National Rivers Authority
(Anglian Region)

Low Flow Augmentation Study River Nar

Phase I, Stage I
Draft Planning Report
May 1990

Mott MacDonald

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CHAPTER 1

INTRODUCTION

1.1 Objectives

Mott MacDonald has been appointed by the National Rivers Authority (Anglian Region) to undertake a study of the Rivers Nar and Wensum. Both river catchments are located in north Norfolk. The rivers are fed by groundwater from the Chalk aquifer and are important sources of abstraction for public water supplies. The catchments are also attractive natural habitats with considerable recreational value. River flow augmentation from groundwater may therefore be necessary to maintain both water supplies and river levels.

The objectives of the study are twofold:

- a short term (Phase 1) assessment of available hydrological and hydrogeological data, leading to augmentation well site selection, engineering design and implementation to meet augmentation requirements in the event of continuation of a drought through the summer of 1990;

- groundwater/surface water interlinked catchment modelling to determine suitable long term augmentation requirements (Phase 2).

Environmental assessment forms an important part of the study in considering the impact of augmentation schemes on habitats, particularly woodland and wetland.

Project planning reports have been prepared following the initial stage of assessment in Phase 1. Separate reports have been prepared for the two catchments. This report for the River Nar catchment presents the following:

- an assessment of hydrological and hydrogeological data;

- prediction of river flows assuming continuation of a drought through the summer of 1990, with estimation of augmentation quantities to meet minimum target flows;

- recommendations for augmentation sites and pipeline routes to the river with costings;

- a programme for the Phase 1 augmentation works;

- discussion of data requirements for the longer term Phase 2 study.

1.2 Methodology

Hydrological and hydrogeological assessments have used pre-existing data provided almost totally by the National Rivers Authority (NRA). The NRA has provided river gauging and abstraction, groundwater level, water quality, test pumping and well abstraction data. Some additional hydrogeological information was available on a hydrogeological map of northern East Anglia. For the environmental assessment information was obtained from the NRA, the Nature Conservancy Council, the Norfolk Naturalists' Trust and the Norfolk Archaeological Unit.

For augmentation site location, topographical mapping at 1 : 25 000 scale was found most useful, as this shows a large number of water-related features and details of land boundaries, as well as contouring at 5 m intervals. Site visits were made by hydrogeological, engineering and environmental staff in selecting recommended augmentation sites from an initial larger number of options determined in a desk study.

In costing augmentation schemes, typical rates were used from other recent engineering schemes involving similar materials or components. For some items budget rates were obtained through inquiries to contractors or suppliers.

CHAPTER 2

HYDROLOGY

2.1 Catchment Description

The Nar catchment upstream of Marham gauging station has an area of 153.3 km^2. It is located south-east of King's Lynn and drains in a westerly direction (see Figure 2.1). The stream length from the point where the river rises at Mileham to the gauging station is about 32 km with a drop in elevation of some 80 m. Mean annual catchment rainfall is about 675 mm.

The flow in the river is heavily dependent on the baseflow contribution from the underlying chalk aquifer. Evidence of this is seen from the annual baseflow index which, using the Flood Studies Report technique (NERC, 1975), was estimated to average 0.87. Consequently throughout the summer months the flow in the river consists largely of baseflow contribution from groundwater controlled by piezometric levels within the catchment.

2.2 Abstraction

Abstraction of water from the river for public water supply is governed by a licence dating back to 1967 which was amended in June 1974. The licence allows for a maximum daily abstraction of 6.818 tcmd (thousand cubic metres per day) and a maximum annual abstraction of 2 489 tcma (thousand cubic metres per annum). This abstraction takes place upstream of the gauging station at Marham. Currently there is no prescribed minimum flow at the gauging station although a residual flow of 0.05 m^3/s is mentioned in connection with licensing. A greater proportion of abstracted water from within the catchment comes from groundwater sources. Groundwater abstractions within the catchment would be expected to influence the baseflow above Marham.

2.3 Data Availability and Quality

Surface water data available at the time of carrying out the investigation is summarised in Table 2.1. In addition some spot flow measurements were available.

A graphical plot of the mean daily flows against time revealed that prior to 1970 there had been a problem with the recording device which at certain times would give a constant reading of stage. Significant examples of this occurred in 1955, 1959 and 1966 (see Appendix 1). In subsequent analyses it was felt that these data problems would have a small but not too significant effect on results.

Figure 2.1

River Nar-Location Map

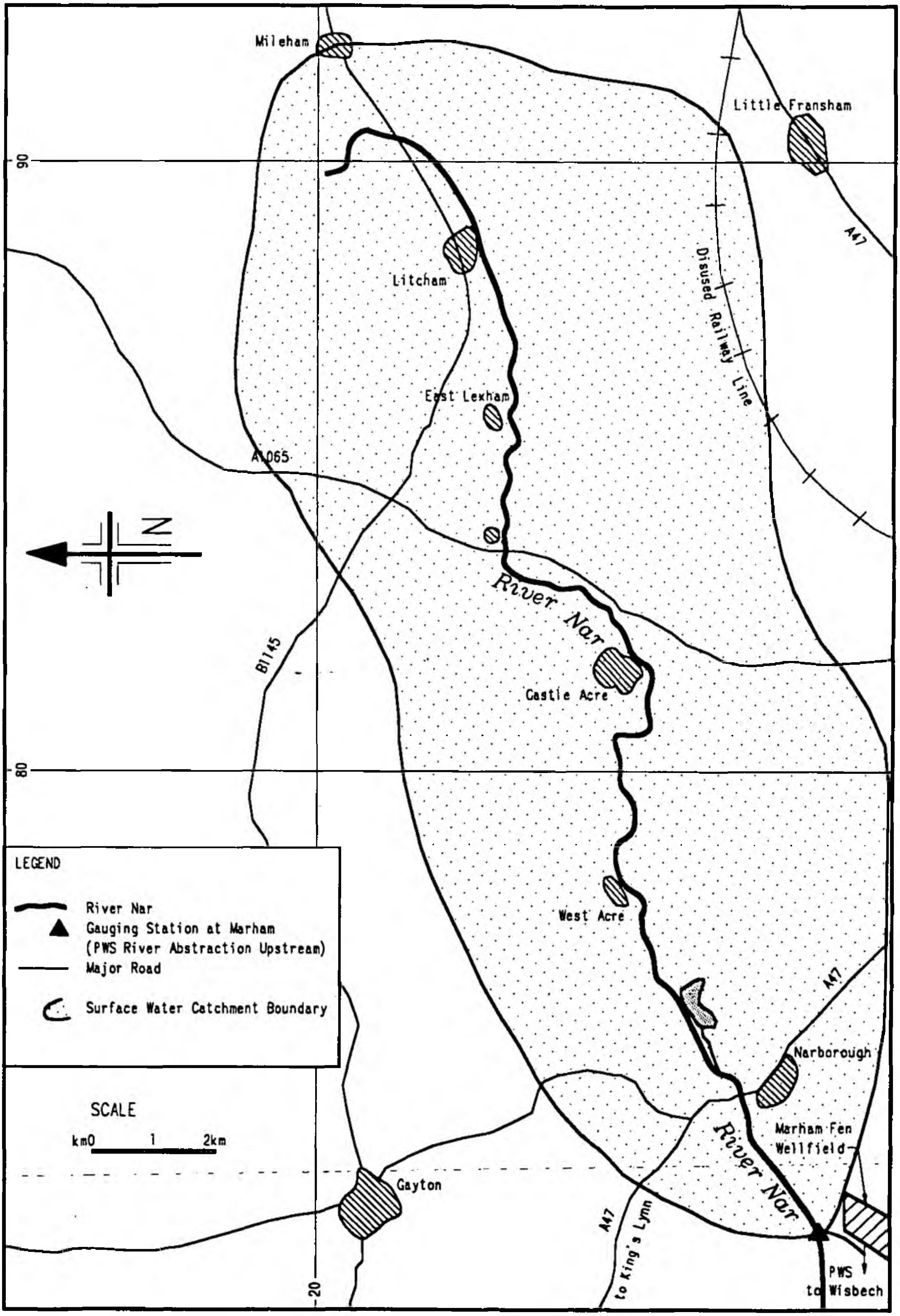


TABLE 2.1

Available Surface Water Data

Type of data	Gauging station	Data available	
		From	To
Mean daily flow	Marham	Sep 1953	Mar 1990
Daily abstractions	Marham	Jan 1971	Dec 1980
Monthly abstractions	Marham	Jan 1981	Dec 1988
Monthly rainfall	Various	Jan 1969	Dec 1989

2.4. Data Analysis

2.4.1 Trend Analysis

Trend analysis was carried out on the river flow data in order to determine:

- whether there is any evidence that low flows are becoming more frequent with time;
- whether groundwater abstraction might be significantly influencing the river flows.

Several statistical tests were carried out on the annual 'naturalised' river flow data. The results of these tests (see Appendix 2) and also a plot of the variation in annual mean flow (Figure 2.2) indicated that there was no statistical evidence to support the hypothesis that there are any trends caused either by climatic changes or variations in groundwater abstraction.

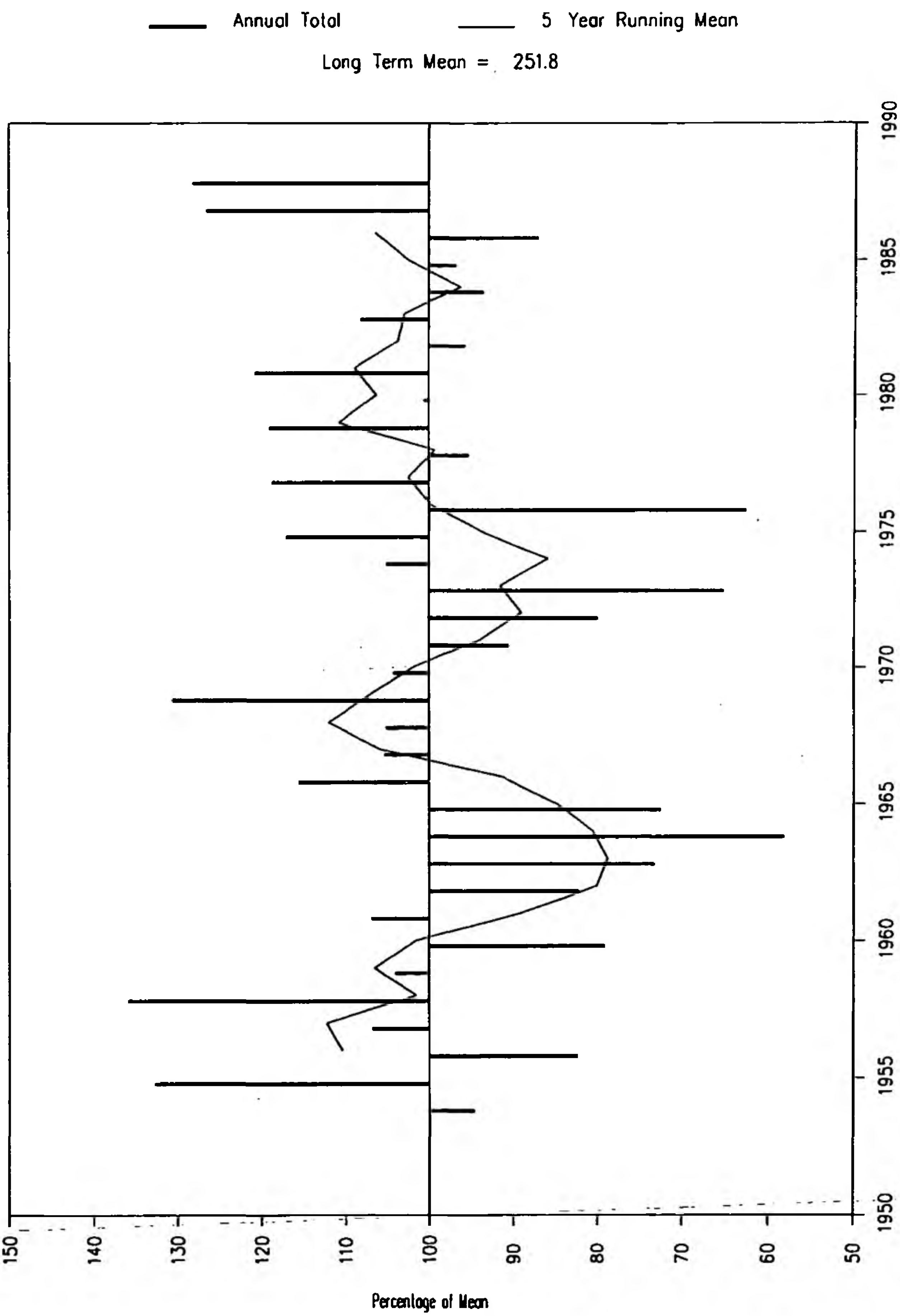
2.4.2 Flow Duration Curve

Frequency analysis of flows was carried out in order to determine an appropriate statistically based target low flow at which augmentation might commence. Flow duration curves were drawn using all the available data, having 'naturalised' the data by adding together the gauged flows and the abstractions (Figures 2.3, 2.4 and 2.5). From this analysis the flow that is exceeded 99% of the time in August (0.3 m^3/s) was selected as a potential target flow.

