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The Yield of the Sussex Ouse with Respect to Abstraction Conditions

Report to
DynamcoLtd for
South East Water PLC

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1 BACKGROUND

The rationalisation that followed the privatisation of the English water industry led to South East Water PLC owning Ardingly Reservoir in the Sussex Ouse mid-reaches (Fig 1). This was built in the mid '70s to increase the yield available from an intake well downstream at Barcombe (above Lewes) where a small bankside storage and major treatment plant exist. These facilities are also owned by SEW (from a separate area office) and hence all the public water supplies from this river are controlled by one water undertaking.

Ardingly gives a small direct supply of about 5 MLD to the Shell Brook treatment plant but its main use is to give drought releases to sustain a supply of about 35 MLD at Barcombe. Somewhat complex licence conditions control abstractions and augmentation releases. Ardingly, lying on a side tributary - Shell Brook, has a modest natural inflow so it is provided with a refill pumping station from the Ouse itself above the Shell Brook confluence; however it has been found that this need not be used in normal weather sequences.

The Sussex Ouse above Barcombe drains a relatively impermeable geological terrain and hence has a flashy flow characteristic. Between the dam and the intake are several privately owned weirs with control sluices that are operated independently by their owners. This is reported to lead to unexpected short duration variations in flow at Barcombe.

The National Rivers Authority gauge the river at Gold Bridge (181 km^2) using a compound broad crested weir for low flows and a velocity-area station for higher floods. They have also gauged it at Barcombe Mills (396 km^2) using a set of rated weirs and sluices but this proved unsatisfactory so in 1994 an ultrasonic measuring station was installed. Its results are awaited with interest.

The major water resource study which identified the Ardingly site was published over 20 years ago (Sussex River Authority, 1970). No complete hydrological survey exists for it although a data compilation volume exists (Southern Science, 1992). The NRA Southern Region has commenced the procedures which will lead to a detailed Catchment Management Plan. Meanwhile its regional resource strategy document (NRA Southern, 1994) does not give much attention to the potential of the Ouse. South East Water has its own divisional resource assessment tables.

A feature of the Ouse basin resource developments is their uncertain destinations. This is partly because of seasonal demand variations when used with groundwater sources but more so because the main population centres served lie nearer the coast than Barcombe or on the Adur/Ouse divide or the Ouse/upper Medway divide. Furthermore the construction of the Barcombe-Arlington link main has increased the conjunctive uses achievable (Rofe, Kennard and Lapworth, 1992).

At present no formal recognition is given in Ouse yield assessment to the return of effluent to the Ouse above Barcombe after the local population has used its water supply. This recycling of resources is assisted by upgraded sewage treatment processes (separately managed by Southern Water PLC) and in future years will be an essential element in sustainable management.

Location map of Sussex Ouse

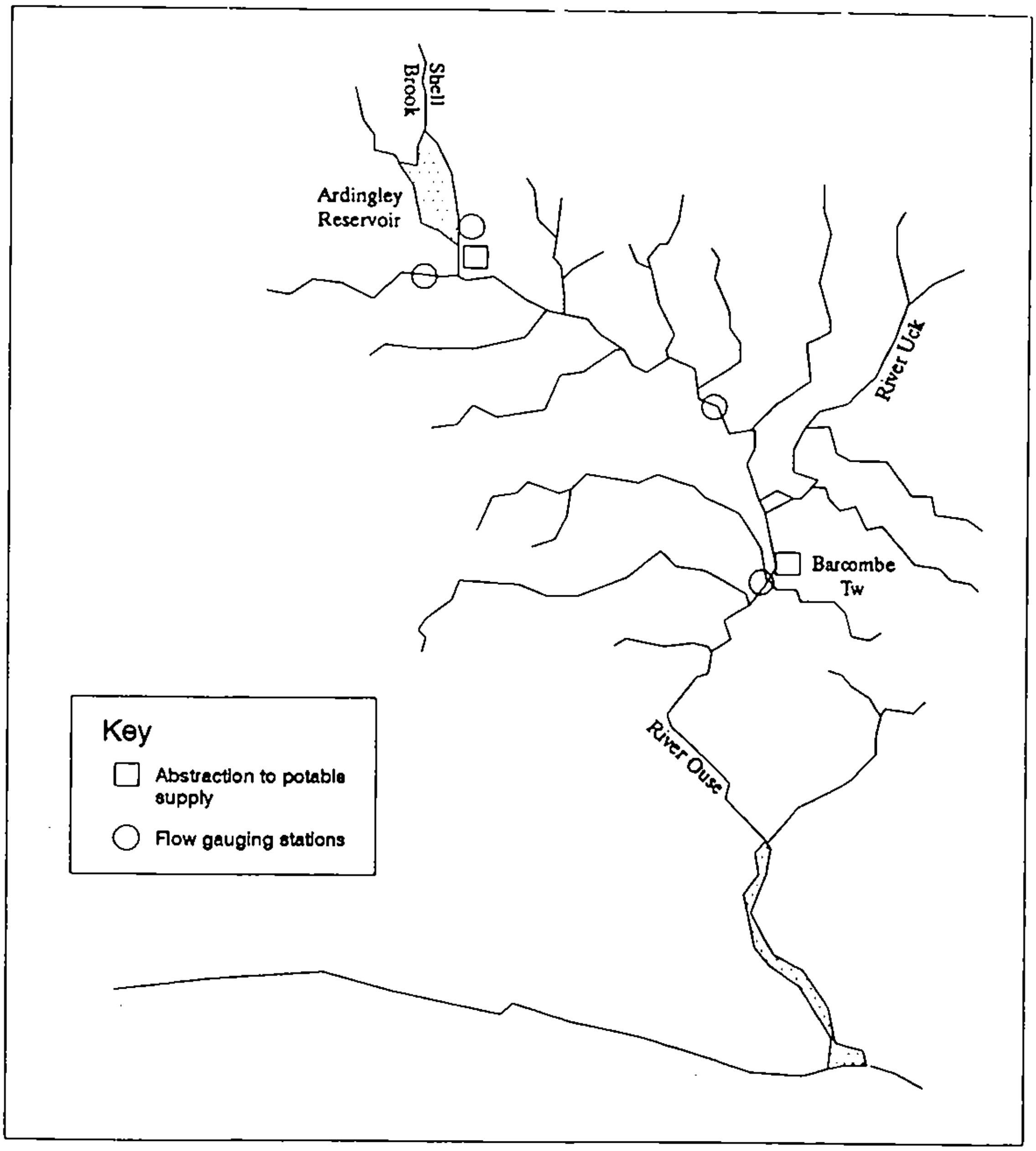


Figure 1

2 OBJECTIVES

This report examines:

(a) The variation from existing system yield that would occur under differnet scenarios of residual flow and abstraction rule;

(b) the sensitivity of yield to the maximum installed Barcombe pump capacity;

(c) the degree to which effluent returning to the river will justify a correspondingly higher yield.

In all cases the calculations are exploratory and no attempt is made here to judge whether changes to abstraction patterns would be acceptable to the NRA or riparian interests. However the range of combinations explored does reflect an awareness of conditions that occur on some other English rivers.

This report assumes that Ardingly Reservoir remains unchanged and that its compensation water conditions and refill works are unchanged likewise. The various abstraction licences are interpreted in line with the formal memorandum (NRA Southern, 1993) which exists on this topic.

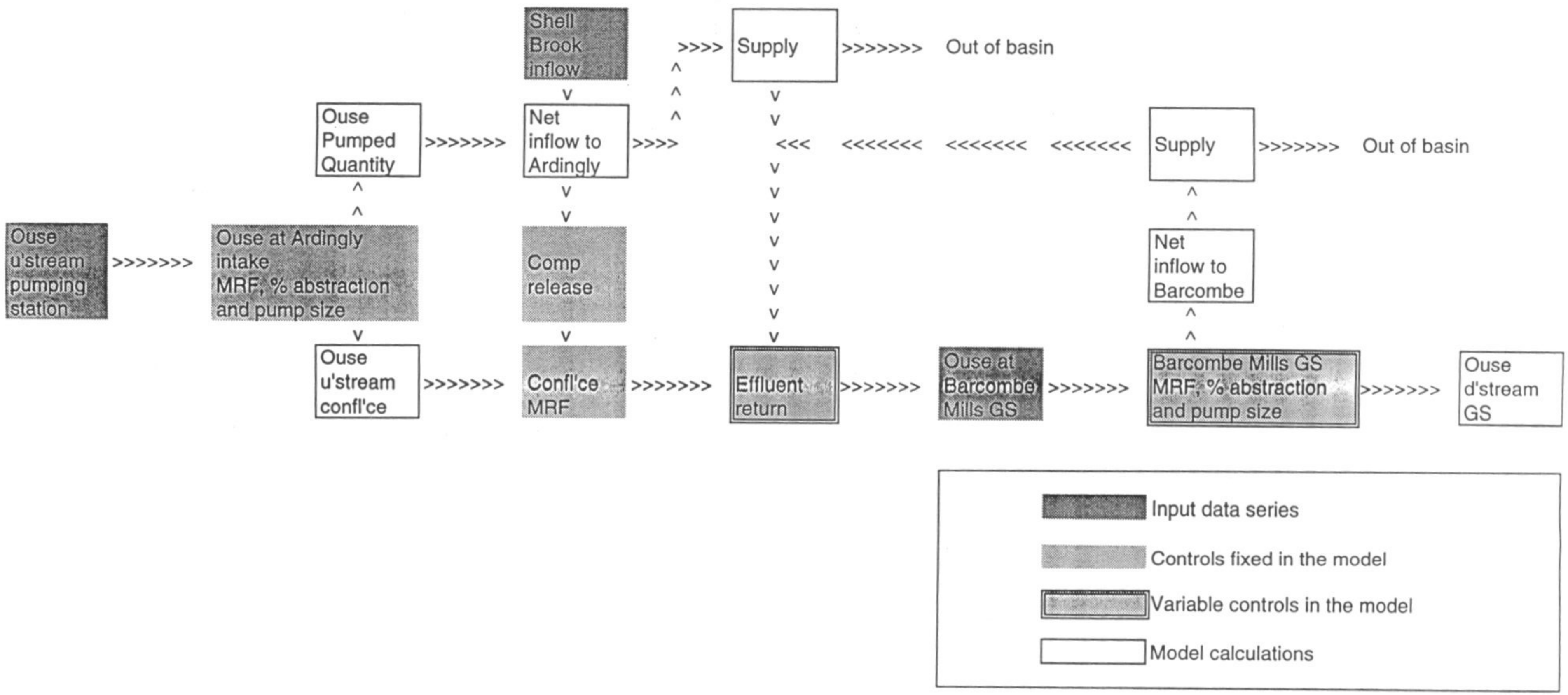
3 METHODOLOGY

The yield assessment of the Sussex Ouse water resource system has been performed through the construction of a spreadsheet model. A schematic diagram of the model is presented in figure 2. The main components of the system are Ardingly Reservoir, which is filled by direct inflow from the Shell Brook and by pumping from the River Ouse, and further downstream a river intake at Barcombe which supplies the main part of the regional demand. In addition to natural runoff into the River Ouse system river flow is boosted by effluent returns from treatment works in both the upper and lower regions of the Ouse catchment.

Two alternative approaches for the management of the system have been considered. Firstly, the use of Ardingly Reservoir solely to provide storage for the augmentation of flows downstream at Barcombe during periods of low flow in order to ensure that supply at that point can always satisfy demand. The second approach allows the use of Ardingly both to augment flows at Barcombe but also as a source of direct supply for local demand centres. The analysis described here has aimed to isolate the maximum yield of the system as a whole as the combination of yield at Barcombe and Ardingly is varied.

The model computes the system yield by way of a three stage procedure: the estimation of inflows to Ardingly and Barcombe; the calculation of yield for a given set of abstraction conditions; and the comparison of alternative Ardingly/Barcombe yield combinations to isolate the maximum system yield and optimum combination.

Figure 2 Sussex Ouse Water Resource System - system components and controls



Estimation of Net Inflows

The estimation of net inflows to Ardingly and Barcombe is performed by running each daily flow record through a series of sequential logical expressions. The sequence of expressions determines, on any given day, whether flow can be abstracted, how much can be abstracted and whether an augmentation release from Ardingly is required to satisfy demand at Barcombe. The system variables which control model output are minimum residual flows (MRFs), the fraction of flow which may be abstracted, pump capacities and efficiencies and the amount of effluent return to the system. In the present study the parameters controlling pumped intake to Ardingly from the upper Ouse were fixed in line with the current licence conditions. These conditions allow the abstraction of 60% of flow above an MRF of 5.9 MLD whilst requiring a compensation release from the reservoir of 0.2 MLD. Variation in model output was therefore achieved solely through the variation of the corresponding parameters at the Barcombe intake. Pump efficiency was assumed to be constant at 90% when working below full capacity; this allows for the variation of flow within a day to be approximated by using a mean daily flow record sequence.

