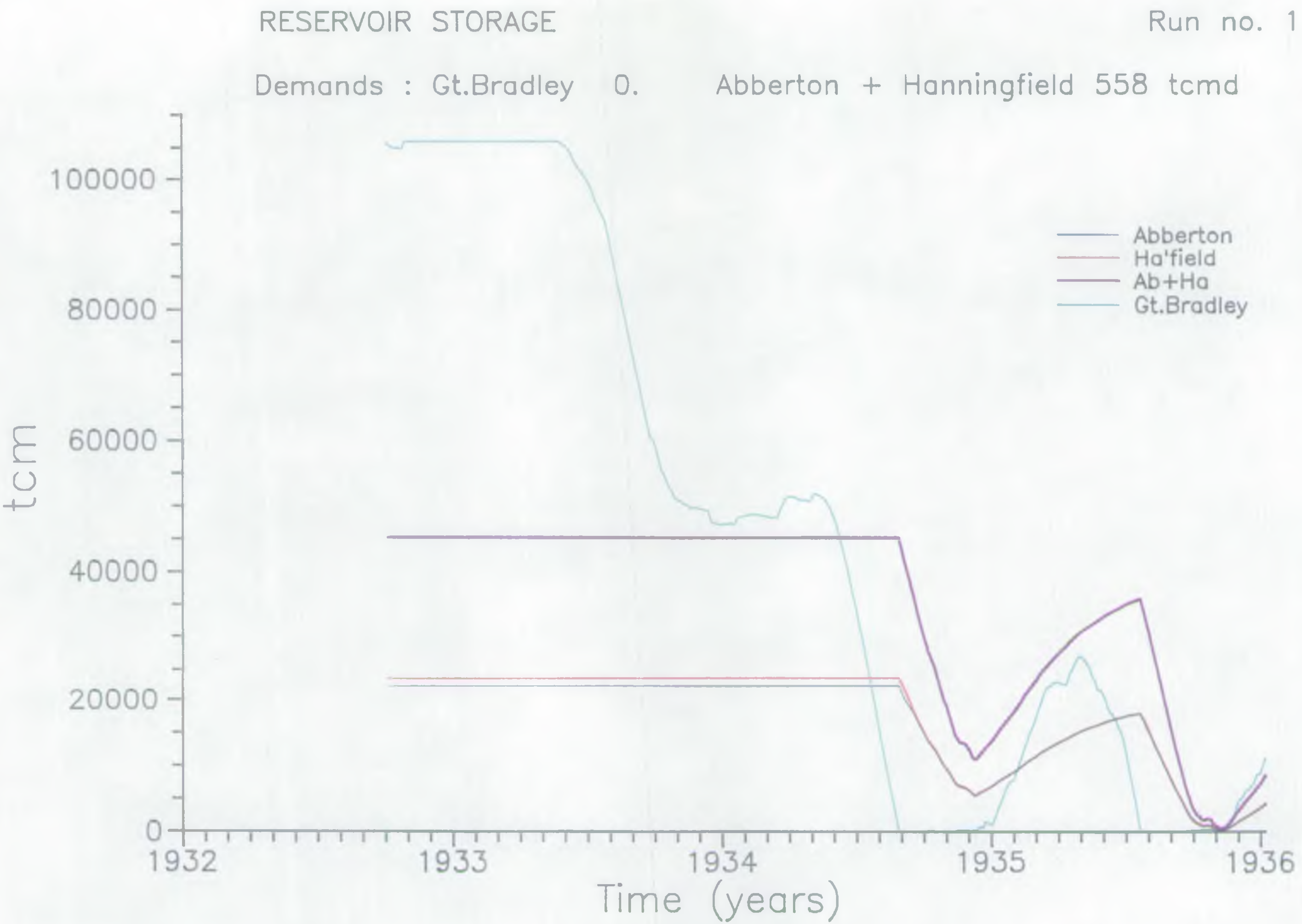
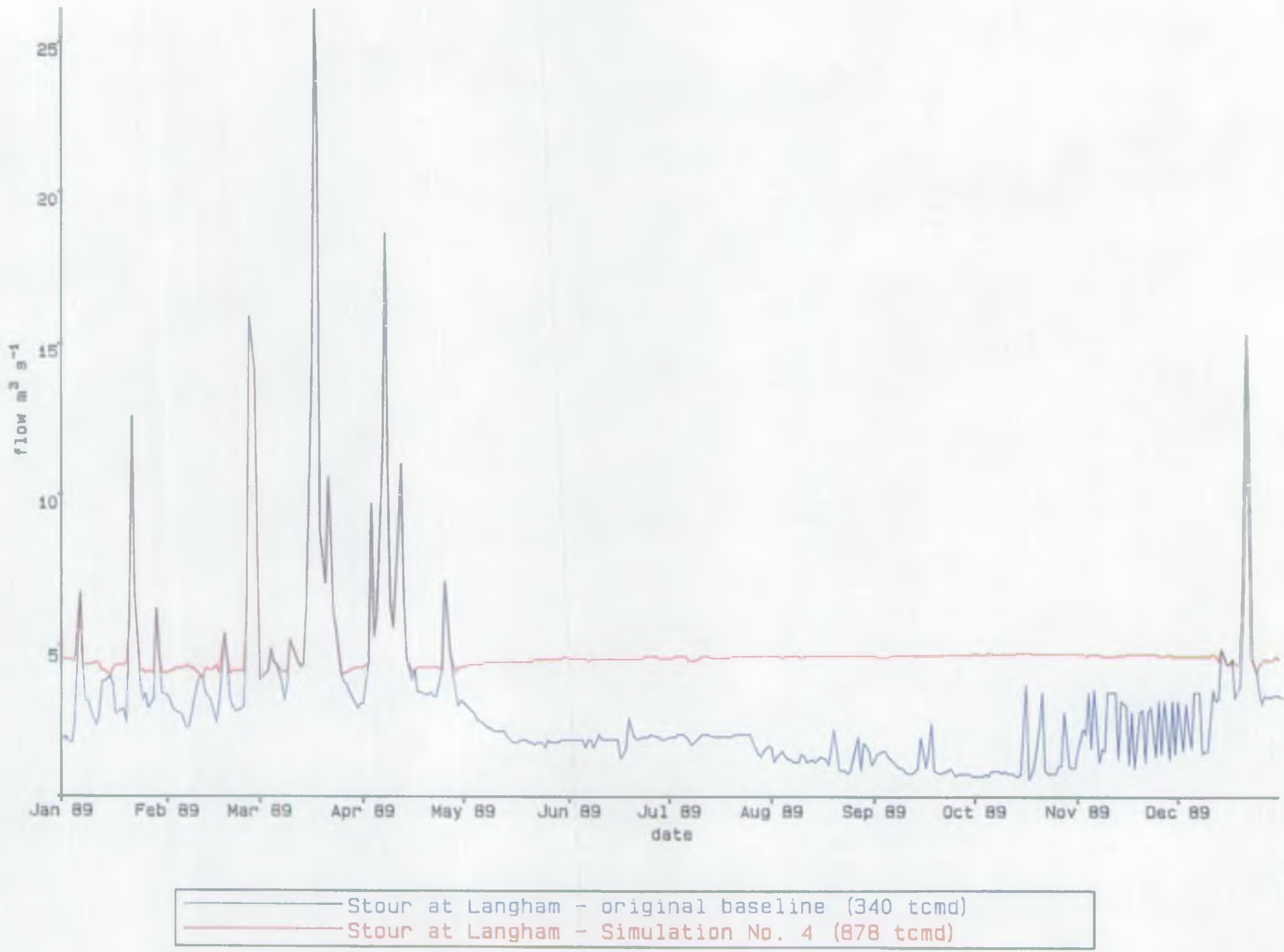


Fig. 1
Water Transfer Systems.
Sluice
Pumping Stn.
Treatment Works
Reservoir
R. Ancholme
Torksey
Fossdyke Canal
Toft Newton Reservoir
R. Trent
R. Witham
Boston
Rutland Water
Tinwell
R. Welland
R. Nene
Wansford
Grafham Water
Offord
R. Ely Ouse
Denver
Cut Off Channel
R. Bedford Ouse
Blackdyke Intake
Kennett
Fenland Res.
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



RESERVOIR STORAGE
Run no. 1
Demands : Gt.Bradley 0. Abberton + Hanningfield 558 tcmd
tcm
100000
80000
60000
40000
20000
0
1932
1933
1934
1935
1936
Time (years)
Abberton
Ha'field
Ab+Ha
Gt.Bradley

Figure 2



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 - original baseline (340 tcmd)
Stour at Langham - Simulation No. 4 (878 tcmd)

Figure 3