FIGURE 2.2

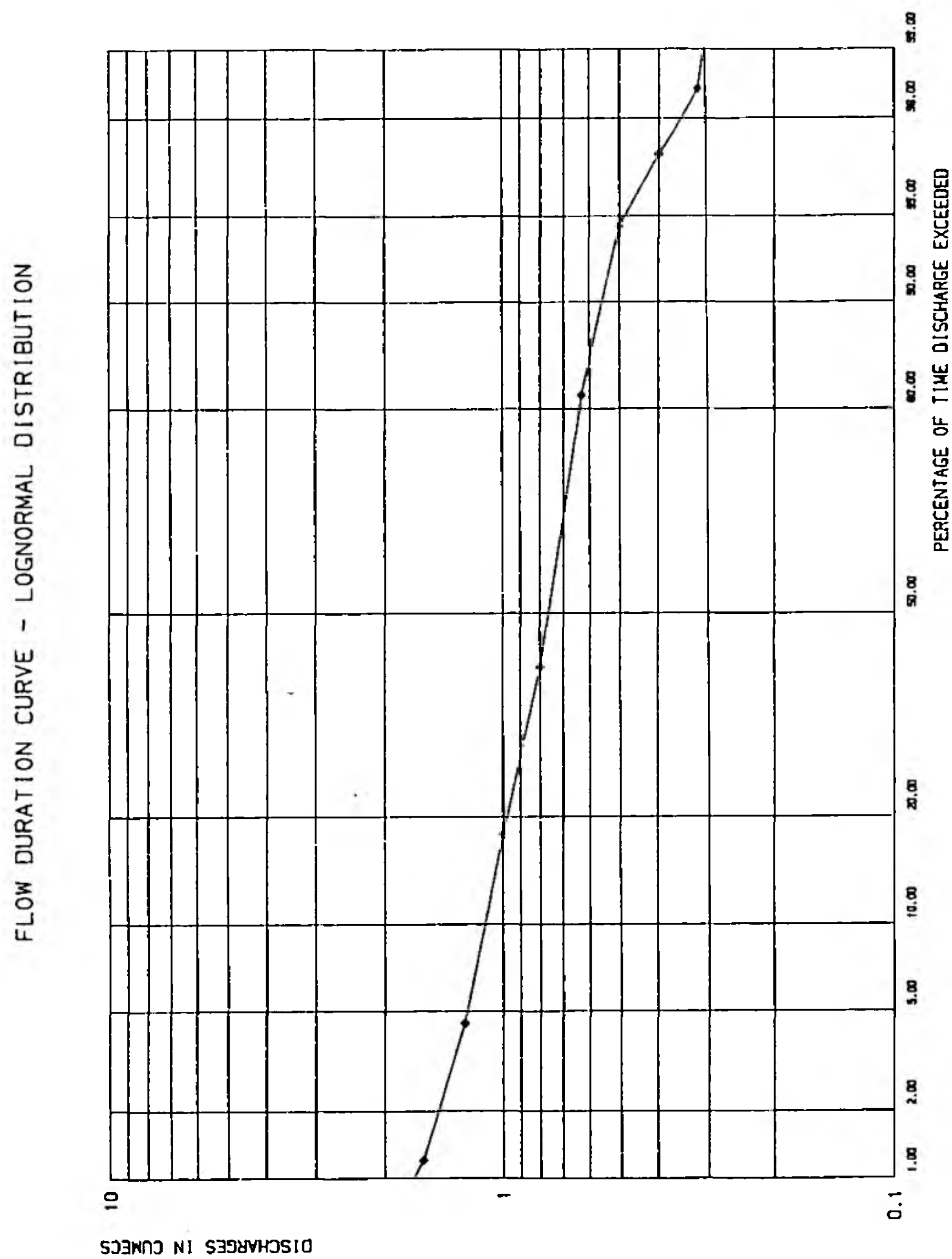
ANNUAL SUMMER RUN-OFF

RIVER NAR, MARHAM



Flow Duration Curve for August Flows

DAILY NATURALISED DISCHARGES (CUMECS)
RIVER NAR AT MARHAM (AUGUST FLOWS)



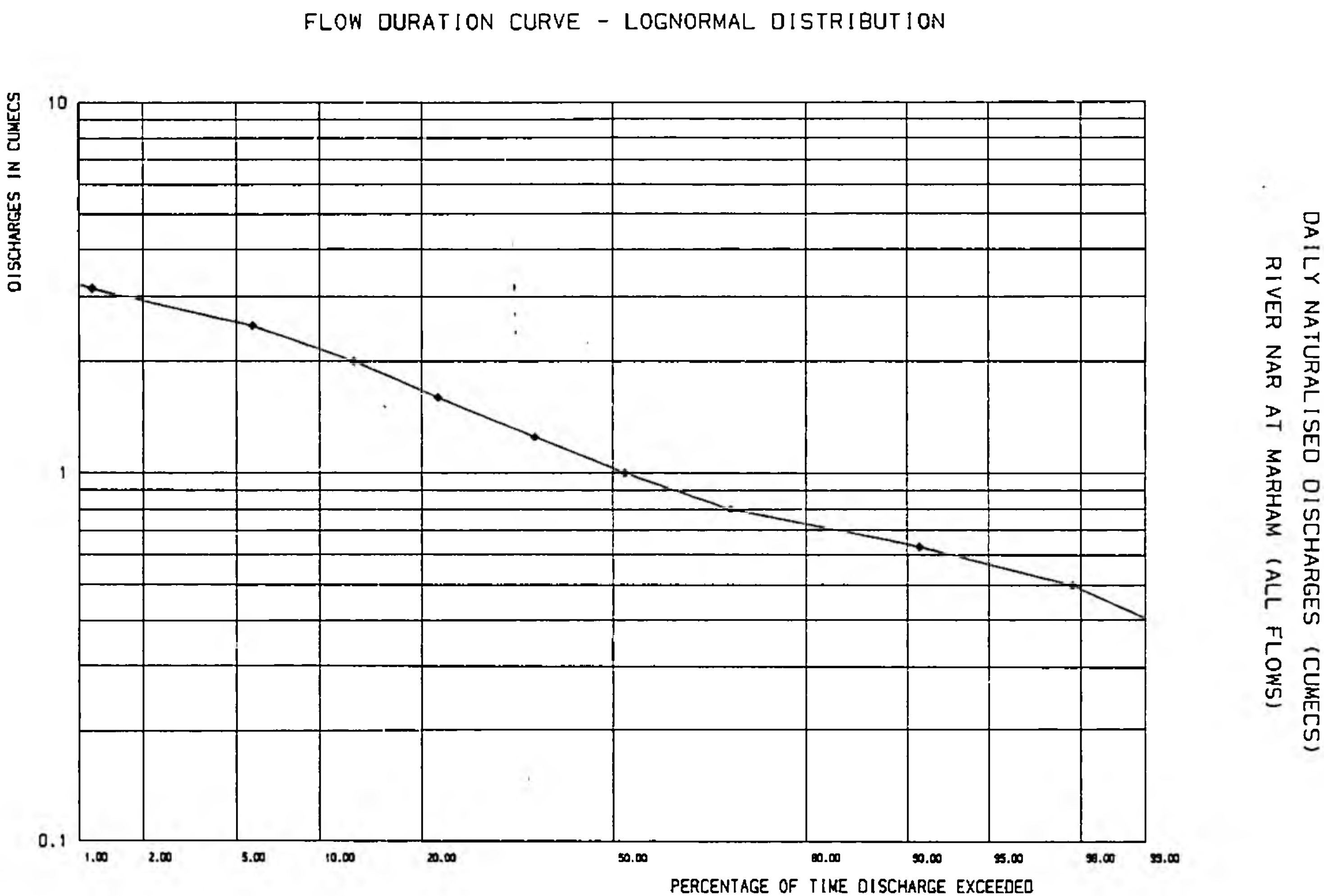
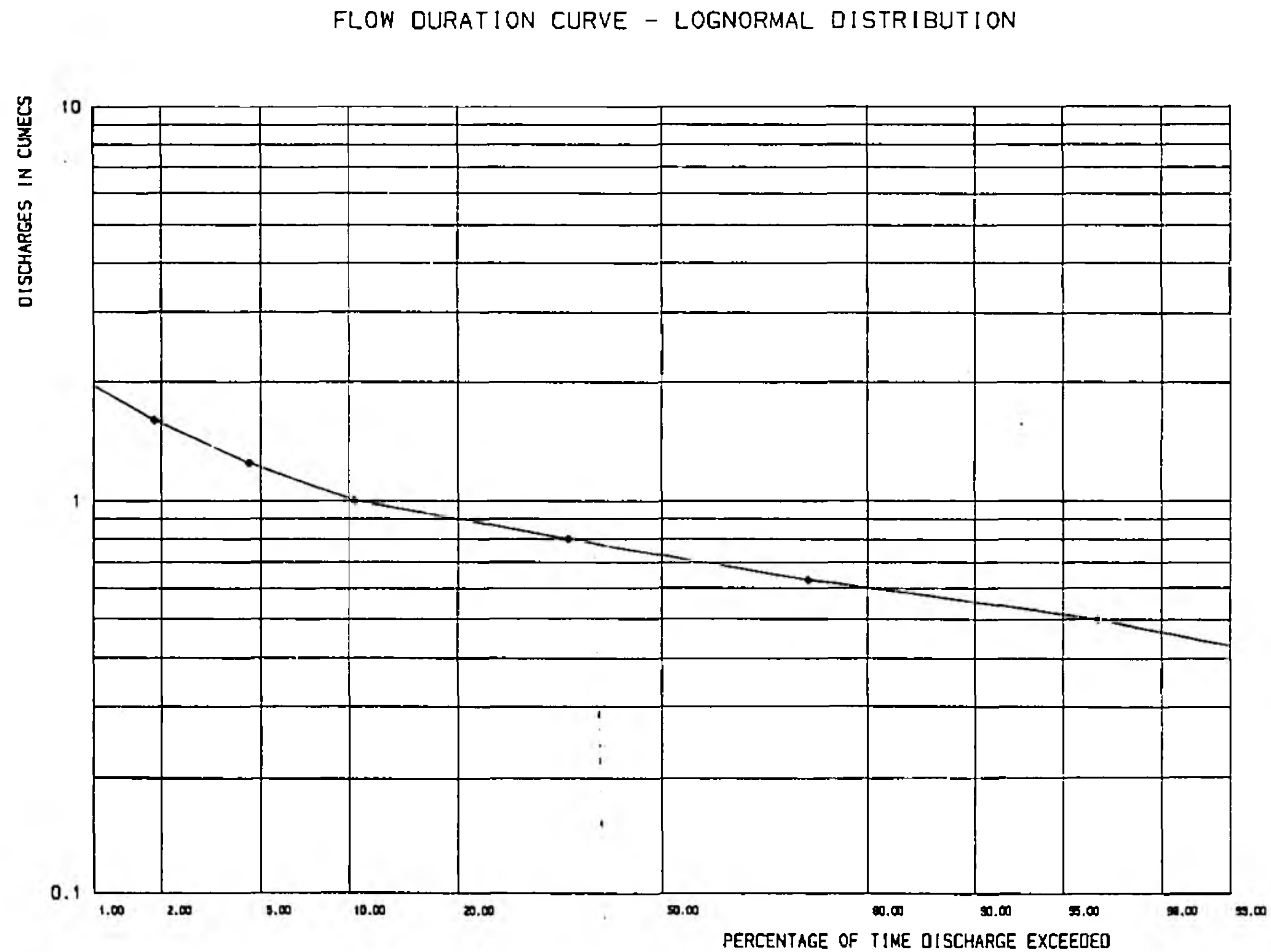


Figure 2.4

Flow Duration Curve for all Flows



DAILY NATURALISED DISCHARGES (CUMECS)
RIVER NAR AT MARHAM (SEPTEMBER FLOWS)

Flow Duration Curve for September Flows

Figure 2.5

2.4.3 Recession Curve Analysis

Naturalised mean daily flow data were analysed using computer software which fits recession curves to selected data, based on Horton's equation:

$$Q(t) = a \exp(-kt^{b})$$

where Q(t) is the naturalised flow at time t days and a, b and k are all constants which are fitted by exponential regression. The results of fitting the equation to many different years of data were compared and indicated some variation in predicting flows depending on the year selected. Two possible reasons for these variations are the quality of streamflow data when the river flows are low and the increased effect of groundwater abstraction variations on recession curves during periods of low flow. It was decided because of these variations that data for 1976, the year when the lowest flow on record occurred, should be used in order to predict low flows for 1990. A similarity is seen between 1976 and 1990 in the fact that in both cases rainfall in the preceding winter months was exceptionally low.

The data that were utilised in plotting the 1976 recession curve are shown in Figure 2.6. A translation of the curve along the x axis showed that it provided a good fit to the data selected. The constants of the recession equation were:

$a = 0.99$
$k = 0.0022$
$b = 1.31$

2.4.4 Estimation of Augmentation for 1990

The 1976 recession curve was superimposed on a plot of the 1990 data, which in the absence of abstraction data for 1990, were naturalised using the average abstractions in 1976 for the months of January, February and March (Figure 2.7).

Three potential targets were set for the minimum allowable flow in the river in 1990. These were:

(i) the lowest flow on record plus the legal abstraction rate

$$= 0.140 + 0.079 = 0.219\ m^3/s$$

(ii) the lowest 'naturalised' flow on record (24 August 1976):