The model first computes maximum inflow to Ardingly from the data series of the Shell Brook and the Ouse at the Ardingly intake whilst allowing for compensation releases. The maximum potential abstraction at Barcombe is then computed from the flow at Barcombe Mills gauging station taking into account that some flow has been lost to Ardingly but some gained through effluent returns. For each model run it is necessary to specify the yield (average daily output - ADO) required at Barcombe since this determines whether and how much augmentation release from Ardingly is required. The Barcombe yield for any given day is calculated by scaling the specified ADO in accordance with the seasonal pattern of demand as given in SEW (1993). The model recalculates both inflow series to take account of augmentation water released from Ardingly and abstracted at Barcombe. The daily values are summed to produce monthly net inflow series.

Estimation of Yield

The monthly net inflows to Ardingly provide the input for the estimation of yield. The flows are summed over periods ranging from three to nineteen months in order to isolate the critical, or minimum, inflows for each of these durations. The model calculates the critical period, in terms of number of days, and a scaling factor for demand associated with each of these critical flows.

Yield is calculated for inflow durations from 3 to 19 months according to the equation:

$$\text{Yield (MLD)} * \text{DSF} = \frac{\text{Critical inflow (ML)} + \text{Storage (ML)}}{\text{Critical period (days)}}$$

where DSF, the demand scaling factor, is calculated as:

$$\text{DSF} = \frac{\Sigma\,(\text{ monthly scaled demand in months } 1,\dots,n\,)}{\text{critical period or n (months)}}$$

Values of monthly scaled demand for January to December are given in SEW (1993) as the ratio between average demand in each month and the average monthly demand for the year as a whole.

Having calculated the yield associated with each critical period the model isolates the minimum of this set of values. This is the yield which can be guaranteed given the inflow series and abstraction conditions and which is added to the specified Barcombe yield to calculate the total system yield.It is necessary to note that the yield quoted on the tables and diagrams that follow is the average annual yield about which seasonal variation takes place; it must therefore be compared with average annual water demand (and not seasonal demand).

Optimum system yield combination

Each model version, having a specified set of abstraction conditions, was subject to a series of runs in which the yield at Barcombe was varied between 20 and 50 ml/d. The maximum total system yield was isolated from each of these series of model runs. The combination of yield at Barcombe and Ardingly corresponding with this maximum represents the optimal operation of the system to secure maximum yield under the specified conditions.

4 INPUT DATA AND ITS SOURCES

Three sets of drought flow series were used in the modelling work. The synthetic 2% (1 in 50 year) drought series used were taken from a Mid Sussex Water Company document describing yield analysis for Ardingly Reservoir (see references). In this original analysis the 2% drought flow series for the Shell Brook and the Ouse above the reservoir intake were derived from records at Wallers Haven whilst the series for the Ouse at Barcombe was based on records from that site. This data covers a period of 20 months from February to September in the following year.

The remaining two sets of flows are based on historical droughts occurring in the recent past. Daily flow at Barcombe Mills was abstracted from the National Surface Water Archive held at the Institute of Hydrology for two 20 month periods in the years 1976-77 and 1989-90. The former case represents the classic drought of recent times with an estimated return period of over 50 years. The 1989-90 drought was less severe but represents a different type of drought, having had a relatively dry winter. No recorded flows were available for either the Shell Brook or the Ouse at the reservoir intake. The daily flows for these sites were therefore estimated by scaling the recorded flows at Barcombe by a factor derived from the ratio of average daily flows in the 2% drought series. Alternative scaling factors could be derived from MicroLowFlows mean flow estimates or from catchment areas and this approach may be adopted in the future.

5 LOWER OUSE ABSTRACTION CONDITIONS

The yield of the Barcombe/Ardingly system was estimated for each of six sets of abstraction conditions. Each of the scenarios was selected to examine the sensitivity of yield to the range of conditions that might be imposed by either licence variation or new legislation. The model was run for each set of conditions on the three input data series: 2% drought flows, 1976-77 and 1989-90. Details of each of the six sets of abstraction conditions are given below and summarised in table 1. The conditions at the Ardingly intake were held constant as described in section 3.

Table 1 Summary of abstraction conditions (in units of MLD)

Abstraction conditions		1
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4
	Ardingly	60% Q>5.9
Pump sizes	Barcombe	91
	Ardingly	45.5
Effluent return	upper	0
	lower	9

Abstraction conditions		1	2a	2b	2c
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<36.4 60% Q>36.4	100% 18.2<Q<36.4 70% Q>36.4	100% 18.2<Q<36.4 80% Q>36.4
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91	91
	Ardingly	45.5	45.5	45.5	45.5
Effluent return	upper	0	0	0	0
	lower	9	9	9	9

Abstraction conditions		1	3a	3b
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	50% Q>10.0	60% Q>10.0
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91
	Ardingly	45.5	45.5	45.5
Effluent return	upper	0	0	0
	lower	9	9	9

Abstraction conditions		1	4a	4b
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<45.0 50% Q>45.0	100% 18.2<Q<60.0 50% Q>60.0
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91
	Ardingly	45.5	45.5	45.5
Effluent return	upper	0	0	0
	lower	9	9	9

Abstraction conditions		1	5
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% Q>18.2
	Ardingly	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	180
	Ardingly	45.5	45.5
Effluent return	upper	0	0
	lower	9	9

Abstraction conditions		1	6
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<36.4 50% Q>36.4
	Ardingly	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91
	Ardingly	45.5	45.5
Effluent return	upper	0	2
	lower	9	18

(1) Current abstraction conditions

The model was run with the current licensed abstraction conditions at Barcombe to serve as a baseline against which the performance of other sets of conditions could be compared. The current licence allows the abstraction of water according to a two stage rule. 100% of flow may be abstracted between the MRF of 18.2 MLD and 36.4 MLD. Above this upper limit only 50 % of flow may be abstracted up to the pump capacity of 91 MLD.

(2) Natural but less so

This set of conditions remains identical to the current regime except that the percentage abstraction allowed above 36.4 MLD is increased. This would ensure that the current protection of flow during periods of low flow is maintained. The percentage take was increased to 60% (2a), 70% (2b) and 80% (2c).

(3) Trade off

As an alternative way to safeguard low flows this set of conditions sets a lower MRF of 10 MLD but scraps the two part rule. Under these conditions it is no longer possible to abstract 100% of the flow at any time. Instead the model was run with 50% abstraction (3a) and 60% abstraction (3b) above the lower MRF.

(4) Hit it when you can

In an attempt to maximise abstraction during periods of high flow this set of conditions involves two changes from the current conditions. Firstly, the pump capacity is increased to 180 MLD (approximately doubled) and secondly, the percentage abstraction allowed is 100% of flows above the MRF.

(5) Tinkering

As the name suggests this set of conditions does not vary greatly from the current ones. The threshold between the first and second stage of the abstraction rule is increased to 45 MLD (5a) and 60 MLD (5b) in order to abstract more water during medium flows.

(6) More effluent return

Finally, the model was run with the current abstraction conditions at Barcombe in place but with increased effluent returns. In all previous model runs effluent returns was set to 9 MLD, a value taken from SEW (1993). This was assumed to represent returns in the lower catchment only. In this run 2 MLD of effluent was returned from the upper catchment and 18 MLD from the lower. This was to investigate the possibility that often neglected effluent returns may have a significant impact on yield calculations. The range examined is believed to bracket the actual case that exists, for which no satisfactory data is known to be measured, collated or published.

6 RESULTS

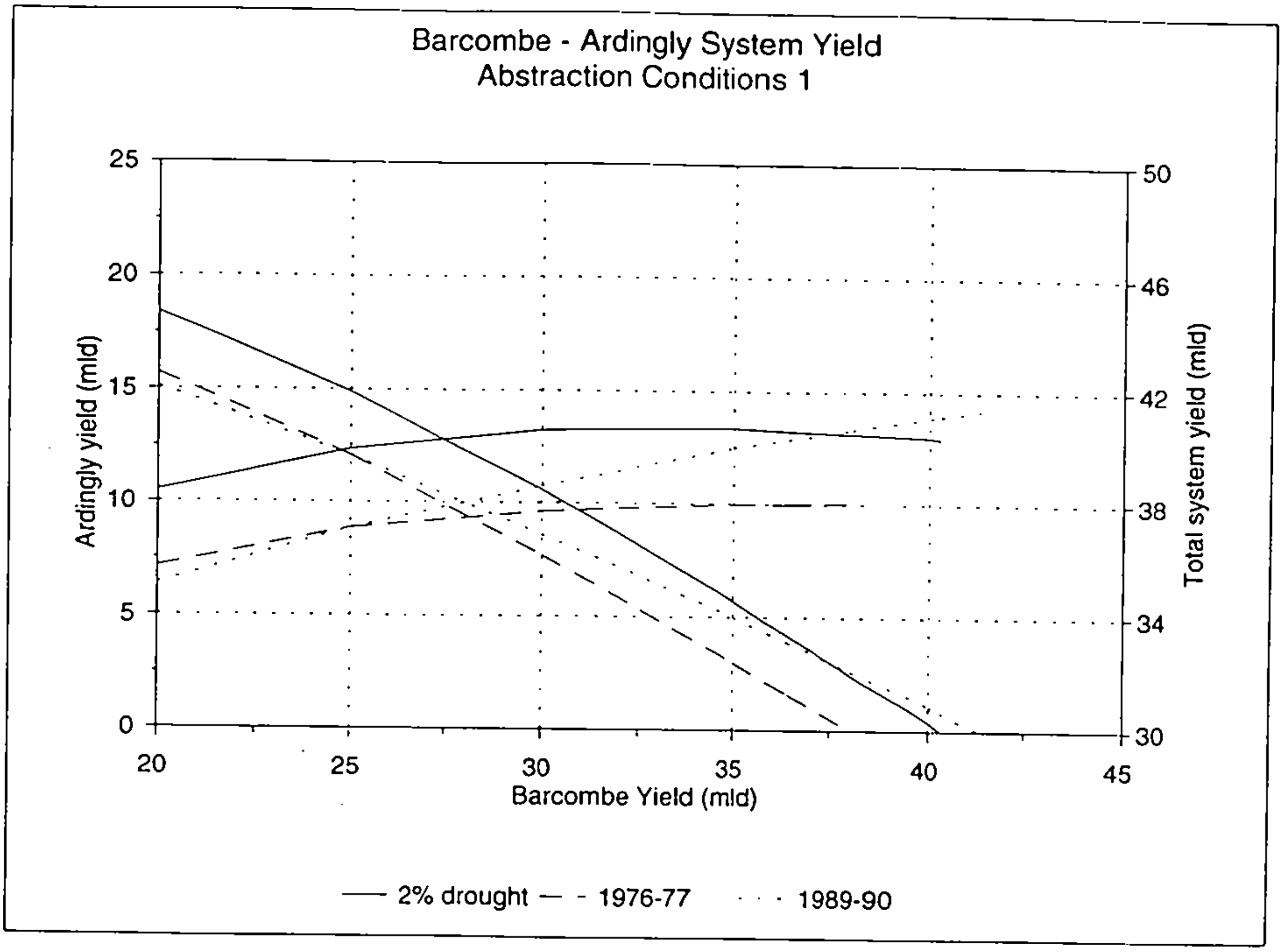
In almost all of the cases considered here varying the abstraction conditions at Barcombe results in an increased total system yield. Table 2 summarises the results of each model run in terms of the change in the maximum yield from that produced with the current abstraction conditions.

Table 2 Model estimates of change from current maximum yield under each alternative set of abstraction conditions.