$$= 0.140 + 0.103 = 0.243\ m^3/s$$

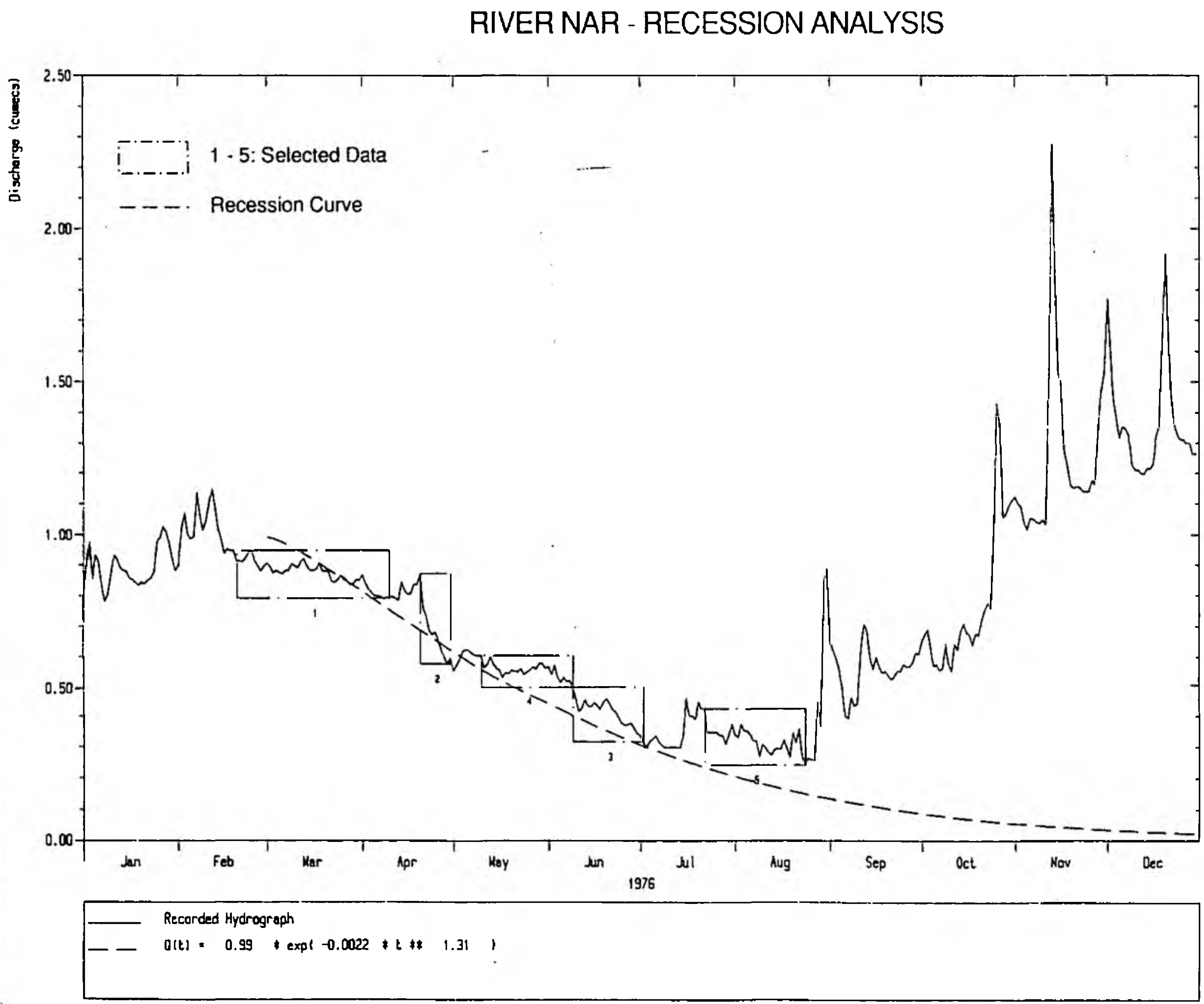


Figure 2.6 Derivation of Recession Curve

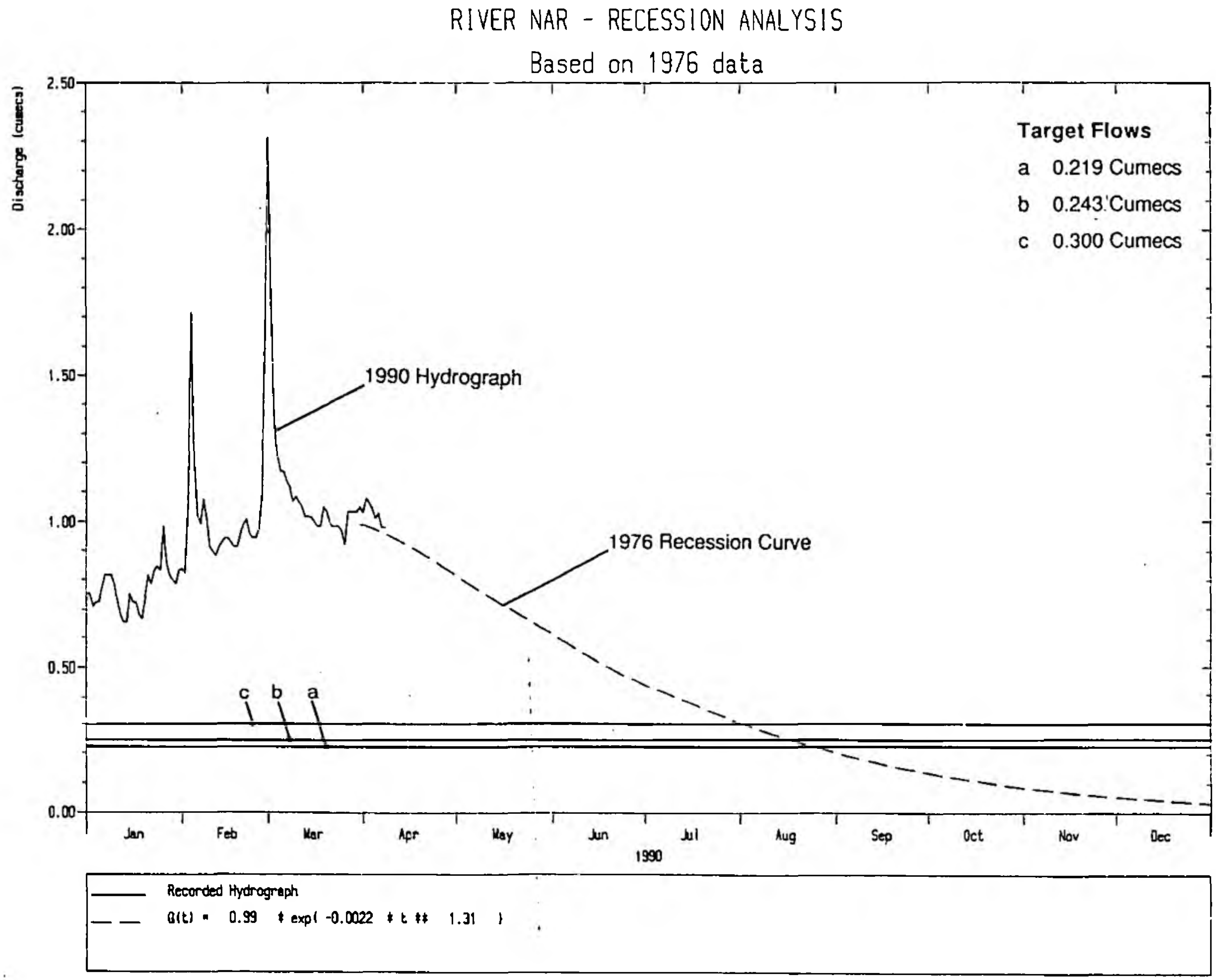


Figure 2.7

Predicted Recession for 1990

(iii) the naturalised flow that is exceeded 99% of the time in August

$= 0.3\ m^3/s$

Based on these potential target flows the pumping rates for augmentation were estimated for periods when the recession curve went below the target flow. Results are shown in Table 2.2.

TABLE 2.2

Augmentation Requirements

Target flow (m^3/s)	Dates	Augmentation pumping rate (m^3/s)	Augmentation pumping rate (tcmd)
0.219	25 - 31 August	0.010	0.9
	1 - 30 September	0.056	4.8
	1 - 31 October	0.114	9.8
	1 - 30 November	0.153	13.2
0.243	18 - 31 August	0.023	2.0
	1 - 30 September	0.080	6.9
	1 - 31 October	0.138	11.9
	1 - 30 November	0.177	15.3
0.300	2 - 31 August	0.086	7.4
	1 - 30 September	0.136	11.8
	1 - 31 October	0.186	16.1
	1 - 30 November	0.229	19.8

The results indicate that for any one target flow the required amount of pumped water increases greatly with time. Therefore the expected time at which the water levels may start to recover in the river is significant in determining how much augmentation is needed. Table 2.3 indicates the months of the year in which recovery of water levels took place in the river for the years of record. It should be noted that in 1976 the water levels started to recover in late August. In the year with the second lowest flow on record (1959), the recession curve was much less steep than for 1976, with a lowest flow of 0.311 m^3/s, which is above all three target flows. From this, one may conclude that it is reasonable to aim to provide augmentation up to around the middle of September rather than through to the later months.

TABLE 2.3

River Level Recovery: 1954 to 1988

Recovery month	Years									
July	68									
August	54	56	57	60	61	63	65	66	76	87
September	55	58	67	73	74	81	82	84		
October	62	70	71	72	80	85	88			
November	59	69	75	77	79	83	86			
December	64	78								

Note: Lowest flows on record were recorded in 1976 and 1959.

CHAPTER 3

HYDROGEOLOGY

3.1 Geology

The River Nar catchment, from Marham to the headwaters at Mileham, is dominated by Chalk of Upper Cretaceous age. The Chalk outcrops at Marham and gently dips from west to east (angle of dip < 1°), with the Chalk surface generally following the surface topography. This Chalk is characterised by three distinct layers:

- Upper Chalk (varying in thickness from 250 to 390 m) is mainly soft, white limestone with bands of flint nodules throughout. The uppermost 5 to 10 m of Upper Chalk often consists of soft putty chalk with a low permeability. Below this the major water-bearing fractures and bedding planes are generally encountered over the top 30 to 60 m of competent formation.

- Middle Chalk (50 to 82 m thick) is largely soft, white limestone with flint nodules in the upper two-thirds;

- the Lower Chalk (15 to 41 m thick) consists predominantly of hard, grey limestone overlying lower Cretaceous Gault Clay, Carstone and Sandringham Sands.

- Between the Middle and Lower Chalk, Melbourne Rock has been encountered in many boreholes. This is a hard, brittle band of chalk 1 to 2 m thick, often with extensive fissuring.

Figure 3.1 details the surface geology of the River Nar catchment.

Lower Cretaceous formations, underlying the Chalk, outcrop to the west of the Chalk. At Marham, Lower Chalk outcrops in an area extending to within 1 km of the River Nar. Middle and Upper Chalk is present between Narborough and Castle Acre. Further to the east, boulder clay partially confines the Chalk aquifer.

In the river valley, a mixture of sands and gravels were deposited during glacial periods. In many instances within north Norfolk, glacial activities have formed buried channels within river valleys. Such a channel has been encountered at a number of boreholes to the north of the river (at Castle Acre and West Acre). The channel has a maximum known depth of 80 m measured from ground level, and generally follows the course of the present River Nar.

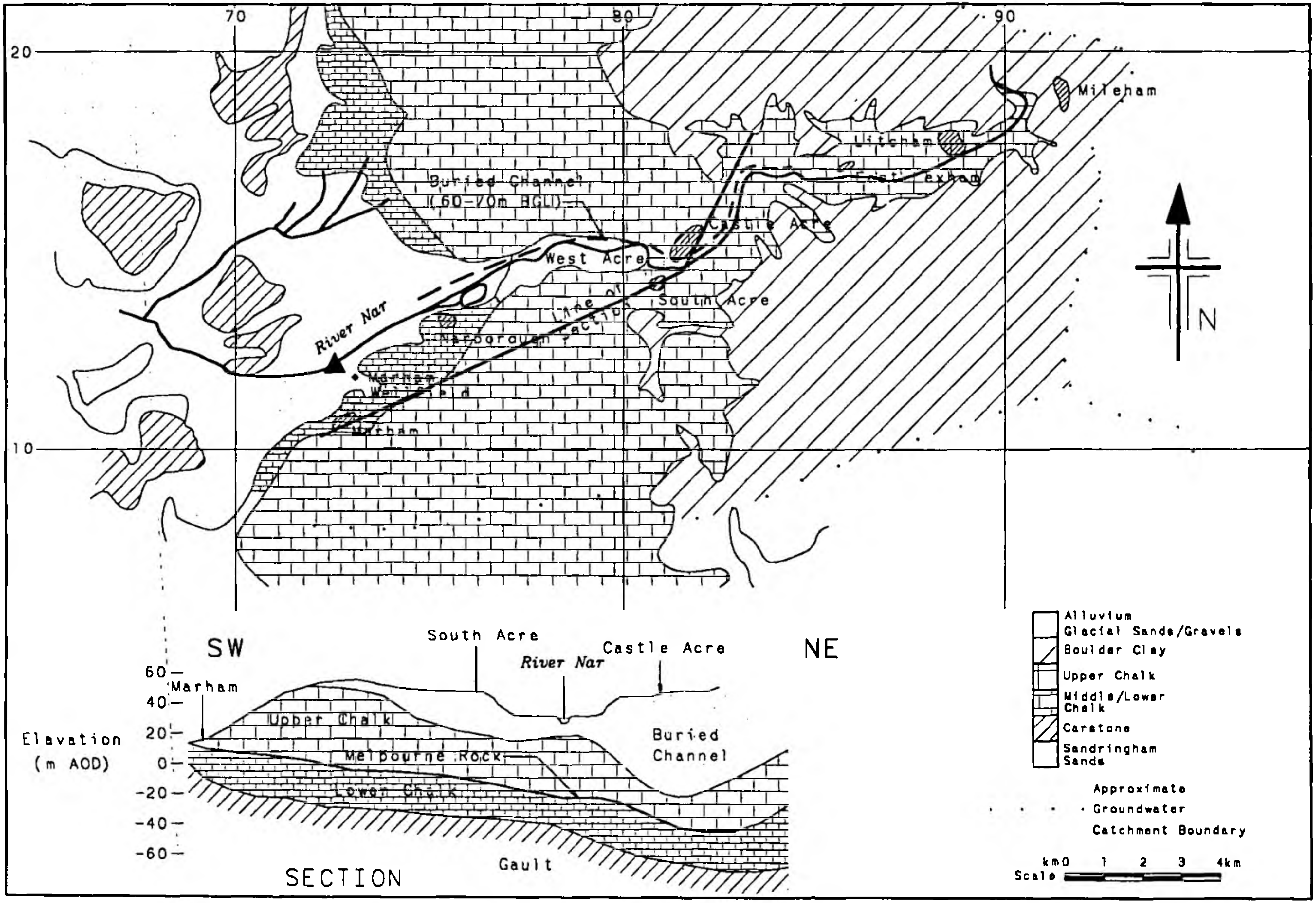


Figure 3.1 Geology

3.2 Groundwater

The Chalk aquifer is the most important groundwater resource within the catchment. The aquifer is unconfined in the west and partially confined by Boulder Clay in the east.

A number of short pumping tests have been carried out by the NRA during licence evaluations over the past 20 years. As expected, the yields from the Chalk aquifer are highly variable. However, yields are generally greater within river valleys. This increase in yield has been produced by concentration of flow near the river, leading to preferential solution of the Chalk in the valley which enhances permeability (Price, 1987).

To the north of the River Nar a buried channel has been encountered at a number of boreholes (West Acre and Castle Acre). The channel extends to a depth of 80 m below ground level. Various papers (Cox and Nickless, 1971 and Cox, 1961) have described these buried channels as being produced by glacial action with deposition produced by sub-glacial melt water. The infill has low permeability and effectively acts as an impermeable barrier. This may account for the very low yields (around 100 m^3/d) from disused PWS boreholes at West Acre and Castle Acre.

To the north of the river at Marham, a secondary aquifer exists in the Sandringham Sands. This is an unconfined aquifer with low storage characteristics. Consequently, pumping from Sandringham Sands results in very high drawdowns.

3.3 Piezometry

The NRA collects monthly water levels from the Nar catchment through a network of observation piezometers. These are indicated in Figure 3.2 and detailed in Table 3.1.

From Figure 3.2 it can be seen that the majority of observation piezometers are located on the valley sides rather than within the river 'floodplain'. It is therefore very difficult to contour piezometric data across the floodplain. The minimum groundwater levels for 1989 and maximum winter groundwater levels have been plotted in Figure 3.2. From this it can be seen that in the upper catchment east of Castle Acre groundwater tends to flow in the direction of the river valley. Downstream groundwater tends to flow from upland areas directly to the river. There is little variation in groundwater gradient and direction of flow between summer and winter.

Figure 3.2

Nar Catchment Hydrogeology

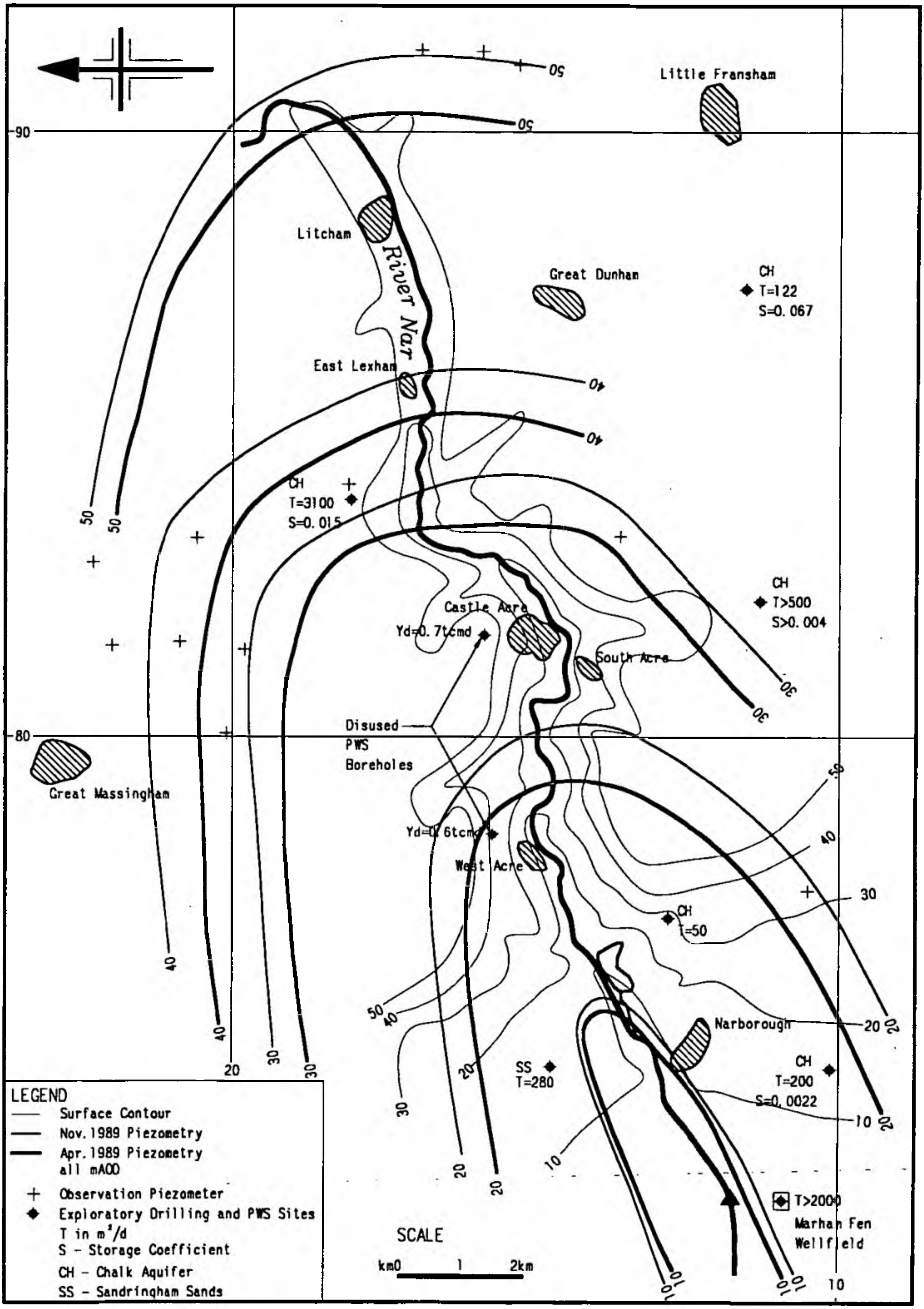
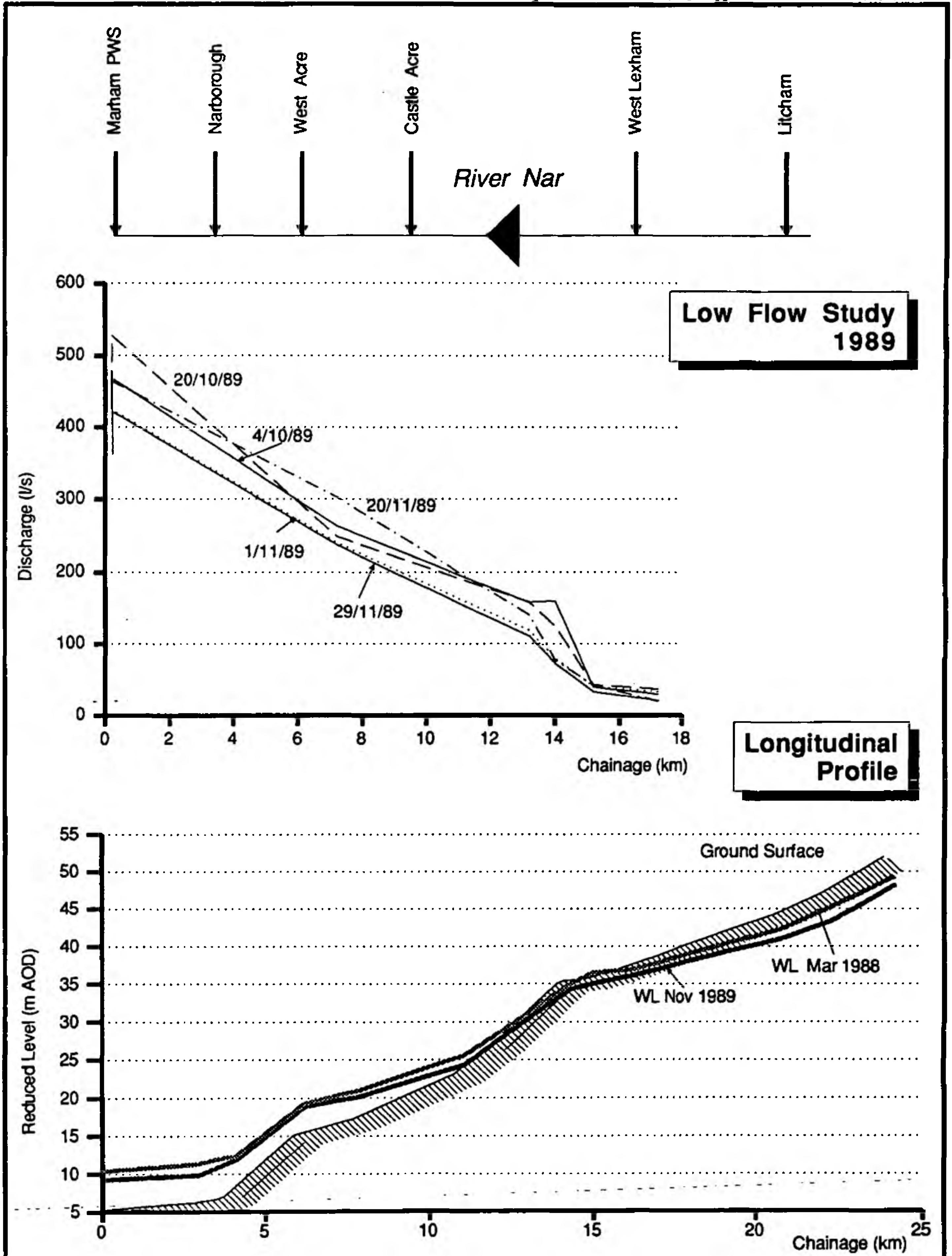


TABLE 3.1

Observation Piezometer Network

NRA reference number	Grid reference	Datum (m AOD)	Records
TF 71/01	TF 748 126	14.79	1972 to Date
TF 71/02	TF 786 104	67.99	1970 to Date
TF 71/03	TF 775 106	48.15	1950 to Date
TF 71/05	TF 743 124	10.88	1950 to Date
TF 71/77	TF 7013 1414	14.51	1985 to Date
TF 81/01	TF 885 117	74.01	to 1985
TF 81/03	TF 823 171	64.35	1972 to Date
TF 81/04	TF 808 191	69.84	1970 to 1984
TF 81/05	TF 877 101	52.01	1973 to Date
TF 81/06	TF 848 118	68.49	? to Date
TF 81/10	TF 814 197	80.21	? to Date
TF 81/11	TF 845 182	69.92	? to Date
TF 81/13	TF 888 178	56.89	1971 to Date
TF 81/15	TF 894 191	57.16	1971 to Date
TF 81/19	TF 812 178	72.64	1950 ? to Date
TF 81/22	TF 8286 1002	70.55	1981 to Date
TF 81/116	TF 8328 1370	85.47	1984 to Date
TF 82/01	TF 816 295	70.20	1971 to Date
TF 82/02	TF 854 222	71.53	1971 to 1982
TF 82/04	TF 826 282	69.07	1971 to Date
TF 82/05	TF 832 204		1971 to Date
TF 82/06	TF 889 210		1973 to Date
TF 82/07	TF 800 200		1972, 1982 to Date
TF 82/08	TF 815 207		1972 to Date
TF 91/01	TF 9109 1537		1978 to Date
TF 91/02	TF 913 160		Pre 1980 to Date
TF 91/133	TF 913 170		Pre 1980 to Date

Figure 3.3
River Nar: Low Flow Study 1989 & Longitudinal Section



Groundwater and river bed profiles are compared in Figure 3.3. This indicates that the river gains from a point between Castle Acre and West Lexham. Upstream, groundwater levels are below the valley surface, indicating that the river is not fed from groundwater. However current metering carried out by the NRA during October and November 1989 showed that the river was gaining from groundwater throughout its length, although this would be partially caused by inflow from tributary catchments. The observation network may not be adequate therefore to assess accurately the influent and effluent characteristics of the river. It can be concluded at this stage that the river is at least gaining in a reach extending up to 10 km from Marham gauging station.

3.4 Existing Boreholes and Aquifer Properties

At Marham, a public water supply wellfield has been in operation under licence since the 1960s (although prior to licensing, it is suspected that abstraction was taking place). The wellfield, consisting of four boreholes, exploits a thin, highly permeable layer of Lower Chalk between 6 and 12 m thick underlain by grey Gault Clay. The boreholes are sited on natural spring lines now dried up under abstraction conditions. Yields are exceptionally high considering the saturated thickness of the aquifer: during summer the saturated thickness is reduced to only 3 to 5 m. Yields vary from 2 000 m^3/d to 3 000 m^3/d with drawdowns ranging from 1.0 m to 2.2 m. The boreholes are 914 mm in diameter. The average aquifer transmissivity has been calculated from test pumping as approximately 2 800 m^2/d (Sir M MacDonald & Partners, 1989). However, this order of transmissivity cannot account for the very high yields achieved. The high yields may be due to direct recharge from the river, although there was no indication of this occurring during test pumping.

The discharge and licensed quantities are shown in Table 3.2 for Marham. The licences for two abandoned public water supply boreholes have recently been revoked. These boreholes are situated at West Acre (TF 779 151) and Castle Acre (TF 821 153). They are low yielding boreholes 150 mm in diameter producing at most 3 to 5 l/s. Both boreholes were drilled on the edge of the buried channel, which may have limited the yields. It is not known why the boreholes were abandoned.

The other licensed boreholes are mainly for agricultural and domestic use. The licensed quantities are shown in Table 3.3.

TABLE 3.2

PWS Borehole Abstraction Records

	Marham			West Acre			Castle Acre		
Year	Winter	Summer	Total	Winter	Summer	Total	Winter	Summer	Total
1970/71	2 875	2 446	5 321	4.2	4.5	8.7	15.8	19.6	35.4
1971/72	2 806	2 610	5 416	2.7	4.3	7.0	18.8	19.6	38.4
1972/73	2 397	2 433	4 830	3.5	14.8	18.3	5.6	-	5.6
1973/74	2 827	2 473	5 300	21.3	24.0	45.3	-	-	-
1974/75	3 315	3 248	6 563	25.1	26.9	52.0	-	0.9	0.9
1975/76	2 582	2 610	5 192	23.6	21.4	45.0	-	-	-
1976/77	3 182	3 171	6 353	16.9	20.6	37.5	-	-	-
1977/78	3 138	2 507	5 645	16.9	21.0	37.9	-	-	-
1978/79	3 166	2 977	6 143	30.3	28.3	58.6	-	-	-
1979/80	2 965	2 995	5 960	27.9	28.4	56.3	-	-	-
1980/81	2 993	3 251	6 244	24.6	24.1	48.7	-	-	-
1981/82	3 109	2 838	5 947	22.0	23.0	45.0	-	-	-
1982/83	2 879	2 998	5 877	22.0	28.3	50.3		ABANDONED	
1983/84	2 690	2 965	5 655		ABANDONED				
1984/85	2 816	2 841	5 657						
1985/86	2 687	2 775	5 462						
1986/87	2 762	3 066	5 828						
1987/88	3 247	2 785	6 032						
1988/89		Not available							
Average	2 913	2 833	5 746						
Licensed			9 541			9.27			29.3

Note: All units: 1 000 m^3
winter: November to April
summer: May to October

TABLE 3.3

Groundwater Licences - Nar Catchment

Use	Number of licences	Licensed quantities Annual (1 000 m^3)	Daily (m^3)	Season
Public Water Supply	1	9 54.0	2 613.6	All Year*
General Agriculture/ Domestic	36	172.8	1 085.8	All Year
Irrigation	20	2972.3	34 343.0	Summer
Industrial	3	1402.2	5 127.5	All Year

Note: * combined with river abstraction licence at Marham.

Many of the above boreholes have been test pumped to assess yields and aquifer properties. Results of some of these tests are shown in Figure 3.2.

Yields and aquifer properties are highly variable throughout the catchment area. The transmissivity varies from 50 m^2/d to more than 3000 m^2/d. Yields are similarly variable. Generally, though, it appears that potential borehole yields will be higher in or close to the river valley than on the high ground.

CHAPTER 4

AUGMENTATION WELL SITES

4.1 Selection Criteria

The following site selection criteria have been considered in choosing sites:

- minimising cost by reducing distance from well/wellfield to the river;

- constructing wells with sufficient yields of good quality water;

- wells should be located so as to minimise effects on existing groundwater flows to the river: wells should not draw directly from the river or affect natural spring flows;

- effects on natural habitats should be minimised: these include effects brought about through disruption during scheme construction and by pumping to augment river flows;

- wells should be located in valley areas where enhanced fissuring and more highly transmissive Chalk would be expected;

- wells should discharge to gaining reaches of the river;

- abstraction for augmentation should cause minimal interference with existing groundwater abstractions;

- land readily available to the NRA should be utilised where possible;

- there should be clear and easy access to the river from well/wellfield areas.

There are few data available from which the distribution of yields from the Chalk can be established. However, from evidence available from public water supply sources and some abstraction wells, it would seem that a yield of 5 tcmd should be obtainable in areas of above average Chalk transmissivity. It has therefore been assumed that 5 tcmd total could be obtained from two wells spaced 500 m apart at each site.