Flow series	Synthetic 2%		1976-77		1989-90	
Abstraction conditions	Change in yield (MLD)	Rank	Change in yield (MLD)	Rank	Change in yield (MLD)	Rank
2a	+ 1.8	4	+ 1.5	5	+ 1.8	4
2b	+ 2.3	1=	+ 2.0	1=	+ 2.6	1=
2c	+ 2.3	1=	+ 2.0	1=	+ 2.6	1=
3a	- 3.5	8	- 2.1	8	- 3.9	8
3b	- 0.8	7	+ 0.4	6	- 1.1	7
4a	+ 0.5	6	+ 0.3	7	+ 0.5	6
4b	+ 1.5	5	+ 1.6	4	+ 1.6	5
5	+ 2.3	1=	+ 1.9	3	+ 2.6	1=
6	+ 5.5		+ 6.8		+ 5.3	

In every case maximum yields are highest when the model is run on the 1989-90 flow series and lowest when it is run on the 1976-77 data. The maximum yields from the synthetic 2% drought series are only slightly lower than those from the 1989-90 data. As figure 3 reveals, however, system yields below the maximum are higher from the 2% drought series than from either the 1976-77 or 1989-90 data. This suggests either that the droughts during these years were of higher return periods than 1 in 50 years or that the 2% drought series used in this analysis is not really representative of a drought of this severity.

Note that on figure 3 and similar graphs the combined system yield is read off from the flatter curve using the right hand y-axis. The maximum system yield is the highest point on this curve. Reading down to the x-axis from the same point on this curve gives the yield at Barcombe contributing to this maximum system yield. Reading from the intersection of this Barcombe yield with the other more inclined curve across to the left hand y-axis gives the corresponding yield at Ardingly. For example, the maximum system yield as shown by the curve representing the results of the 2% drought flow analysis is 40.7 MLD. Reading down from this point on the upper curve to the x-axis shows that the yield at Barcombe associated with this total system yield is 35 MLD. Reading across to the left hand y-axis from the lower inclined curve at the point where Barcombe yield equals 35 MLD shows that the corresponding Ardingly yield is 5.7 MLD.



Abstraction conditions		1
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4
	Ardingly	60% Q>5.9
Pump sizes	Barcombe	91
	Ardingly	45.5
Effluent return	upper	0
	lower	9

Figure 3

An interesting feature of figure 3 is the difference in the trajectories of the total system yield curves for the three data series. The synthetic 2% drought data results plot as a smooth curve which reaches a maximum and then declines. This is indicative of a yield combination in which both Barcombe and Ardingly are used for direct supply. In contrast the curve representing the results of the model runs on the 1989-90 is relatively straight and reaches a maximum only at its most right hand extent. This represents the point at which yield from Ardingly is zero and hence all supply, if the total system yield is a to be a maximum, must come from Barcombe. In this instance Ardingly is therefore used for augmentation only. These results (Ardingly for augmentation/supply or augmentation only) are replicated in the results of each model run on the 2% drought and 1989-90 data respectively. The curve representing the results of the model runs on the 1976-77 data lies between these two extremes. Under most of the abstraction scenarios considered here the results of the 1976-77 data point to maximum yield being achieved when Ardingly is used for augmentation only although in some instances the maximum coincides with a small amount of direct yield from the reservoir (see table 4).

Plots similar to figure 3 comparing estimated yields under each of the sets of abstraction conditions are contained in the Annex. In each case the change in yield is plotted against the baseline condition of the current abstraction regime. A summary of these results is given in tables 3, 4 and 5. Each table compares the best yield combination at Ardingly and Barcombe under abstraction conditions 2-6 with that under the current set of conditions. The details of the results are described below with reference to each set of conditions in turn.

(2) Natural but less so

The system yield increases significantly when the percentage abstraction above the second stage threshold at Barcombe is increase from 50% to 60% of flow (2a). However, a further increase in take to 70% (2b) results in only a small additional yield and increases above this, to 80% of flow (2c), make no difference at all. The increase in the estimated maximum system yield when the second stage percentage take at Barcombe is 70% is in the range 2.0 MLD (1976-77) to 2.6 MLD (1989-90).

(3) Trade off

Changing to a single stage abstraction rule, with the percentage take set to 50% (3a) or 60% (3b), generally results in lower system yields despite lowering the MRF at Barcombe from 18.2 MLD to 10 MLD. The estimated maximum yield of the system falls by up to 3.9 MLD (1989-90) when the take at Barcombe is only 50%. When take is increased to 60% the system yield is only slightly less than under the current conditions and may be even slightly increased (1976-77).

(4) Tinkering

With an increase in the second stage threshold at Barcombe from 36.4 MLD to 45 MLD the total system yield increases only slightly, by 0.3-0.5 MLD. A more significant increase is gained by increasing the threshold to 60 MLD, with the total system yield 1.5-1.6 MLD greater than under current abstraction conditions.

Table 3 Maximum system yields (MLD) - synthetic 2% drought flows

Abstraction conditions		1	2a	2b	2c
Maximum system yield	Barcombe	35.0	40.0	40.0	40.0
	Ardingly	5.7	2.5	3.0	3.0
	Total	40.7	42.5	43.0	43.0

Abstraction conditions		1	3a	3b
Maximum system yield	Barcombe	35.0	30.0	35.0
	Ardingly	5.7	7.2	4.9
	Total	40.7	37.2	39.9

Abstraction conditions		1	4a	4b
Maximum system yield	Barcombe	35.0	35.0	35.0
	Ardingly	5.7	6.2	7.2
	Total	40.7	41.2	42.2

Abstraction conditions		1	5
Maximum system yield	Barcombe	35.0	40.0
	Ardingly	5.7	3.0
	Total	40.7	43.0

Abstraction conditions		1	6
Maximum system yield	Barcombe	35.0	40.0
	Ardingly	5.7	6.2
	Total	40.7	46.2

Table 4 Maximum system yields (MLD) - 1976-77 flows

Abstraction conditions		1	2a	2b	2c
Maximum system yield	Barcombe	38.1	38.1	38.1	38.1
	Ardingly	0.0	1.4	1.9	1.9
	Total	38.0	39.5	40.0	40.0

Abstraction conditions		1	3a	3b
Maximum system yield	Barcombe	38.1	36.0	38.1
	Ardingly	0.0	0.0	0.4
	Total	38.1	36.0	38.5

Abstraction conditions		1	4a	4b
Maximum system yield	Barcombe	38.1	38.1	38.1
	Ardingly	0.0	0.3	1.6
	Total	38.1	38.4	39.7

Abstraction conditions		1	5
Maximum system yield	Barcombe	38.1	38.1
	Ardingly	0.0	1.9
	Total	38.1	40.0

Abstraction conditions		1	6
Maximum system yield	Barcombe	38.1	44.9
	Ardingly	0.0	0.0
	Total	38.1	44.9

Table 5 Maximum system yields (MLD) - 1989-90 flows

Abstraction conditions		1	2a	2b	2c
Maximum system yield	Barcombe	41.4	43.2	44.0	44.0
	Ardingly	0.0	0.0	0.0	0.0
	Total	41.4	43.2	44.0	44.0

Abstraction conditions		1	3a	3b
Maximum system yield	Barcombe	41.4	37.5	40.3
	Ardingly	0.0	0.0	0.0
	Total	41.4	37.5	40.3

Abstraction conditions		1	4a	4b
Maximum system yield	Barcombe	41.4	41.9	43.0
	Ardingly	0.0	0.0	0.0
	Total	41.4	41.9	43.0

Abstraction conditions		1	5
Maximum system yield	Barcombe	41.4	44.0
	Ardingly	0.0	0.0
	Total	41.4	44.0

Abstraction conditions		1	6
Maximum system yield	Barcombe	41.4	46.7
	Ardingly	0.0	0.0
	Total	41.4	46.7

(5) Hit it when you can

The 'hit it when you can' scenario, designed to boost yields by abstracting more water during high flows, does result in an increased maximum system yield of, for example, 2.3 MLD (2% drought). However, comparison with the outcome of model runs under abstraction conditions (2) reveals that these results are identical with those for condition sets (2b) and (2c). No extra yield is gained either by increasing from 70% to 100% abstraction above the threshold of 36.4 MLD or by doubling the pump size. The yield is limited by the same critical event once above the 70% take threshold.

(6) Increased effluent returns

Increasing the effluent returns in the catchment from 9 MLD to 20 MLD increases the estimated maximum yield of the Ouse system by up to 6.8 MLD (1976-77).

Ignoring the results of the model runs on increased effluent returns the improvement in system yield under each of the sets of abstraction conditions 2-5 are ranked in table 3. The greatest increase in total system yield results from changing the percentage abstraction at Barcombe (2b,2c and 5). Of these three alternatives, the increase in take to 70% (2b) represents least modification of the current operating conditions. Increasing the percentage abstraction to 60% (2a) provides the next most additional yield except from the 1976-77 data where increasing the second stage threshold to 60 MLD (4b) provides a greater system yield. This is then the next ranked alternative in the results of the other two data series. Least yield is gained by increasing the second stage threshold to 45 MLD (4a). Yield is lost by scrapping the two stage abstraction rule and lowering the MRF at Barcombe to 10 MLD (3a and 3b).

7 CONCLUSIONS IN CONTEXT OF SEARCH FOR 5 MLD OR GREATER YIELD GAIN

None of the sets of abstraction conditions considered in this analysis of the Sussex Ouse result in an increase in system yield of 5 MLD or greater. The greatest estimated increase in maximum system yield is 2.0-2.6 MLD (depending on the input data series) achieved by increasing the second stage percentage take at Barcombe to 70% or more. By increasing the second stage take to 60% the model estimates an increase in yield of just under 2 MLD. A change in the abstraction conditions at Barcombe to accommodate an increase in take of the order 60-70% has the added benefit of requiring minimal change from the current conditions. In contrast, the 'hit it when you can' scenario requires two major changes to be made to the current abstraction conditions (100% take and doubling of pump capacity) but provides no extra yield above that from the 'natural but less so' scenario described above. The 'natural but less so' set of conditions are therefore preferred both in terms of performance and degree of change from the current conditions.

Only one other of the alternative sets of abstraction conditions considered here appears to generate significant additional yield. This is the 'tinkering' scenario involving an increase in the second stage threshold at Barcombe from 36.4 MLD to 60 MLD. The model estimates an increase in yield of 1.5 MLD to 1.6 MLD could be gained under this scenario.

Changes such as these to the abstraction conditions at Barcombe are clearly insufficient in themselves to generate additional yield of the order of 5 MLD. Other alternatives must therefore be considered as ways to secure this extra yield. Given that any more extreme changes to the abstraction conditions at Barcombe (such as lowering the MRF whilst allowing the same or more percentage abstraction) are probably unworkable in practice it appears that the search for additional yield must move upstream. One option would be to modify the abstraction conditions at the pumped intake to Ardingly reservoir on the upper Ouse. Changes in MRF, percentage take and pump capacity (such as those considered here for Barcombe) could allow more rapid refilling, and therefore greater release of augmentation water to Barcombe. Alternatively, raising the dam at Ardingly would create additional storage with the same result of allowing increased augmentation releases.

The results of the analysis presented here are inconclusive in determining the best use of Ardingly reservoir for maximum system yield. Model runs on the synthetic 2% drought flows always result in a maximum yield when direct supply occurs from both Barcombe and Ardingly. A change from the current operating conditions so that the reservoir is used for augmentation only results in lower system yields in these model runs. In contrast the results of the model runs on the 1989-90 (and to a large extent on 1976-77) data indicate that the optimum system yield is gained when yield at Ardingly is zero. On the basis of this data the use of Ardingly reservoir for augmentation only can result in an additional system yield of up to 2 MLD.

A final conclusion relates to the results of model runs on the scenario of increased effluent returns. This is the one scenario under which the estimated increase in yield is greater than 5 MLD. This increase is, of course, a function of the arbitrarily specified increase in effluent returns from 9 MLD to 20 MLD and no claim is made that this realistically represents additional resources available in the system. This analysis does, however, confirm the importance of fully taking account of effluent returns in water resource investigations and indicates that recycled water can be a significant component of system yield.

8 POTENTIAL FOLLOW ON INVESTIGATIONS

The conclusions presented in the previous section suggest a number of potential follow on investigations. These would incorporate the modelling approach used in the present study and would aim to assess the effect on system yield resulting from:

(i) varying the abstraction conditions at the Ardingly intake

(ii) raising Ardingly dam

(iii) varying the abstraction conditions at both Barcombe and Ardingly with or without Ardingly raised

(iv) adding an intake at a new tidal barrier above or below Lewes

(v) the input of water to the system from additional sources, such as the River Adur.