Sites have been sought within dry side valleys adjacent to the main river valley, at about 1 to 2 km from the river. There is general evidence that valley sites within Chalk are higher yielding than intervalley uplands, as fissuring has developed to a greater extent through concentration of surface and sub-surface flow. Abstraction from dry side valleys should also minimise effects on springs. A distance of 1 to 2 km from the river should create a drawdown of only a few centimetres, perhaps only millimetres in the vicinity of any wetland surrounding the river. Precise drawdown effects could only be obtained by siting observation wells in wetland areas.

The area of highly permeable Lower Chalk in the area of Marham and Narborough was considered initially. The Lower Chalk provides very large yields at Marham. However the outcrop area is very limited with the possibility already existing of the wells drawing river water through the Chalk. This area was therefore discounted as a potential augmentation site.

Unfortunately, to the north of the Nar, the Lower Chalk outcrops at 2 to 4 km from the river, making pipeline routing difficult and expensive.

Existing wells at Castle Acre and West Acre were too low yielding and close to the river to be worth considering. No other suitable sites were readily available to the NRA. The Castle Acre and West Acre well data indicate that a buried glacial channel lies within the river valley, mainly to the north of the present river course. The buried channel may act as a barrier to Chalk groundwater flow, deflecting it westward and preventing it contributing directly to the river in this area. With a view to utilising this groundwater, dry valley sites were sought on the north side of the river beyond the buried channel. Gauging in the summer of 1989 indicated that the Nar gains from groundwater throughout its length.

4.2 Potential Sites

Four potential sites were chosen, namely:

- Broom Covert, West Acre;
- Warren Farm, West Acre;
- Fiddler's Green, Castle Acre
- West Lexham.

The sites, all in side valleys, are shown on Figure 4.1. On a field reconnaissance visit, Fiddler's Green and West Lexham both proved to have springs and wetland located at the foot of the side valley. Broom Covert and Warren Farm sites (Figure 4.2) are both located within marked valley features which are almost certainly related to the underlying Chalk surface.

Figure 4.1

Possible Augmentation Sites

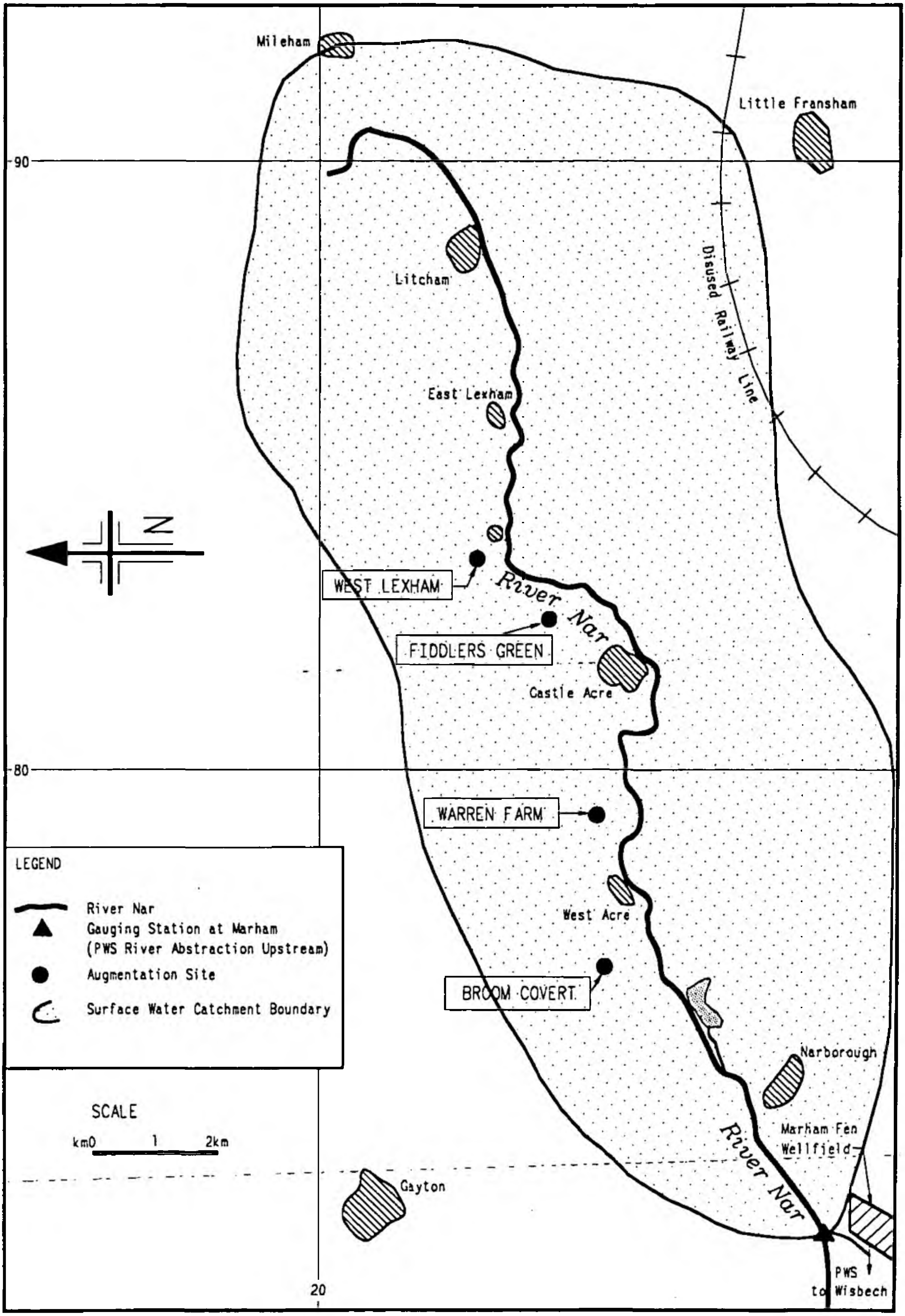
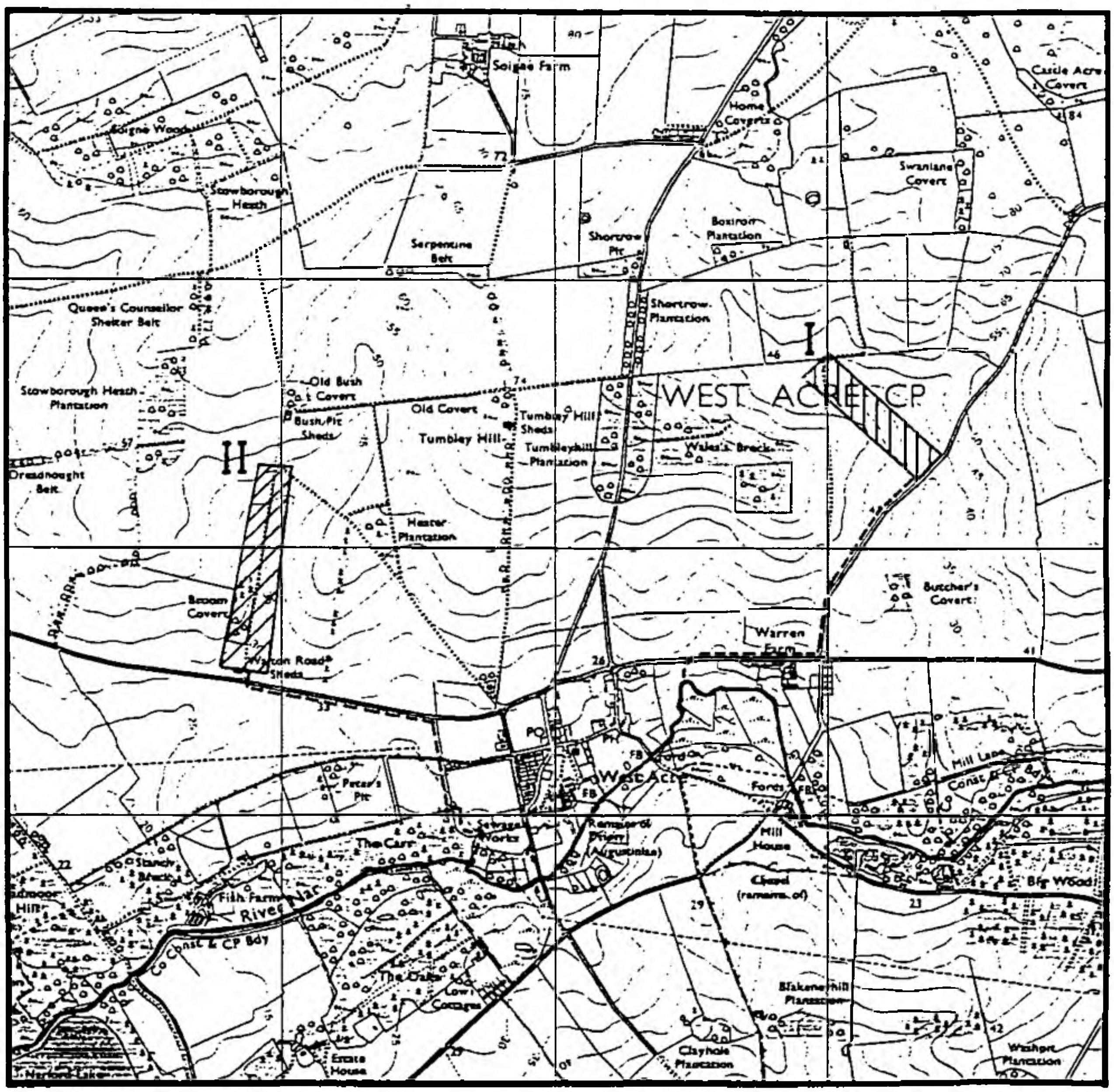


Figure 4.2

Proposed Augmentation Sites



N

SCALE

km 0.5 0 0.5 km

LEGEND

WELLFIELD

PIPELINE ROUTE

RIVER NAR

I : BROOM COVERT, WEST ACRE

II : WARREN COVERT, WEST ACRE

4.3 Environmental Assessment

4.3.1 Criteria for Assessment

The environmental effects of this scheme broadly fall into three categories. The first concerns the immediate short-term effect of the siting and construction of the boreholes and associated pipe runs. The pipelines in particular may pass through mature hedge lines or woodlands, and other sensitive wetland or grassland habitats on route to the river. Secondly, the drawdown in the watertable caused by the boreholes may locally affect wildlife sites in the vicinity. For example, mature beech trees are particularly susceptible to changes in the watertable and die off as a result of watertable decline. Similarly, any wetland sites would be damaged by drawdown and the resulting drying out of the habitat. Thirdly, there is the long-term effect of pumping groundwater into the river which may alter the ecological balance. Both the Nar and Wensum are proposed as Sites of Special Scientific Interest by the Nature Conservancy Council on account of their ecological richness.

Pumping groundwater from Chalk may affect the vegetation types that exist over the clay catchment areas on the Wensum. It is not yet known what level of flow is required to sustain the ecological richness of the rivers in times of drought.

These long-term effects require detailed investigation which is outside the timespan of the Phase 1 study. They are therefore not covered in this report but would be dealt with in the Phase 2 study.

For this report, the assessment concentrated on possible drawdown effects and the impact of the pipeline routes. A nominal 1 km cone of depression was assumed around the proposed borehole location and a survey made within that area for potential habitats affected. It should be noted that the 1 km figure is fairly notional, since drawdown effects are difficult to predict. For instance, it is assumed that a woodland on a ridge would be less affected that one within a valley as depth to water is much greater on ridges. The actual size of the cone of depression may also vary (the Nature Conservancy Council assumes a 3 km diameter 'cone' around a borehole), but again it is difficult to accurately predict this effect.

Generally, it was found that the choice of dry side valley sites coincided with largely arable land uses, with minimal habitat affected within the immediate area of the proposed borehole. Of more immediate concern was the actual routing of the pipes, since wildlife interest, particularly wetland sites, increased in proximity to the river. Sketch plans showing wellfield areas, pipeline routes and discharge points have been prepared for schemes which are considered to be most reasonable on environmental grounds (Figure 4.2). (Sketch plans for the other schemes will be included in the final report.)

4.3.2 Assessment of Sites

(a) Broom Covert, West Acre

The borehole location is in a large arable area, with only a few small young coniferous plantations within 1 km of the site, of little wildlife value (Figure 4.2). On crossing the road, the pipeline route would cross several small pastures before entering a damp woodland adjacent to the river. The pastures are largely reseeded and of little wildlife value, but the enclosing hedges contain some fine mature trees and care should be taken to avoid these. The woodland belt next to the river has been noted as having some wildlife interest by the Norfolk Naturalists' Trust (NNT), and care will be needed in crossing it to minimise damage. The most acceptable route would be to cross the area close to West Acre, where the semi-natural woodland has been replanted with poplar trees and is therefore of less value.

(b) Warren Farm, West Acre

Again, the borehole location is heavily arable, but with two mature broad-leaved woods within the potential drawdown area, one of which has been rated by the NNT as being of interest (Figure 4.2). However, both exhibit very dry conditions within the woodland, which would indicate that further drawdown is unlikely to have a significant effect. It is proposed to run the pipeline along a road verge between Warren Farm and West Acre. The verge is sufficiently wide at this location. Crossing the road, the pipe would pass through a small area of pasture before entering the river.

(c) Fiddler's Green, Castle Acre

Extensive wetland is located at the foot of the side valley at Fiddler's Green. This could well be affected by drawdown due to abstraction as the wetland is likely to be springfed. The area contains two sites in particular which have been noted by the NNT as having wildlife interest, and is therefore less preferable than the two West Acre sites.

(d) West Lexham

The borehole would be sited in an arable area with minimal wildlife interest. The pipeline route, however, would pass through an area of semi-natural wet woodland which should be avoided. For environmental reasons this site is also less preferable than the sites at West Acre.

4.4 Engineering Feasibility

4.4.1 General

Each site has been visited to appraise its suitability with regard to the following elements:

- pipeline route;
- river discharge site;
- power supply.

Within the time available it has not been possible to contact the statutory authorities, landowners, occupiers or other organisations with an interest in the proposed development to determine if there are any major obstructions or difficulties to be expected at each of the proposed sites.

(a) Pipeline Route

Owing to the location of the proposed wellfields relative to the river discharge sites almost all the pipelines will run downhill for their entire length (refer to figure 4.2). Normally, this would be undesirable because of the negative pressures induced when the pumps are shut down; however, it is proposed that air valves are installed at appropriate locations along the route to prevent this.

Each pipeline route has been chosen to minimise the number of road and field crossings required and where possible to avoid developed areas. Each of the sites was examined to see if there were any suitable streams or drainage channels to transfer the water to the river minimising the length of pipeline required. All the streams and ditches located near to the wellfield sites had small or negligible flow and followed circuitous routes before meeting the main river. There is a high risk that were water discharged to a ditch during drought conditions, much of it would be blocked by reed growth and absorbed into wetland with very little reaching the intended discharge point.