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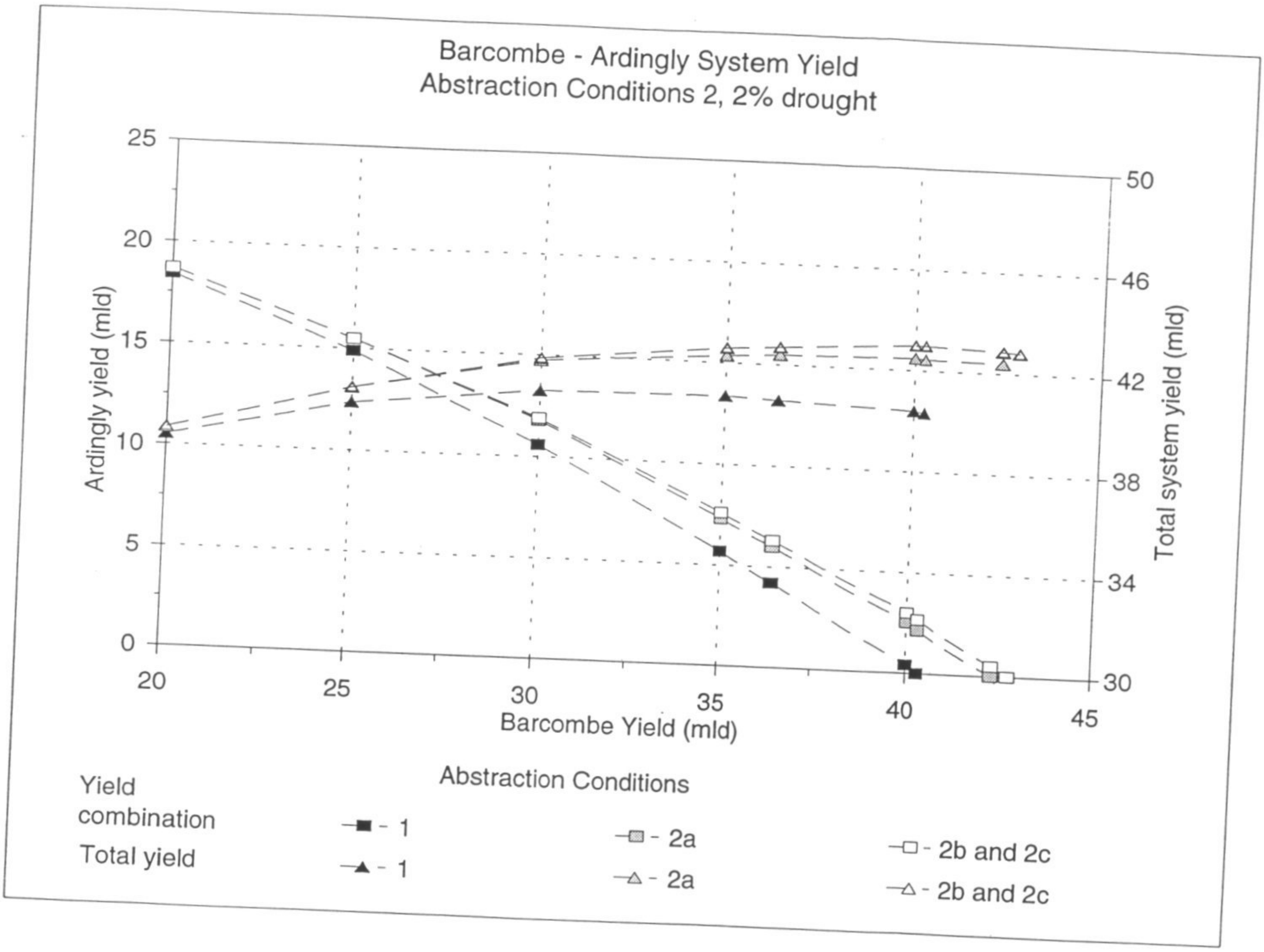
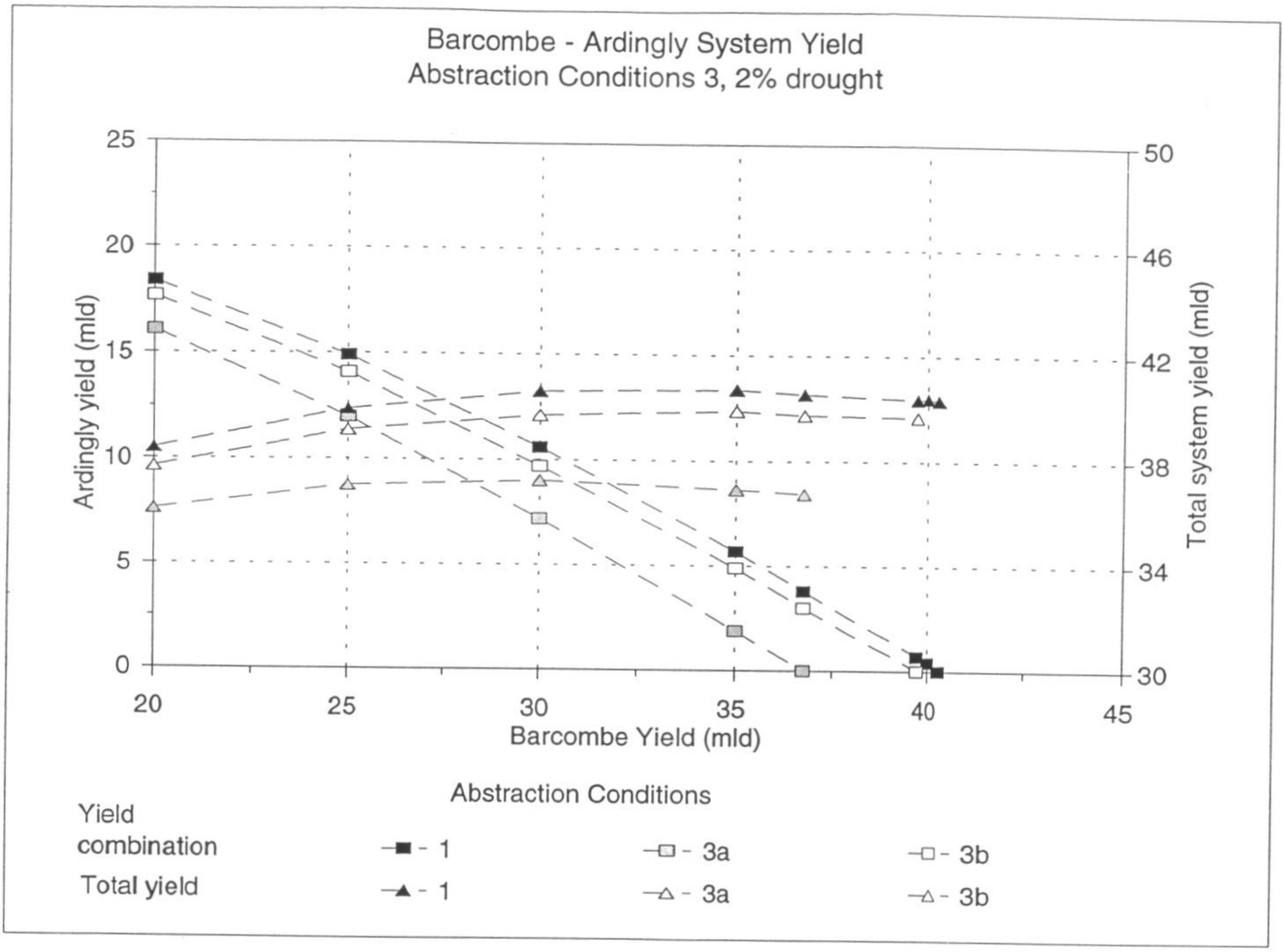
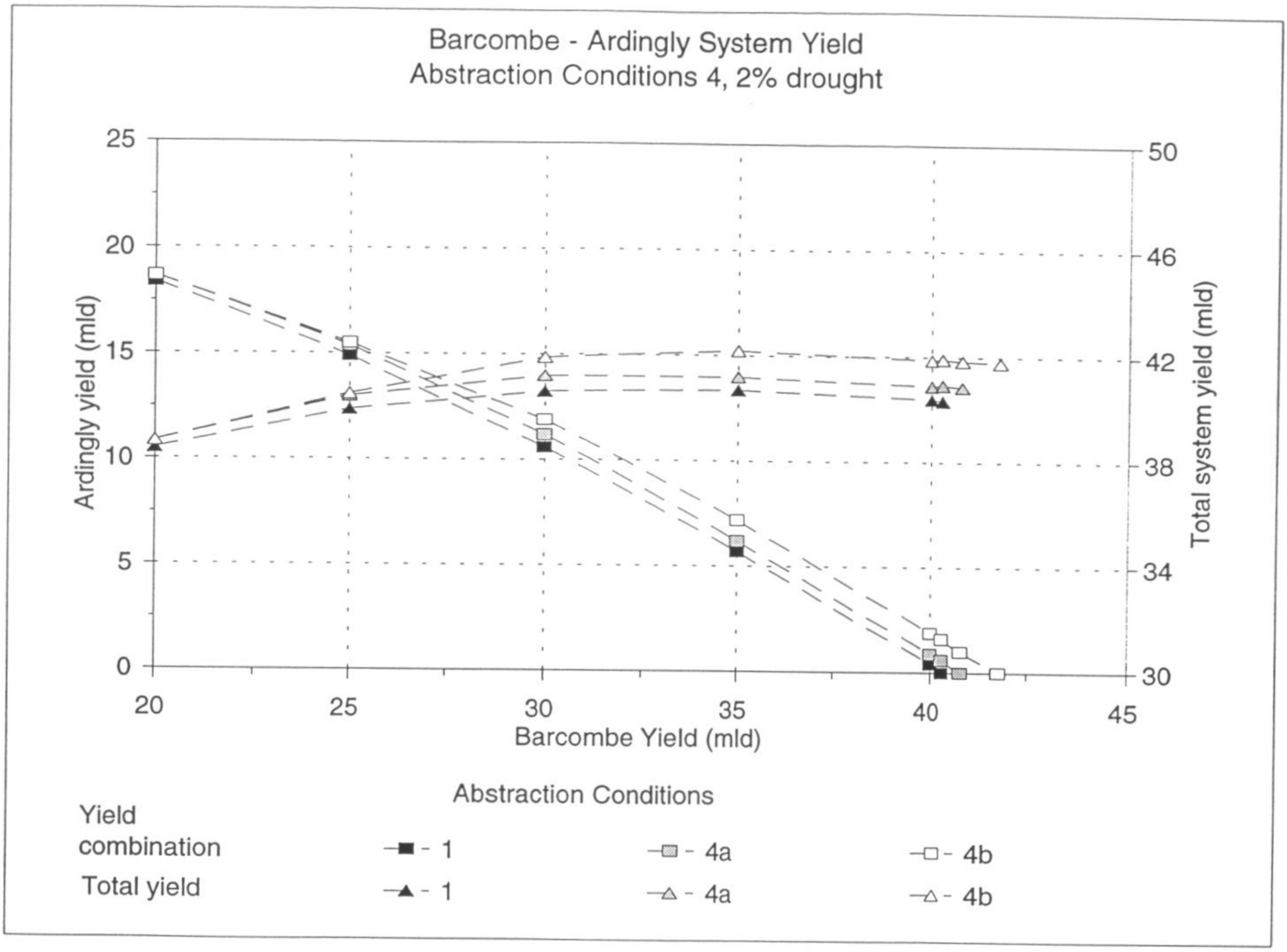


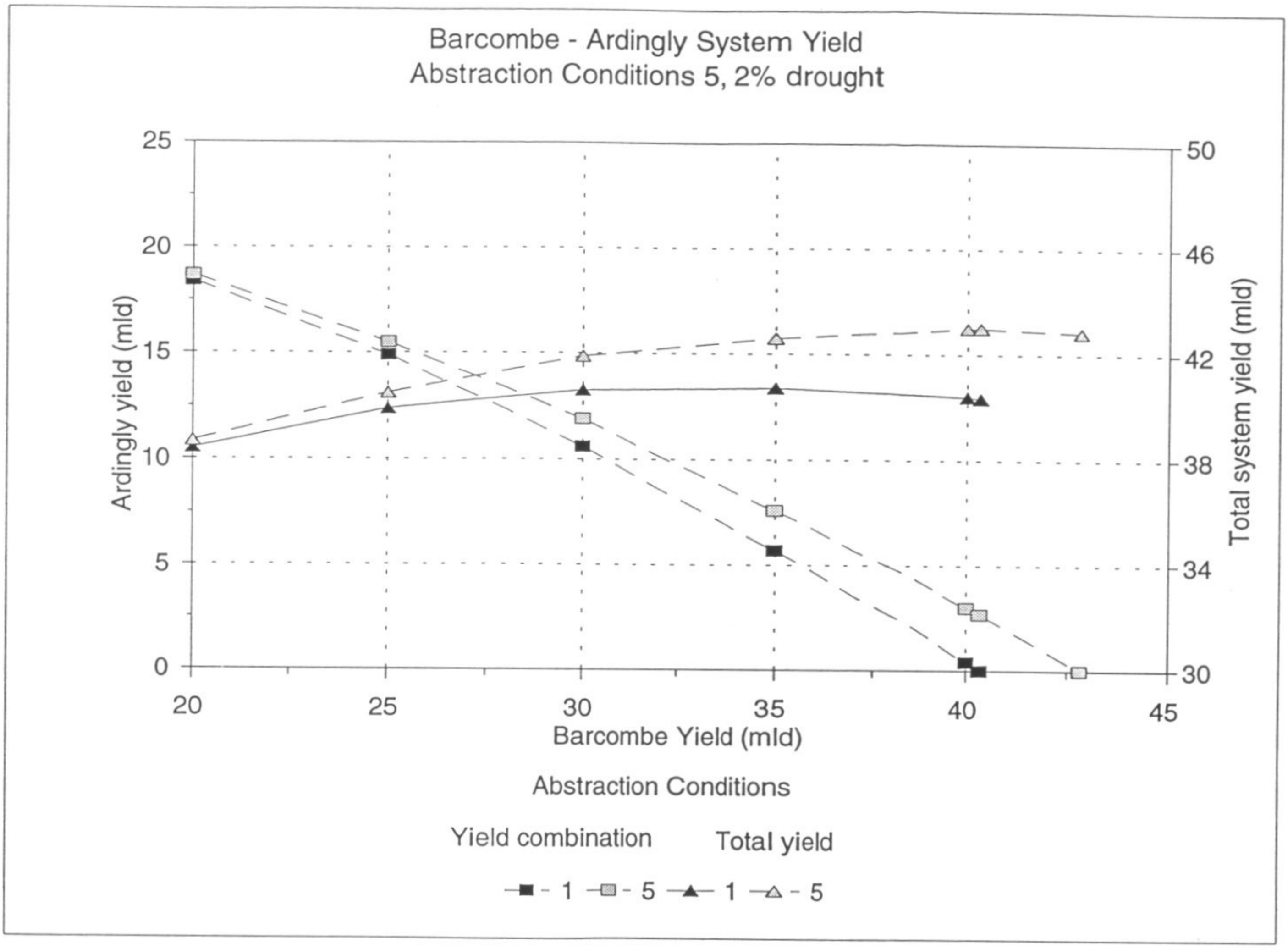
Abstraction conditions		1	2a	2b	2c
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<36.4 60% Q>36.4	100% 18.2<Q<36.4 70% Q>36.4	100% 18.2<Q<36.4 80% Q>36.4
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91	91
	Ardingly	45.5	45.5	45.5	45.5
Effluent return	upper	0	0	0	0
	lower	9	9	9	9



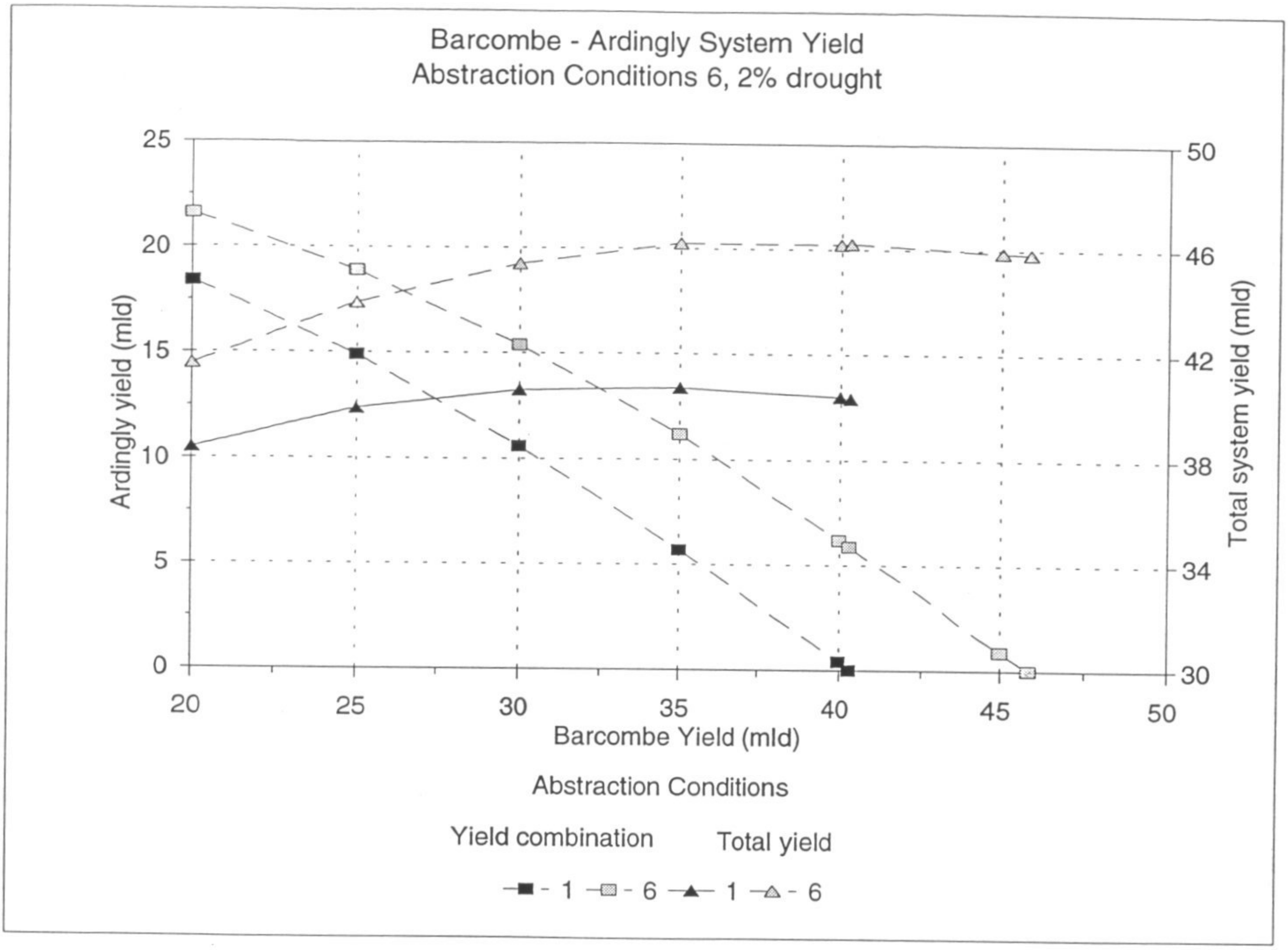
Abstraction conditions		1	3a	3b
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	50% Q>10.0	60% Q>10.0
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91
	Ardingly	45.5	45.5	45.5
Effluent return	upper	0	0	0
	lower	9	9	9



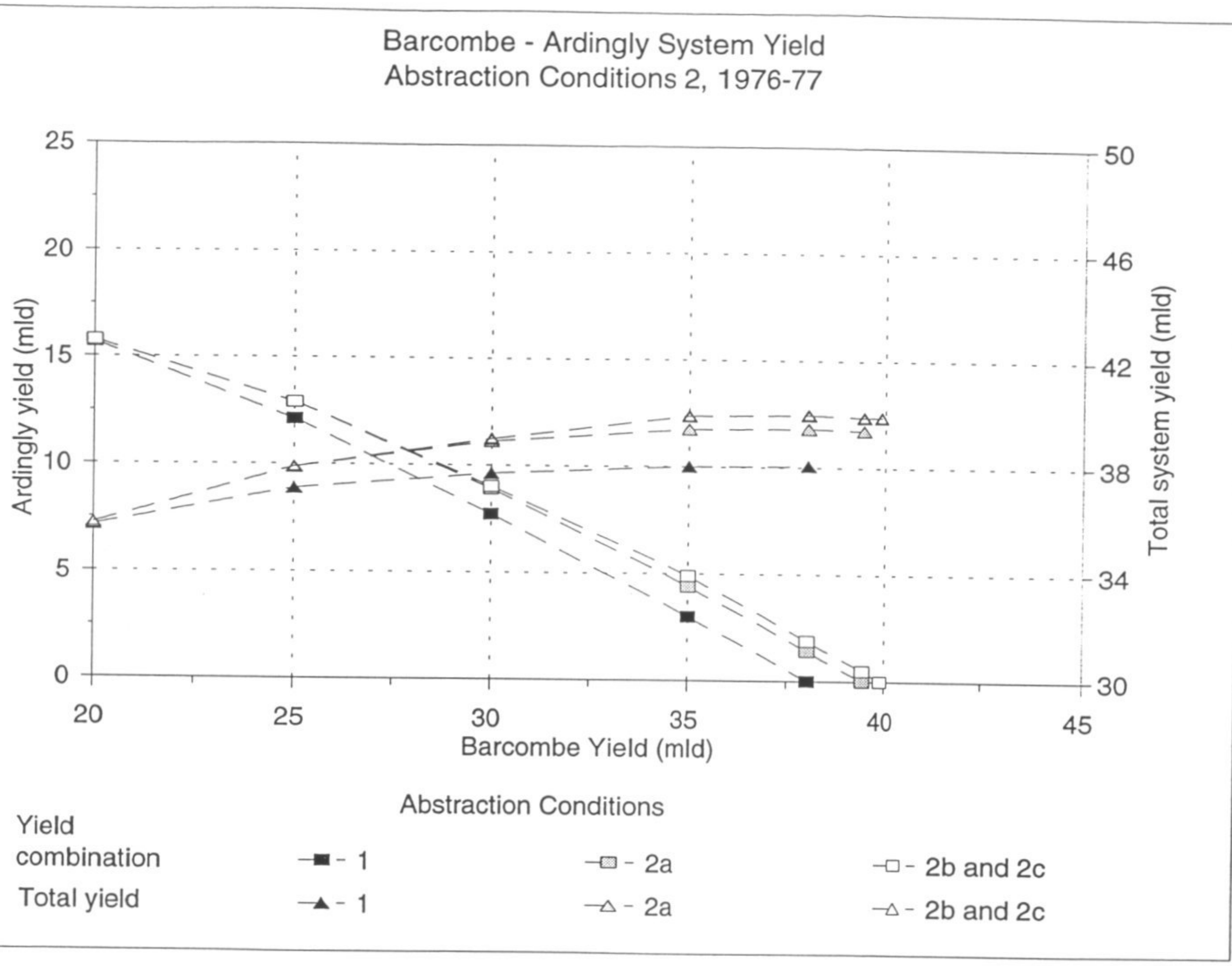
Abstraction conditions		1	4a	4b
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<45.0 50% Q>45.0	100% 18.2<Q<60.0 50% Q>60.0
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91
	Ardingly	45.5	45.5	45.5
Effluent return	upper	0	0	0
	lower	9	9	9