Ditches do not generally fall within the NRA's 'main river' responsibility. If maintenance of a ditch is the responsibility of a local landowner then this could create difficulties if used for augmentation discharge.

(b) River Discharge Site

Because of the low level of dissolved oxygen normally present in groundwater it will be necessary to aerate the water prior to its discharge to the river.

(c) Power Supply

During a brief appraisal of each wellfield site the location of overhead power lines close to the site was noted.

(d) Permanent Scheme Implementation

Since the proposal stage, the validity of temporary pipeline construction has been re-assessed. If a temporary pipeline were to be installed above ground it would still be subject to the same statutory notices as an underground pipeline and would also require continuous compensation to the landowners or occupiers. It has been found that irrigation pipe which might be used on a temporary basis is not readily available in the quantities required, ie about 2 000 m per wellfield. The majority of the cost of a buried pipeline will be procurement, stringing, jointing, field and ditch crossings and road crossings rather than the excavation and laying, giving little financial saving for a surface pipeline. For these reasons it is felt that there is insufficient benefit to be gained from temporary construction and therefore a permanent pipeline is recommended.

4.4.2 Detailed Requirements of Possible Sites

(a) Broom Covert, West Acre

The wellfield would be located in arable land 500 m north of the unclassified road between West Acre and East Walton (Figure 4.2). The pipeline runs downhill for its entire length of approximately 2 090 m. There are six field boundaries to cross, together with one road crossing (unclassified, between West Acre and East Walton) and one bridleway. The discharge point into the River Nar would be approximately 300 m west of the road bridge to the south of West Acre. The pipeline route is predominantly through arable land with little disruption likely to domestic services. No power supply was evident at this site but there is an electricity transmission line some 700 m to the south of the wellfield.

(b) Warren Farm, West Acre

The wellfield would be located in arable land 750 m north of Warren Farm, West Acre (Figure 4.2). The pipeline would run downhill through the wellfield and then follow along a field boundary over the shallow crest of a hill and down towards the road at Warren Farm. The route then follows the road westwards either in the field (preferred) or in the verge before heading due south across the road and 75 m of pasture before discharging into the River Nar on the outside north bank of a meander. One minor road crossing and four field boundary crossings will be required. The total pipeline length is 2 100 m, the route is predominantly in arable land with little disruption to domestic services. An alternative discharge point could be at the ford due south of Warren Farm. The pipeline route would probably interrupt a number of domestic services and the discharge would have to be away from the farm to avoid becoming a local leisure amenity.

(c) Fiddlers Green, Castle Acre

Visual inspection of this site showed that it is a wetland area and not suitable for wellfield development. No engineering feasibility study was carried out.

(d) West Lexham

The wellfield would be developed in arable land approximately 750 m north-west of the A1065 at West Lexham. The pipeline would run downhill for approximately 1 500 m south-east to the north bank of the River Nar. It would be necessary to cross two field boundaries and one farm track (unmetalled). The route would continue along the road verge to discharge near the road bridge on the A1065. Discharging at the road bridge would provide an appreciable fall to enable better aeration of the water before entering the river.

4.5 Selected Sites

Assuming that each augmentation scheme can provide 5 tcmd and considering the augmentation requirements indicated in Table 2.2 then:

(a) One scheme would meet target flow levels at Marham to early or mid-September.

(b) Two schemes could meet target flow levels to early or mid-October.

If the drought continued beyond these times then minimum target flows could not be maintained. However, as indicated in Section 2.4.4, continuation of such a severe drought would be unprecedented.

The target flows considered are those related to the lowest flow on record at Marham ie 0.219 m^3/s and 0.243 m^3/s and not the statistically derived target flow of 0.3 m^3/s. To ensure that these measurement related target flows could be met at least through September (and for some time on into October) two augmentation schemes should be developed. The recommended schemes are:

- Broom Covert, West Acre;
- Warren Farm, West Acre.

Fiddler's Green and West Lexham would be unacceptable on grounds of proximity to wetland and spring sources.

CHAPTER 5

PRELIMINARY DESIGNS AND CONSTRUCTION COSTS

5.1 Introduction

Technical requirements and preliminary designs of various components which make up each augmentation scheme are discussed in Sections 5.2 to 5.5. The costs of these components are brought together in Section 5.6 and the cost of individual selected schemes presented. Consultancy inputs for design of the schemes are dicussed in Section 5.7.

5.2 Wells

A typical augmentation well design is illustrated in Figure 5.1. Following initial drilling to the top of Chalk, steel conductor casing would be installed and grouted in place through overburden/Glacial Drift. This would ensure stability of the upper hole prior to drilling through the Chalk aquifer.

The uppermost 30 m or so of more highly fissured Chalk would be drilled at sufficient diameter for installation of nominal 300 mm diameter casing and screen. The borehole would be completed as open hole some 15 to 35 m below screen, depending on further yield available at these depths.

The casing and screen proposed would be thermoplastic. The screen is installed to protect the production pump from any falling chalk debris. It would have the largest manufactured slot size available of 3 to 4 mm width.

Two wells have been allowed per augmentation site. If sufficient yields were not obtained then allowance has been made in costing for acidising treatment of the wells using hydrochloric acid.

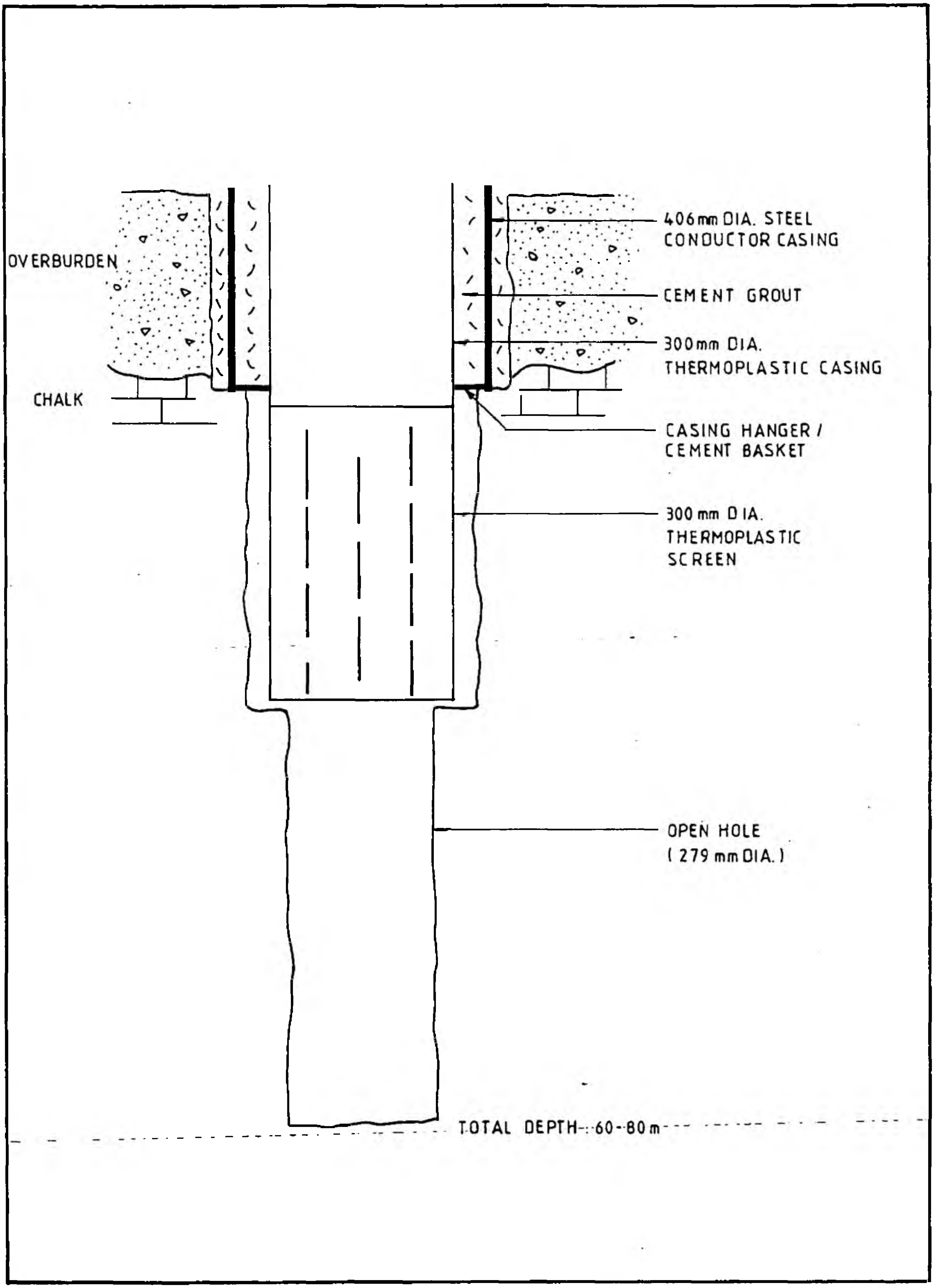
5.3 Pumps and Electricity Supply

Electric submersible multistage centrifugal pumps would be used to pump water from the borehole to the discharge point located at the river.

Each pump would have its own control panel housed in a GRP kiosk located at the wellhead.

It is anticipated that the pumping head for each pump would be in the range 50 to 75 m. Each wellfield would have two duty pumps 2 500 m^3/d (each) with a maximum total running power requirement of 80 kW.

Figure 5.1
Typical Augmentation Well



None of the sites selected appears to have a suitable electricity supply nearby that could be extended. Due to time constraints and the number and sites available in the initial screening it has not been possible to contact Eastern Electricity PLC to determine the magnitude of works required at each site. Under normal circumstances the provision of a 3-phase, 415 V supply using overhead lines might take between 3 and 9 months. It is essential that NRA negotiates the rapid provision of an electricity supply to each site in order to effectively implement this project.

The option of using diesel generators (approximately 160 kVA) has been examined but the environmental impact of engine noise is considered unacceptable.

5.4 Pipelines

5.4.1 Pipeline Sizing

It is normal practice to consider the pipeline size and cost together with the running costs of a water transfer scheme. Since it is expected that this development would only run for a maximum of 4 months per year the operating costs are unlikely to be significant in relation to the capital cost and outweighed by the scheme's benefit. Nominal pipeline diameters between 150 mm and 350 mm were considered for each scheme. For a flow of 5 tcmd a pipe diameter of 200 mm produces a headloss gradient of 14 m/km which is acceptable for a scheme of this type.

5.4.2 Material Options

On cost and technical grounds the review has been limited to 200 mm diameter ductile iron, 250 mm outside diameter medium density polyethylene (MDPE) and 8 inch nominal bore unplasticised polyvinyl chloride (PVC-U) pipes. Since this scheme is not intended for potable water the cheaper polymer, black MDPE pipe can be considered rather than blue MDPE.

(a) Availability

The suppliers of the pipes considered have been contacted to determine the probable delivery period for pipes, which is given below.

Ductile iron	12 weeks
PVC-U	4 weeks
MDPE	4 weeks

It should be noted that delivery periods for fittings such as bends, tees etc are usually considerably longer than for pipes.

(b) Cost Comparison

Significant items for ductile iron, MDPE and PVC-U pipelines have been quantified and approximately costed. Work which would be required irrespective of pipe material has not been costed. Unit costs have been determined using information obtained from pipeline manufacturers.

For a typical scheme with 2 000 m of pipeline the costs are as follows:

MDPE	£58 920
PVC-U	£74 910
Ductile iron	£77 400

The reduced cost of MDPE has been obtained by assuming that the pipeline will be laid using a trenchless mole ploughing technique, thus saving the need for trench excavation, pipe bedding and reinstatement.

(c) Technical Review

Maximum pipeline pressure will occur at the pipeline connection to the wellfield pipework and is not likely to exceed 3 bar. Site hydraulic test pressure will be 1.5 x operating pressure, ie 4.5 bar.

Ductile iron pipe is usually manufactured with a 16 bar pressure rating.

MDPE pipe comes in a variety of pressure ratings. For this scheme SDR17, 6 bar would be used.

PVC-U pipe is supplied in three pressure ratings. For this scheme Class C, 9 bar would be used.

Ductile iron pipe has greater resistance to surge pressures than either PVC-U or MDPE. The reduced tolerance to surge in plastic pipes can be overcome by carrying out a detailed surge analysis of each scheme and installing the necessary surge protection, normally air valves. Both PVC-U and ductile iron pipe will require more careful site handling because of their mechanical joints and additionally will require thrust blocks at bends and fittings to provide restraint.

MDPE is effectively a single length of pipe once butt fusion jointing has been carried out, and due to tension in the pipe and skin friction along the pipe wall minimal restraint along its length will be required, provided the ends are secured.

(d) Recommendation

In view of the cost saving between MDPE and other pipe materials and the urgent nature of this scheme we recommend that black MDPE pipes and fittings are specified for the pipeline route.

5.5 Discharge to River

Due to the relatively low dissolved oxygen content of the augmentation water it will be preferable to make some attempt to aerate the water before it enters the river. Normal types of aeration structure are required to be sited above normal river level to prevent siltation and fouling by debris when not in use. Owing to the low river banks and the shallow nature of the floodplain, this type of structure would have to be sited at water level and be protected by a trash screen. Erosion of the material around the structure would be prevented by surrounding it with a small area of gabion mattress.

A cheaper alternative to partially aerate the water would be simply to discharge the water directly from the pipe into the river. However, this might cause erosion of the river bed exposed at low flows and is therefore not recommended.

5.6 Summary of Construction Costs

For each of the sites selected, preliminary cost estimates have been prepared and are shown in Tables 5.1 and 5.2. The estimates do not include for land purchase at the wellfield sites or for compensation along the pipeline routes. These costs would have to be established separately by NRA Estates Department prior to implementing the project.

Budget costs for engineering construction aspects of the two schemes for the River Nar are as follows:

Broom Covert	£178 000
Warren Farm	£177 000
Total	£355 000

These costs are much higher than for the works originally envisaged for the project. Increased cost has resulted from a need for more complex, buried pipeline routes of a permanent nature, crossing land which is not owned or easily accessible to the NRA. The schemes are similar to those envisaged as resulting from the longer term Phase 2 and Phase 3 of the augmentation study. Additional costs are also associated with location of augmentation wells in the West Acre rather than Marham area. Wells at Marham would have been shallow, but, following hydrogeological assessment, the Marham area is not considered suitable (see Section 4.1).

5.7 Consultancy Inputs

Estimates of hydrogeological inputs for Phase 1 remain the same as originally envisaged, as design, tendering and supervision of well construction are much as originally programmed. The engineering aspects of Phase 1 implementation have however changed. Whereas temporary schemes on land readily accessible to the NRA were originally envisaged, the requirement for land purchase and negotiation for land access combined with complexity of pipeline routes, makes temporary schemes impractical and uneconomic.

The permanent nature of schemes proposed requires greater engineering inputs in design, tendering and site supervision. Design and implementation of permanent schemes were originally envisaged in Phase 3 of the study, following on from the Phase 2 investigation of long term requirements.

For budgeting purposes the following is an assessment of design time required by engineering staff for two schemes for the River Nar:

Water Engineer	: 22 days
Mechanical/Electrical Engineer	: 9 days
Draughtsman	: 11 days

Including expenses, a total sum of £14 000 should be allowed.

Due to the extent and nature of the works together with the number of project sites, full time site supervision of the civil construction contract would be required. The mechanical and electrical contract would require limited site inputs from a mechanical engineer.

For budgeting purposes the following is an assessment of the supervision time for the two schemes.

Resident Engineer	25 days
Project Manager	3 days
Mechanical Engineer	6 days.

Including expenses a total sum of £11 000 should be allowed for. The estimated costs for the design (£14 000) and supervision (£11 000) would be additional to the Phase 1 budget consultancy inputs as originally proposed.

TABLE 5.1

Augmentation Works for River Nar

Site name: Broom Covert

	Unit	Quantity	Rate £	Amount £
Well drilling, development and testing	Nr	2	17 300	34 600
Acidisation	Nr	2	2 000	4 000
Supply and install pumps and starter, control panel and rising main	Nr	2	14 000	28 000
Construct wellhead	Nr	2	1 500	3 000
Supply MDPE pipework 250 mm OD	m	2 090	15	31 400
Valves and fittings	sum			5 000
Lay MDPE pipeline	m	2 090	14	29 300
Valve chambers	Nr	5	200	1 000
Road crossings	Nr	2	1 000	2 000
Field boundaries	Nr	6	300	1 800
Discharge structure	Nr	1	5 000	5 000
Power supply (Eastern Electricity PLC)	Nr	1	10 000	10 000
Sub-total				155 100
Contingency (15%)				23 265
Budget Cost				178 365

TABLE 5.2

Augmentation Works for River Nar

Site name: Warren Farm

	Unit	Quantity	Rate £	Amount £
well drilling development and testing	Nr	2	17 300	34 600
Acidisation	Nr	2	2 000	4 000
Supply and install pumps and starter, control panel and rising main	Nr	2	14 000	28 000
Construct wellhead	Nr	2	1 500	3 000
Supply MDPE pipework 250 mm OD	m	2 100	15	31 500
Valves and fittings	Sum			5 000
Lay MDPE pipeline	m	2 100	14	29 400
Valve chambers	Nr	5	200	1 000
Road crossings	Nr	1	1 000	1 000
Field boundaries	Nr	4	300	1 200
Discharge structure	Nr	1	5 000	5 000
Power supply (Eastern Electricity PLC)	Nr	1	10 000	10 000
Sub-total				153 700
Contingency (15%)				23 055
Budget Cost				176 755

CHAPTER 6

PROGRAMME

6.1 Phase 1

6.1.1 Introduction

A programme for design, tendering and implementation of two augmentation schemes for the River Nar is shown in Figure 6.1. River augmentation to meet minimum target flows is predicted as being required from mid to late August. The programme indicates that the first of the two schemes could be ready by the end of August.

The programme is, however, extremely tight and would, in any situation other than an emergency, be regarded as undesirably rushed and probably unrealistic. In reply to enquiries, some contractors and suppliers have, at this time, expressed interest in undertaking the work. The programme needs to proceed as shown in order to secure suppliers' and contractors' services at the earliest opportunity.

The programme assumes:

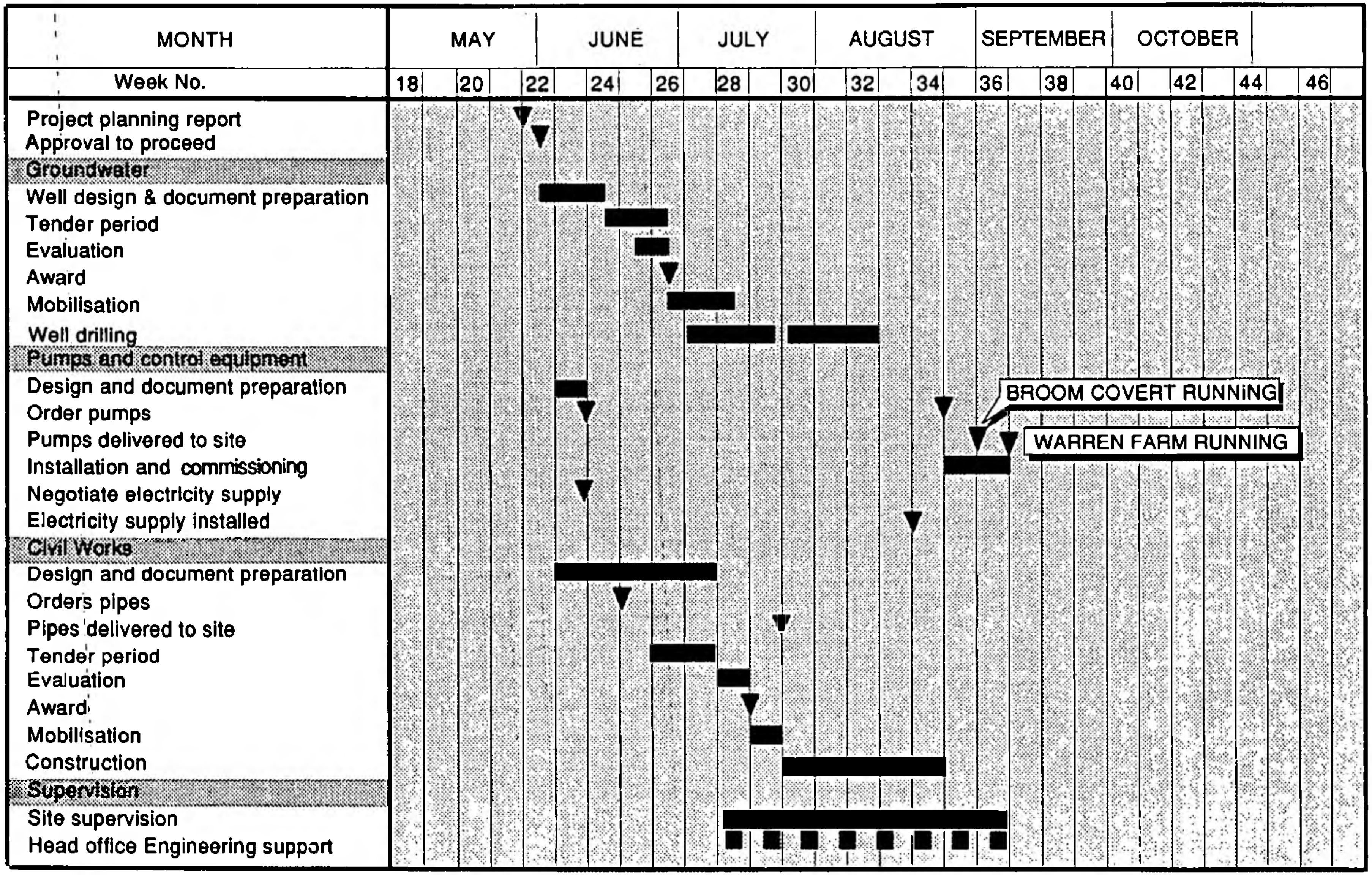
(a) Landowners would be contacted immediately on approval to proceed with schemes in order to obtain necessary permissions for access to undertake pipeline route surveys.

(b) Negotiation of purchase of land would be successfully completed prior to award of a drilling contract at the end of June.

(c) Negotiation of access to land for pipelaying and serving of land entry notice would be sufficiently well underway by the end of June to ensure the overall schemes can proceed as planned.

(d) The drilling contractor could start work on the first well almost immediately within the mobilisation period.

(e) Arrangements for electricity supplies and well pump and pipeline material orders would have to be made in advance of well drilling. The normal procedure would be to establish well yields in advance of ordering the engineering components of a scheme. There are few firm data on the distribution of yields for chalk boreholes and there is, therefore, a significant risk that a yield of 2.5 tcmd might not be obtained at some wells. To some extent, oversized pumps could be throttled back to a reduced safe yield. However, there are locations in the Chalk at which only very



River Nar Phase 1 Implementation - Activities Programme

Figure 6.1

low yields are obtained (less than 0.5 tcmd) and a risk remains that sites may fail to produce yields of the order required. Conversely, if yields larger than 2.5 tcmd were obtained from single wells, then these could not be utilised with the pumps available.

A major concern within the programme is the time required for electricity supplies to be arranged. Initial enquiries with the electricity company indicated that a lead-in time of at least 3 months was required before any new work of this nature could be undertaken. It is recommended that immediate contact be established between the NRA and the electricity company, setting out requirements. Otherwise there is little likelihood of power supplies being available by end of August.

Whilst, as a firm, Mott MacDonald has experience of obtaining clearance from relevant authorities for construction works (PUSWA procedure), we are reluctant to become involved in land purchase or wayleave arrangements since our previous experience has shown that the cost of engineering staff undertaking this work can be inordinately high. We recommend that this work either be undertaken by the Estates Office of the NRA or by a firm with the necessary estates experience, appointed by the NRA.

6.1.2 Design and Tendering

(a) Statutory Undertakings

Pipeline route plans will be issued to all statutory undertakings to ascertain if any diversion of existing services will be required.

(b) Survey and Detailed Design

A detailed level survey would be carried out to determine the precise route and optimum hydraulic design of the pipeline. Plan and long section drawings would be produced for each pipeline. Possible pressure surge problems associated with pump start up and failure would be taken into account in design.

(c) Contract Preparation

It is recommended that all the augmentation schemes along the River Nar are amalgamated so that only three contracts are required to implement each of the following elements of the project:

- drilling and well development and testing;
- supply and installation of mechanical and electrical equipment;
- construction of the pipeline and river discharge structures.

Bills of quantities, specifications and tender documents would be drawn up using appropriate forms of contracts.

(d) Procurement

The manufacture and supply of the electric submersible well pumps is critical to the overall implementation of each scheme. Preliminary discussions with manufacturers indicate that 11 weeks would be required between placement of a firm order and delivery to site. It is clear that a firm order for the pumping plant at the beginning of Week 24 will be required in order to enable satisfactory commissioning of the schemes by the end of Week 35.

Manufacture and supply of the necessary pipework and fittings for each scheme is estimated at around 4 weeks although this is very dependent on the demand at the time of purchase. It is recommended that NRA should procure the pumps and pipeline pipework based on schedules of items, specifications and recommendations for suppliers provided by the Consultant.

6.2 Phase 2 Requirements

6.2.1 Hydrological Data Collection

For the hydrological studies in Phase 2, the principal task will be the setting up of a hydraulic model for the river systems for simulating flows and water levels. This would be used in conjunction with the groundwater model to provide an integrated picture of water movement within the surface water and groundwater systems.

The principal data required for running and calibrating the hydraulic model will be river channel cross-section data together with current meter gauging during an extended low flow period. The Phase 1 data assessment has shown that very few channel cross-section data are available for the catchment. Cross sectional surveys and gauging will therefore be required at 300 to 400 m intervals along the river channel. The timing of the survey will depend on the nature of the river flow recession during the coming summer months. Once the river flow has declined to a pre-determined threshold and continuing dry weather appears likely, the survey would proceed.

Hydrological modelling has also been reassessed in Stage 1. The most appropriate hydrological model for interlinking with groundwater modelling is considered to be the Stanford Watershed Model. Hourly rainfall data are required as one input in calibration. Hourly (and daily) rainfall will be required for stations within the catchment for the period 1953 to 1990. Daily potential evapotranspiration data would also be required for this period, if available. Relevant existing river flow data have already been received. Flow data and abstraction data for the period in 1990 leading up to modelling would also be required.

6.2.2 Observation Piezometers

The piezometry described in Section 3.3 was estimated from a small number of piezometers mostly situated some distance from the river. In order to assess the effects of pumping from augmentation sites as well as to correlate between river and valley groundwater levels during computer model studies a number of additional observation boreholes need to be drilled and constructed. These piezometers should be sited within 1 000 m of the river.

It is proposed that drilling should be performed using the NRA's own rig. This rig drills at 6 inches to 8 inches diameter using the cable tool percussion method and is capable of drilling up to 50 m. It is recommended that drilling is programmed to start as soon as possible so that data records of the possible recession during 1990 can be used for model calibration.

Eight boreholes are required within the Nar valley. These are positioned as follows:

- one or two piezometers per augmentation site, preferably situated between the river and the augmentation wells, to study the influence of borehole pumping on river baseflow;

- three piezometers between Marham and Castle Acre, on the south side of the river valley;

- two piezometers between West Lexham and the headwaters at Mileham so that more accurate piezometry can be established.

These observation boreholes should be drilled to intercept at least the top 15 m of chalk and would be cased/screened using PVC-U plastic casing. The total depth drilled will be of the order of 350 m maximum. The boreholes should be incorporated within the observation network as soon as complete so that monthly records are available to calibrate the groundwater model.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Hydrology

(a) The target minimum flow at Marham Gauging Station below which augmentation would be required has been taken as the lowest recorded flow (0.14 m^3/s) plus an allowance for abstraction at Marham. The required flow just upstream of Marham intake would be 0.219 m^3/s or 0.243 m^3/s depending on whether allowance is made for the legal abstraction (0.079 m^3/s) or the abstraction which was taking place at the time the lowest flow was recorded (0.103 m^3/s).

(b) Abstraction data at Marham for early 1990 have not been available for recession analysis. Recession predictions have been made assuming certain abstraction levels for early 1990 based on 1976 figures. Actual 1990 abstraction data should be made available to confirm the validity of the recession analysis.

(c) For 1990 augmentation would be required at the earliest in mid to late August.

(d) In the year with the lowest recorded flow (1976) the recession terminated in late August. Although slightly more recessions have finished in August than in any one later month, there is a very even spread of recession termination from September to November.

7.2 Augmentation Schemes

Two augmentation schemes are proposed for the River Nar, as follows:

Broom Covert, West Acre
Warren Farm, West Acre

It is assumed that each scheme would provide 5 tcmd from two wells. With a total of 10 tcmd for augmentation, it is estimated that the minimum target flow could be maintained until about mid-October.

7.3 Scheme Costs

(a) It is not considered economical to construct schemes with temporary overland pipework. Temporary electricity supplies are considered undesirable.

(b) Each scheme would require about 2.1 km of supply pipeline.

(c) The estimated costs of individual schemes are:

Broom Covent	£178 000
Warren Farm	£177 000
Total	£355 000

(d) The cost of consultancy design and supervision, additional to budget costs as originally envisaged at the proposal stage, would be £25 000 due to the permanent nature of schemes proposed.