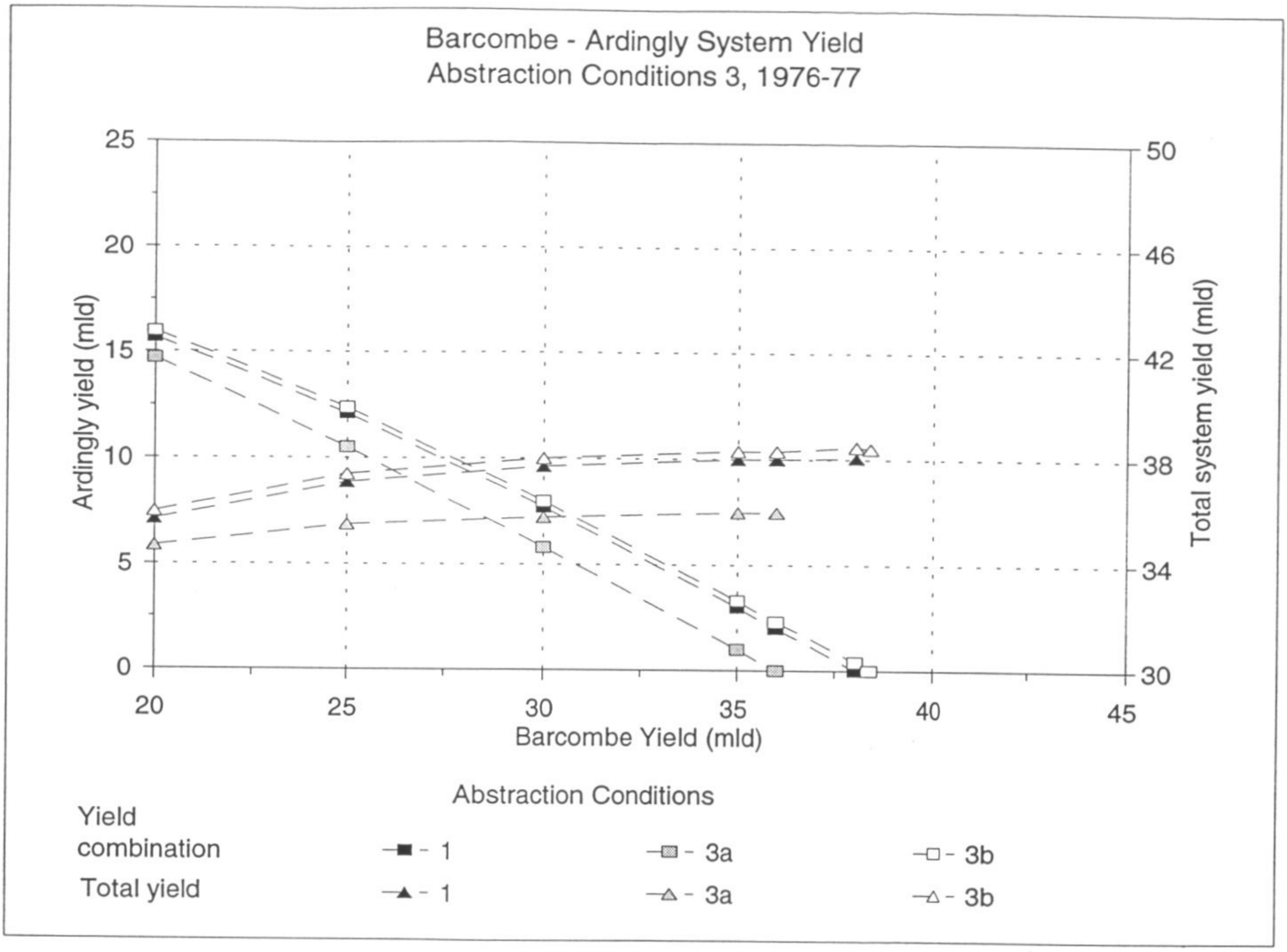
Abstraction conditions		1	5
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% Q>18.2
	Ardingly	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	180
	Ardingly	45.5	45.5
Effluent return	upper	0	0
	lower	9	9



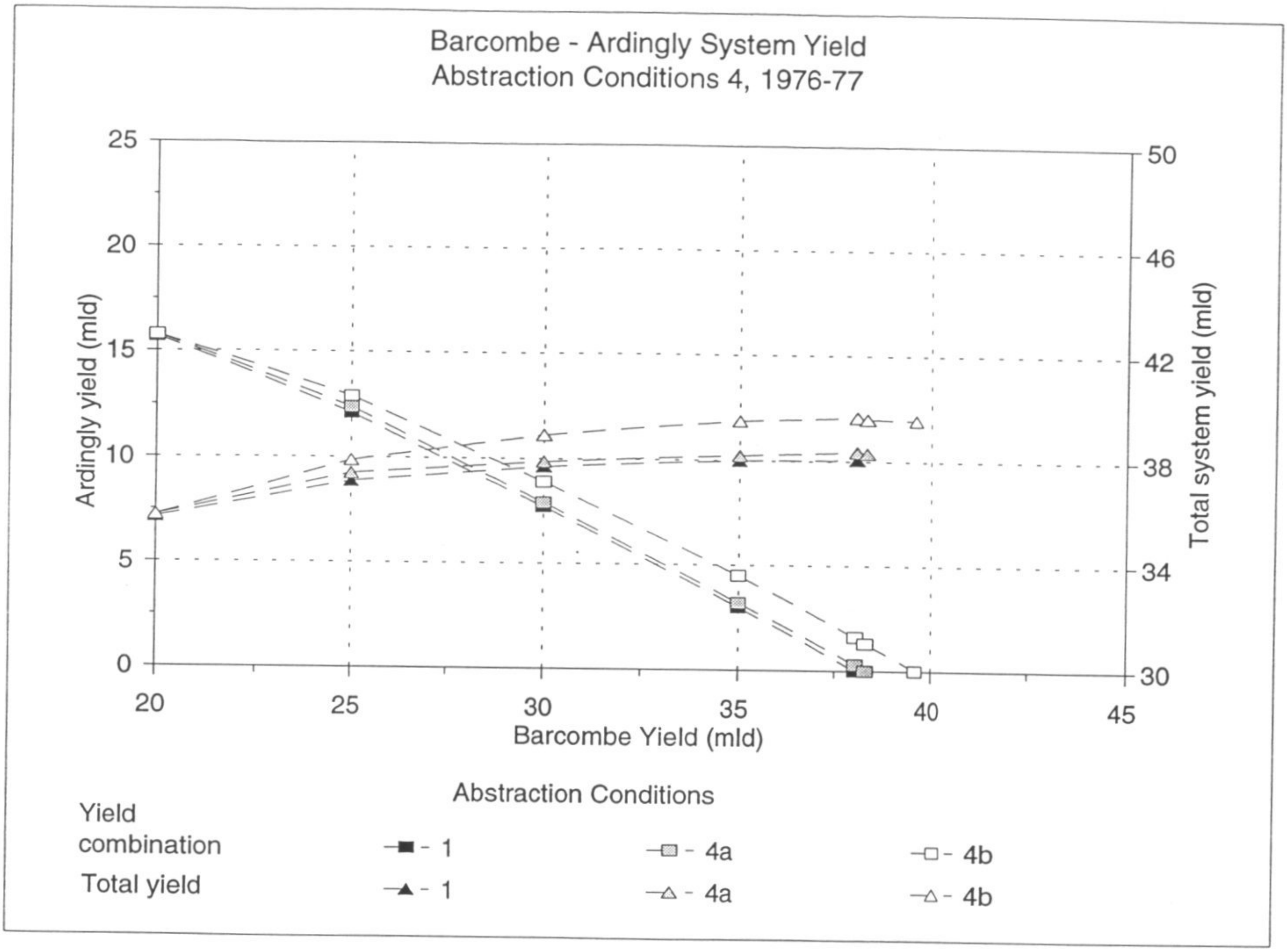
Abstraction conditions		1	6
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<36.4 50% Q>36.4
	Ardingly	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91
	Ardingly	45.5	45.5
Effluent return	upper	0	2
	lower	9	18



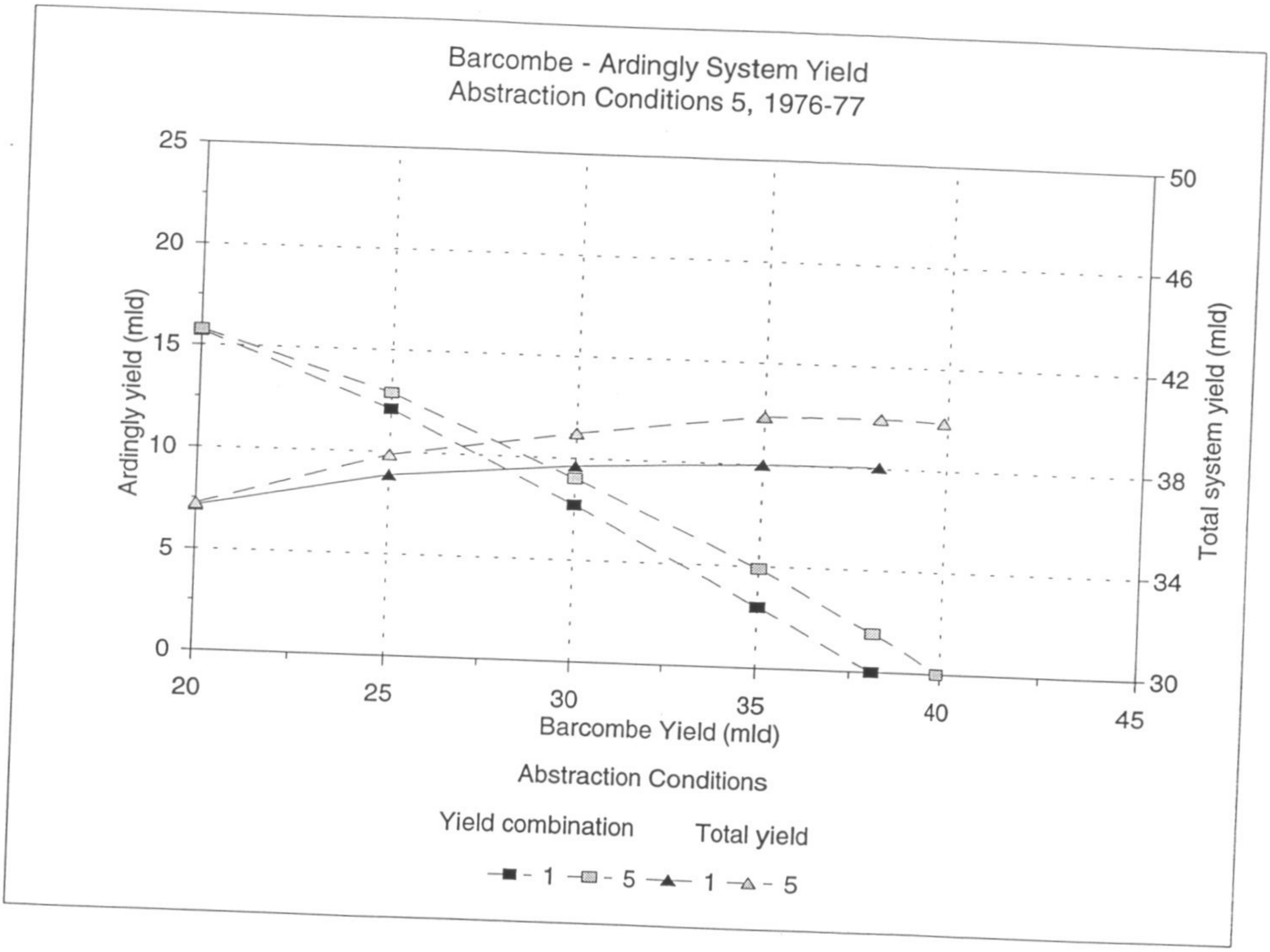
Abstraction conditions		1	2a	2b	2c
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<36.4 60% Q>36.4	100% 18.2<Q<36.4 70% Q>36.4	100% 18.2<Q<36.4 80% Q>36.4
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91	91
	Ardingly	45.5	45.5	45.5	45.5
Effluent return	upper	0	0	0	0
	lower	9	9	9	9



Abstraction conditions		1	3a	3b
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	50% Q>10.0	60% Q>10.0
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91
	Ardingly	45.5	45.5	45.5
Effluent return	upper	0	0	0
	lower	9	9	9



Abstraction conditions		1	4a	4b
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<45.0 50% Q>45.0	100% 18.2<Q<60.0 50% Q>60.0
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91
	Ardingly	45.5	45.5	45.5
Effluent return	upper	0	0	0
	lower	9	9	9