(e) Costs do not cover land purchase, compensation for access for pipelaying or the work involved in contacting or negotiating with landowners. This work would best be undertaken by experienced estates personnel.

7.4 Programme

(a) The programme indicates that the first of the two schemes might be operational by the end of August 1990, and the second in early September. The programme is extremely tight.

(b) In order to have the schemes working on programme, pipeline materials, well pumps and electricity supplies would have to be ordered or confirmed in advance of well completion and confirmation of yields. In normal circumstances this would not be recommended as wells might not produce the required yields.

(c) Negotiation for purchase of and access to land would need to be completed by the end of June.

(d) Arrangements for electricity supplies need to be discussed and agreed with Eastern Electricity as a matter of urgency.

(e) The programme for construction has been tailored for implementation in 1990. The programme is extremely tight and would, in any situation other than an emergency, be regarded as undesirably rushed and probably unrealistic. We would rate the chance of completing construction to programme as being remote.

7.5 Observation Wells

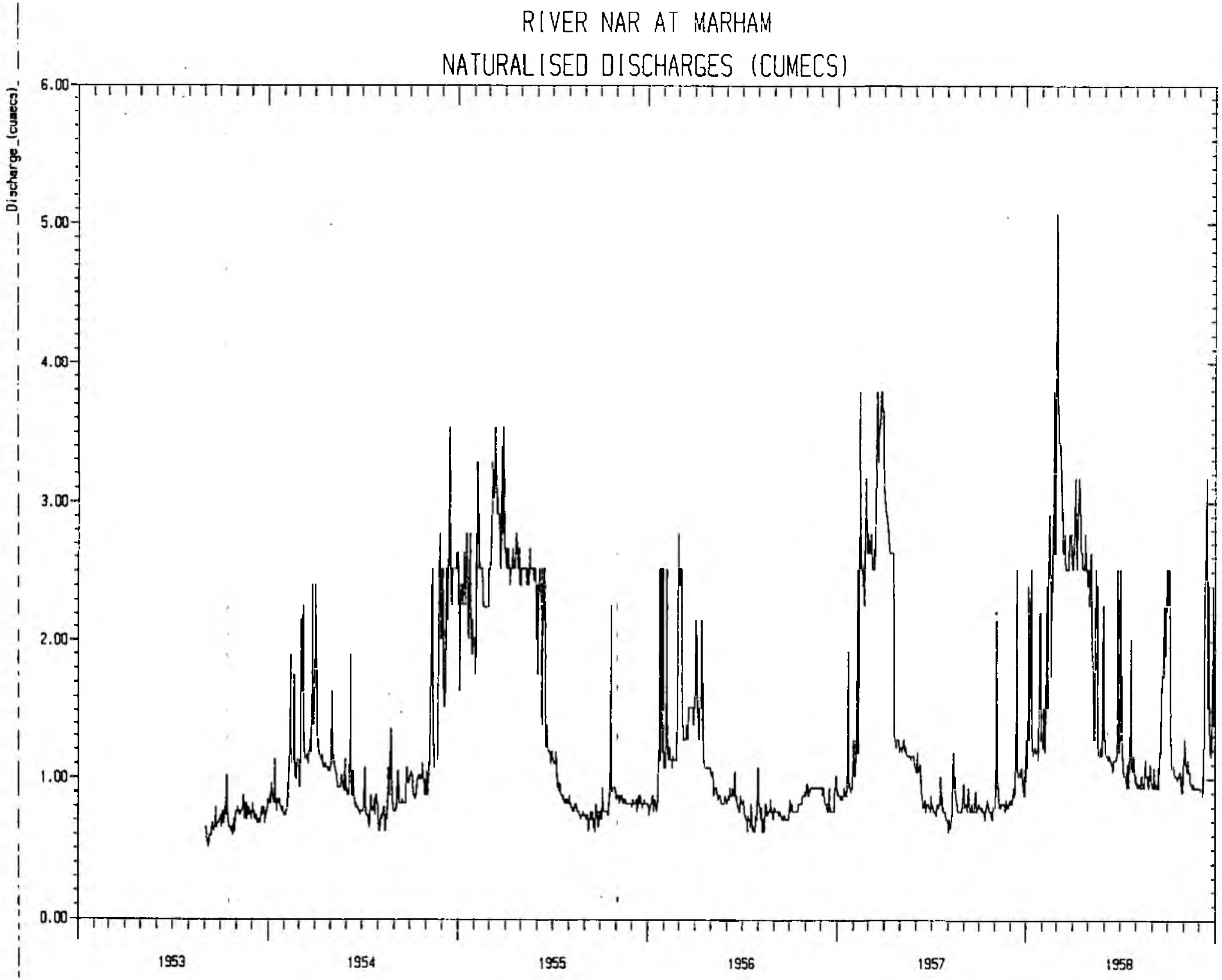
Up to eight observation wells should be drilled as a matter of urgency to provide piezometric data for the Phase 2 modelling studies. The drilling rig owned by the NRA would be suitable for this work.

REFERENCES

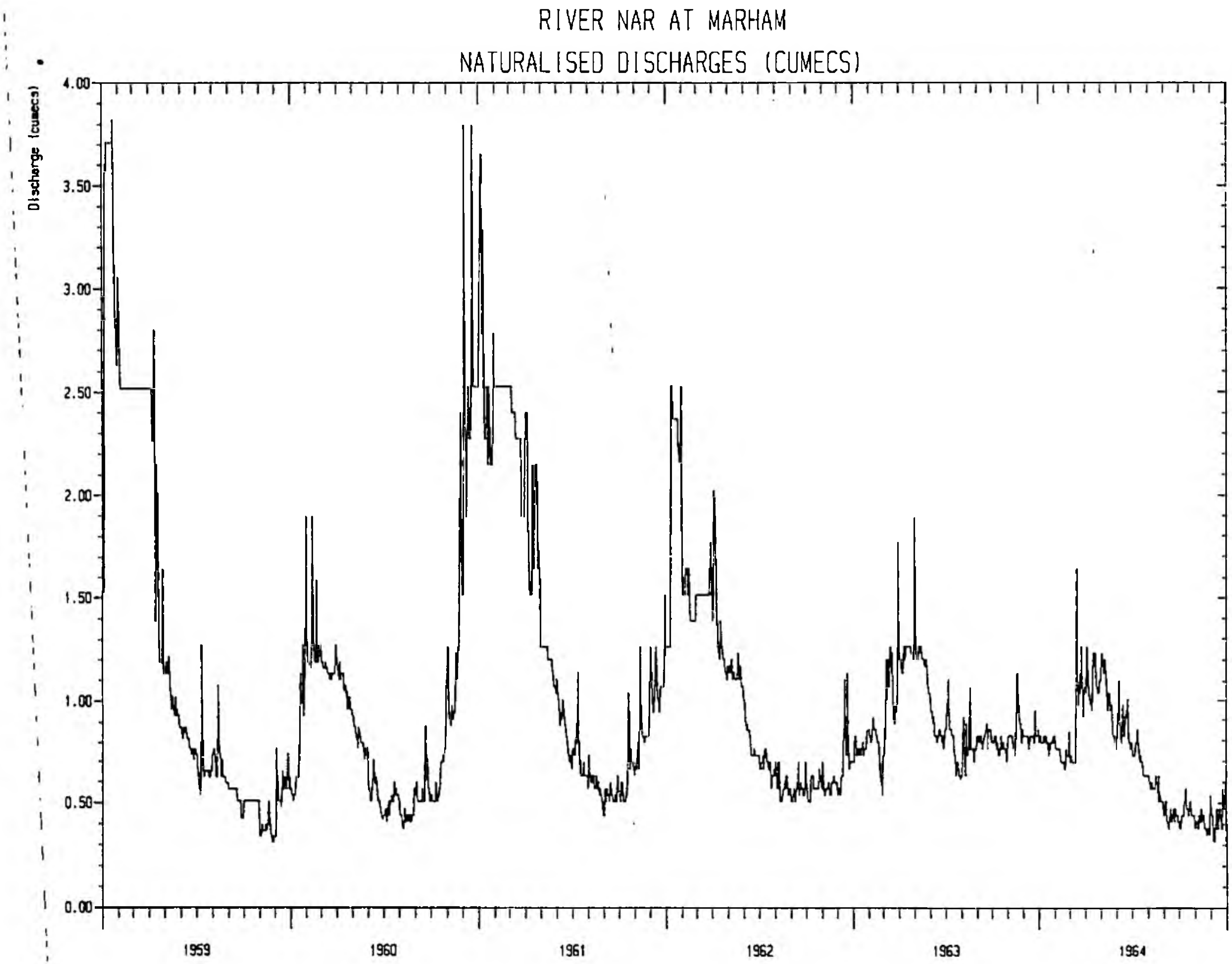
Cox, F C and Nickless, G F P	1972	Some aspects of the glacial history of Central Norfolk. Bull Geol. Surv 42, pp 78-98.
Cox, F C	1985	The Tunnel-valleys of Norfolk. East Anglia Proc. Geol. Ass. 96(4), pp 357-369.
Sir M MacDonald & Partners	1989	Source Reliable Output Study.
Natural Environmental Research Council	1975	Low flow studies.

APPENDIX 1

MEAN DAILY FLOW PLOTS



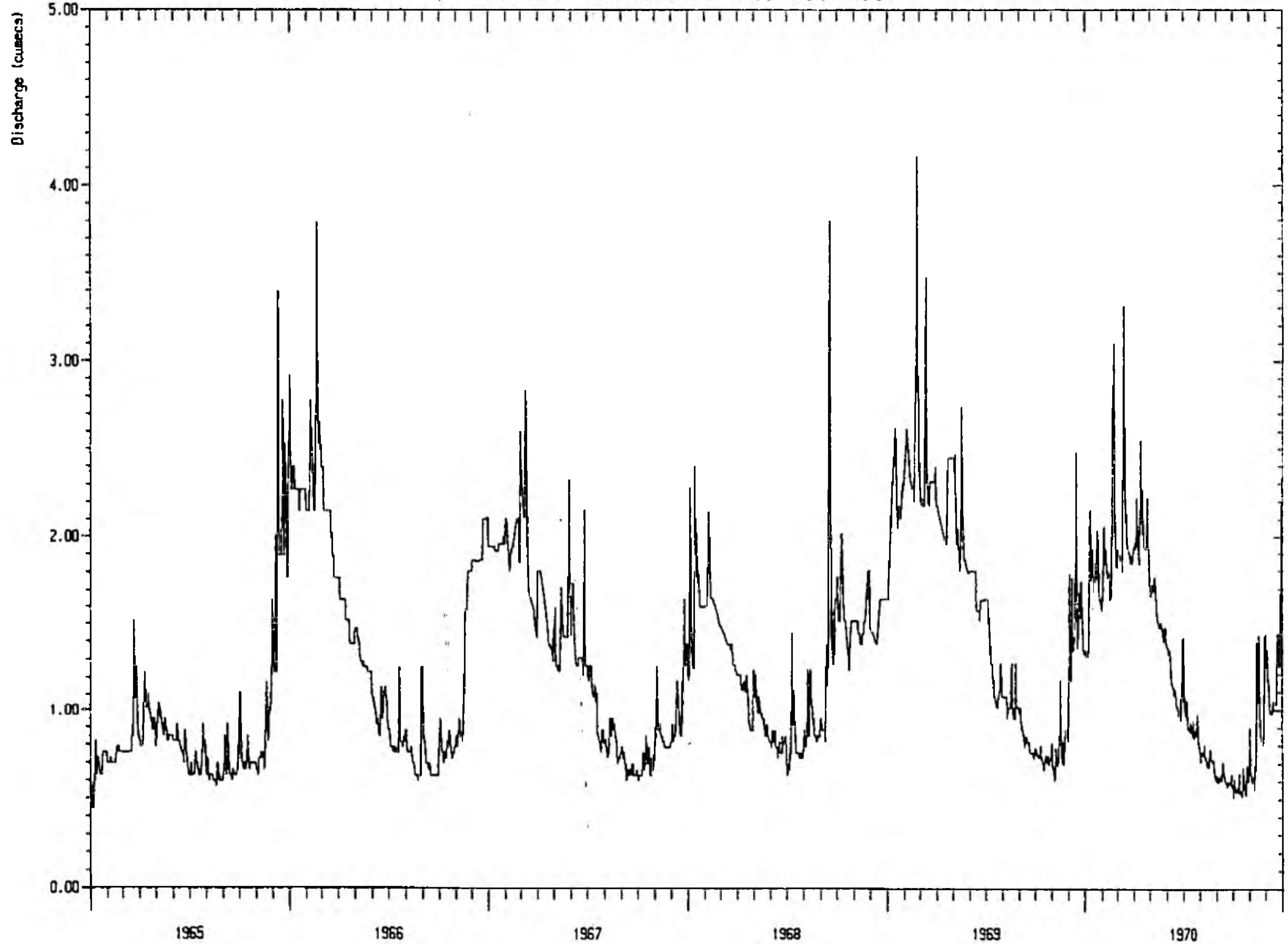
River Nar Mean Daily Flows
1953 - 1958



River Nar Mean Daily Flows
1959 - 1964

RIVER NAR AT MARHAM

NATURALISED DISCHARGES (CUMECS)



River Nar Mean Daily Flows
1965 - 1970

APPENDIX 2

TREND ANALYSIS RESULTS

APPENDIX 2 RESULTS OF TREND ANALYSIS

Various statistical tests were carried out to test the runoff data from the River Nar at Marham for randomness, persistance and trends. In all tests the observed test statistic falls within the expected range, thus providing no evidence of any trends in the data.

GENERAL RANDOMNESS TESTS

1) NUMBER OF MEDIAN-CROSSES
   EXPECTED: 17 +/- 8 (FOR A RANDOM SERIES)
   OBSERVED: 18

2) NUMBER OF TURNING-POINTS
   EXPECTED: 22 +/- 4 (FOR A RANDOM SERIES)
   OBSERVED: 22

PERSISTANCE TESTS

3) FIRST-ORDER SERIAL CORRELATION
   EXPECTED: -0.03 +/- 0.34 (FOR A CIRCULAR SERIES)
   OBSERVED: 0.10

4) SPEARMAN RANK TEST

   EXPECTED: -0.03 +/- 0.34 (FOR A RANDOM SERIES)
   OBSERVED: -0.03

TREND TESTS

5) RANK ORDER TEST

EXPECTED: -0.03 +/- 0.33 (FOR A RANDOM SERIES)
OBSERVED: -0.13

6) MANN-WHITNEY U TEST

EXPECTED: 153 +/- 59 (FOR A RANDOM SERIES)
OBSERVED: 148

7) WALD-WOLFOWITZ RUNS TEST
EXPECTED: 18 +/- 6 (FOR A RANDOM SERIES)
OBSERVED: 15