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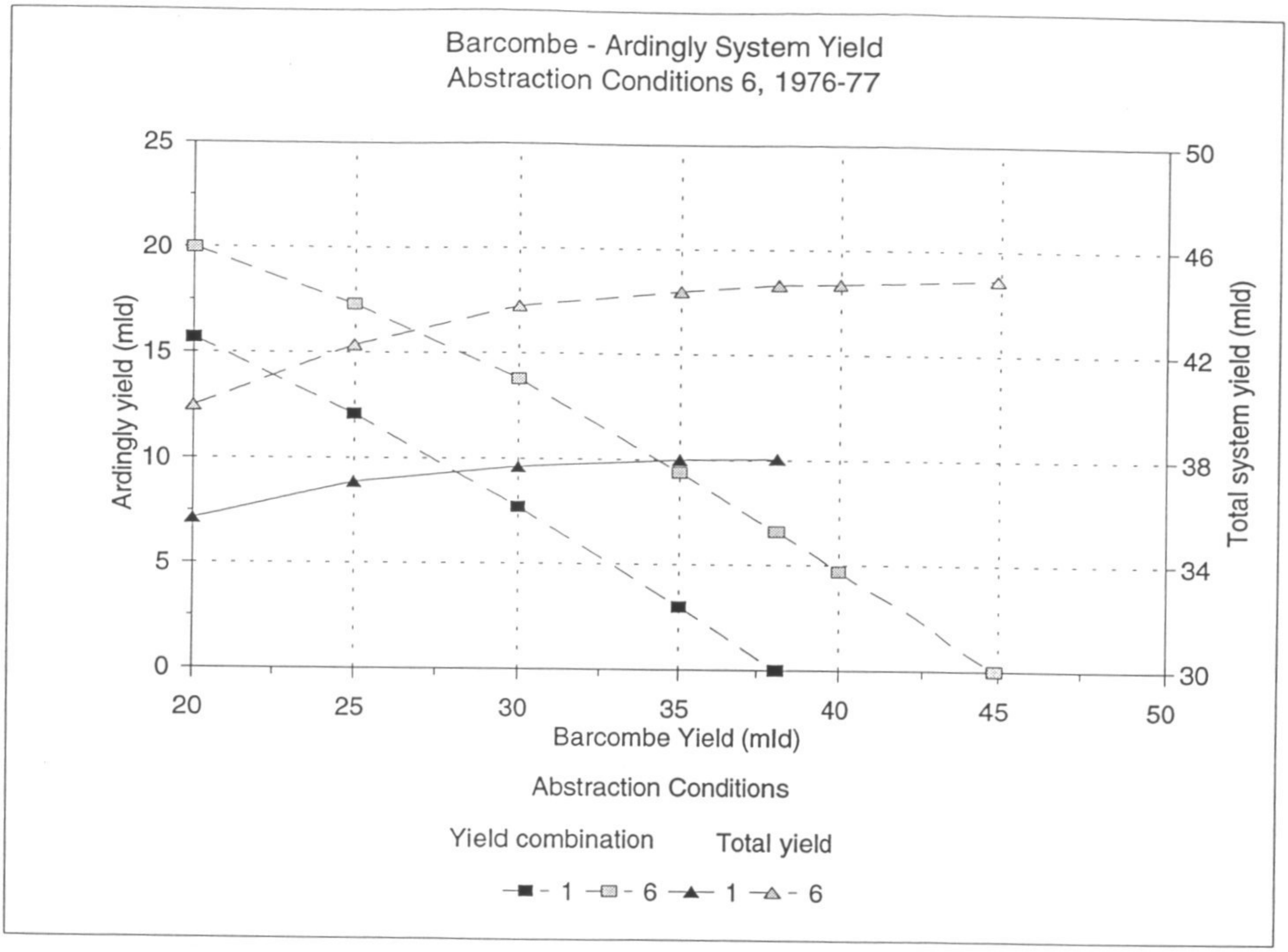
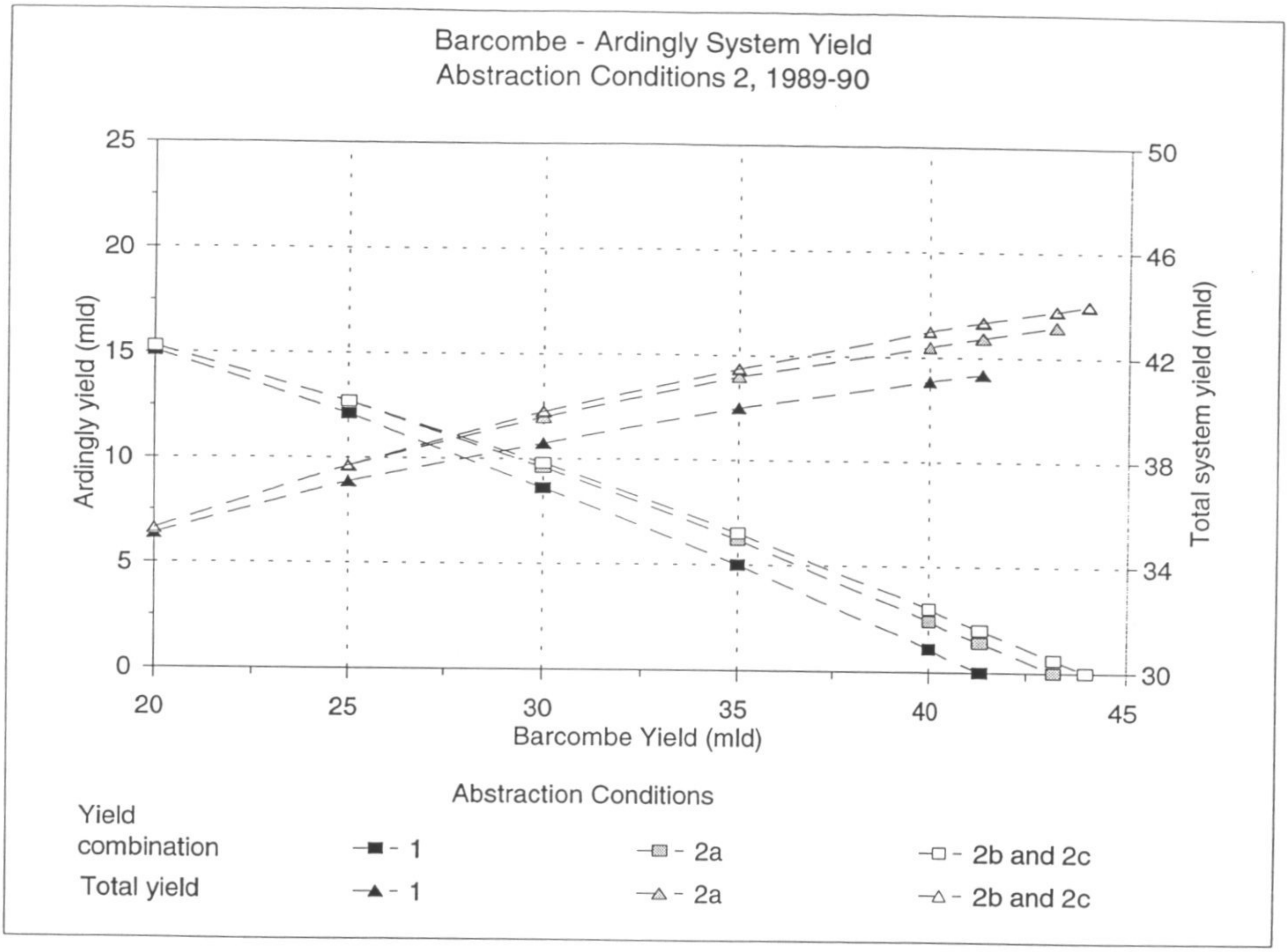
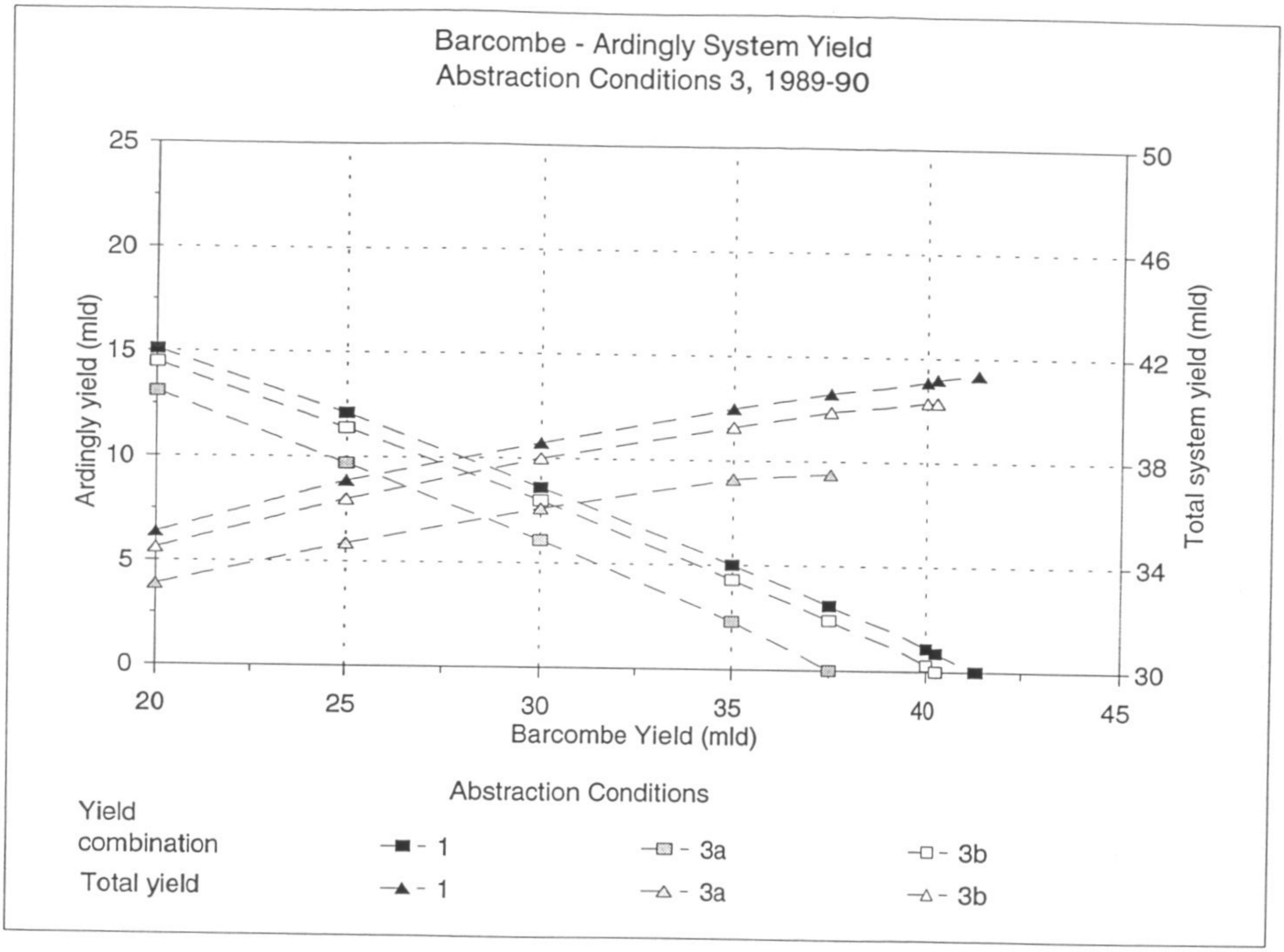
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% Q>18.2
	Ardingly	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	180
	Ardingly	45.5	45.5
Effluent return	upper	0	0
	lower	9	9



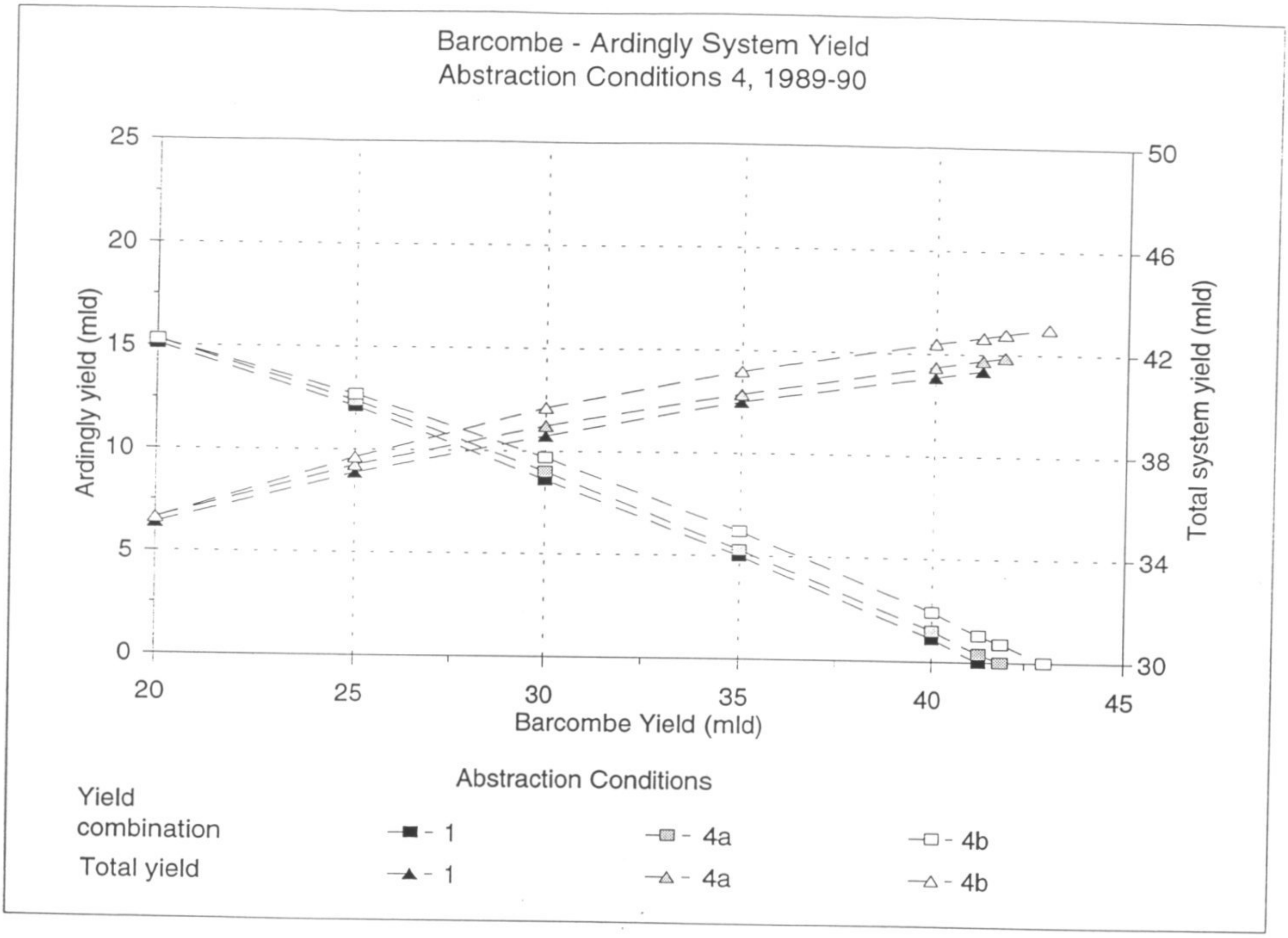
Abstraction conditions		1	6
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<36.4 50% Q>36.4
	Ardingly	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91
	Ardingly	45.5	45.5
Effluent return	upper	0	2
	lower	9	18



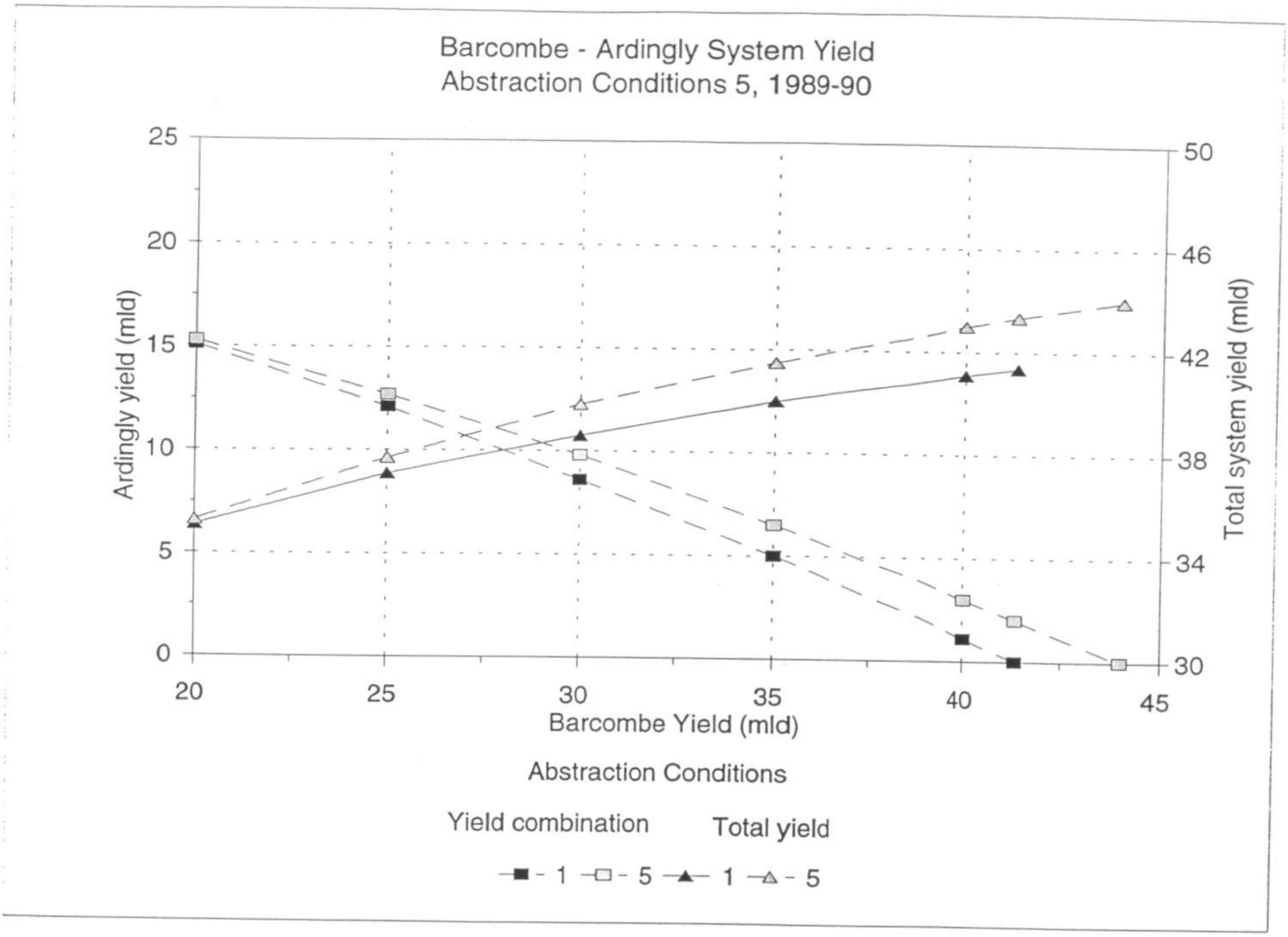
Abstraction conditions		1	2a	2b	2c
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<36.4 60% Q>36.4	100% 18.2<Q<36.4 70% Q>36.4	100% 18.2<Q<36.4 80% Q>36.4
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91	91
	Ardingly	45.5	45.5	45.5	45.5
Effluent return	upper	0	0	0	0
	lower	9	9	9	9



Abstraction conditions		1	3a	3b
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	50% Q>10.0	60% Q>10.0
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91
	Ardingly	45.5	45.5	45.5
Effluent return	upper	0	0	0
	lower	9	9	9



Abstraction conditions		1	4a	4b
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<45.0 50% Q>45.0	100% 18.2<Q<60.0 50% Q>60.0
	Ardingly	60% Q>5.9	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91	91
	Ardingly	45.5	45.5	45.5
Effluent return	upper	0	0	0
	lower	9	9	9



Abstraction conditions		1	5
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% Q>18.2
	Ardingly	60% Q>5.9	60% Q>5.9
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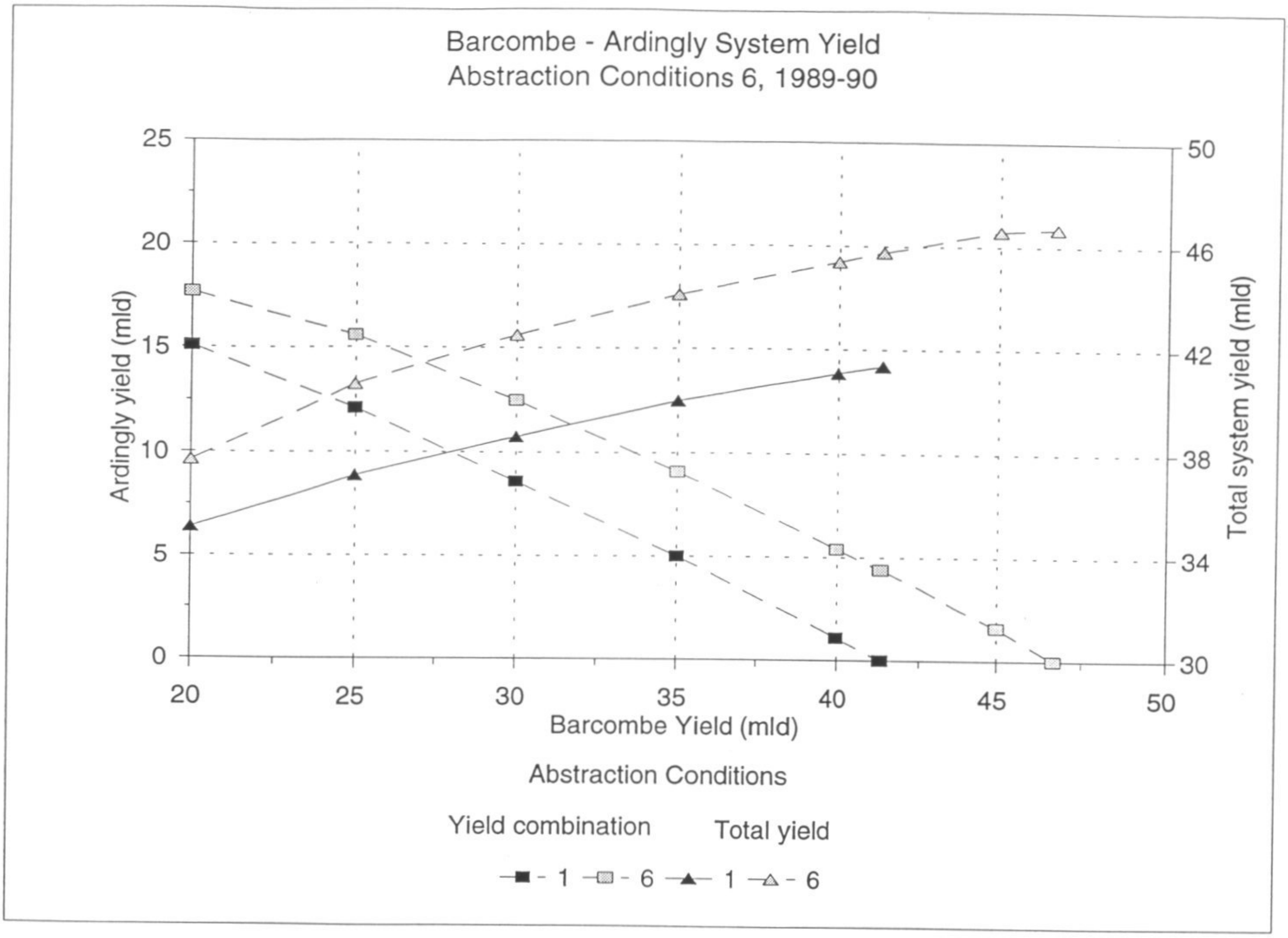

Abstraction conditions		1	6
MRFs and % abstraction	Barcombe	100% 18.2<Q<36.4 50% Q>36.4	100% 18.2<Q<36.4 50% Q>36.4
	Ardingly	60% Q>5.9	60% Q>5.9
Pump sizes	Barcombe	91	91
	Ardingly	45.5	45.5
Effluent return	upper	0	2
	lower	9	18

Sussex R. A. (1970)

Water for Sussex

Table 2.7.8

RESOURCE AREA C4 – RIVER OUSE (428 sq.Km)

EFFLUENT DISCHARGES

LOCATION	WORKS	DRY WEATHER DISCHARGE M^3/D
TQ 378245	SCAYNES HILL	2,160
TQ 464205	UCKFIELD	1,160
TQ 496236	BUXTED	495
TQ 421219	NEWICK	395
TQ 456232	MARESFIELD	190
TQ 261290	HANDCROSS	170
TQ 335283	SHELLBROOK P.S. (Lagoon Eff.)	160
TQ 314284	BALCOMBE	140
TQ 336154	DITCHLING	135
TQ 350286	ARDINGLY	135
TQ 407276	DANEHILL	90
TQ 337284	ARDINGLY COLLEGE	80
TQ 422162	BARCOMBE CROSS	70
TQ 367162	PLUMPTON	70
TQ 383173	POUCHLANDS	70
TQ 375282	HORSTED KEYNES	65
TQ 520212	BLACKBOYS	60
TQ 358140	SCHOOL OF AGRICULTURE	55
TQ 280274	STAPLEFIELD	55
TQ 499200	FRAMFIELD	55
TQ 322340	WORTH PRIORY	55
TQ 407136	COOKSBRIDGE	45
TQ 472263	FAIRWARP	45
TQ 250270	WARNINGLID	40
TQ 394173	SOUTH STREET, CHAILEY	30
TQ 303267	BROOK STREET	25
TQ 370248	GT. WALSTEAD SCHOOL	25
TQ 332314	WAKEHURST PLACE (Discharge into U/G)	25
	TOTAL	6,260

Mean Minimum Flow Equivalent = 0.07 cumecs

Equivalent Yield = 0.17 1/sec/sq. Km.