National Rivers Authority
Anglian Region

THE MANAGEMENT OF THE WATER RESOURCES OF THE LARK GROUNDWATER UNIT

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SUMMARY

The Lark groundwater unit covers parts of several river catchments, including those of the Lark, Kennett, Cut-Off Channel and Sapiston (see Figure 1).

The current issues in the Lark catchment include; the depletion of water levels and river flows, the reduction of river quality and the increasing demand for water abstraction. These effects are due to a combination of the current drought conditions and the long terms policies of allocating water for abstraction. This report recommends a future strategy for the management of the water resource in the Lark groundwater unit.

The water in the river Lark is derived in three ways;
- rainfall runoff, predominately in areas of Boulder Clay cover in the upper part of the catchment,
- baseflow from the Chalk aquifer, which underlies the whole catchment, and from minor sand and gravel deposits, and
- effluent discharges.

During the present drought conditions, the river flows have been sustained by the baseflow and effluent discharges only. Some of the tributaries have little contribution from groundwater as baseflow.

The river Lark sometimes fails to meet it's river quality objectives.

There are six water dependent S.S.S.I.s in the unit and thirteen wetland Wildlife Trust sites. Part of the Lark unit is included in the Breckland Environmentally Sensitive Area.

The loss of invertebrates and fish populations has been attributed to persistent low flows and poor water quality.

The long term average available water resource is allocated firstly to meet environmental needs and secondly for abstraction purposes. It is shown that the water resources of the Lark unit are fully committed. This conclusion is sensitive to the amount allocated to the river, which is provisional and requires further investigation. However, for the present, applications for additional groundwater abstraction will not be recommended.

Several options are examined to ameliorate the long term issues of low flow and quality problems in the river. It is recommended that studies are made over the next five years with respect to "in river needs", recharge estimation, the impact of groundwater abstraction on river flows, the hydrogeology of the wetlands, river channel improvements and river support/augmentation schemes.

CONTENTS

List of Tables

List of Figures

National Rivers Authority
Anglian Region

WATER RESOURCES OF
THE LARK GROUNDWATER UNIT

1. INTRODUCTION

The aim of this report are:

- to report on the current status in the Lark groundwater unit in particular with respect to the hydrogeology, hydrology, navigation, water quality, conservation issues, fisheries and biological aspects,

- to present a groundwater resource balance for the unit calculated for average conditions,

- to recommend a policy for the future allocation and management of water resources, and

- to identify future studies to be undertaken to allow better management of the water resource.

The Lark groundwater unit covers parts of several river catchments, including those of the Lark, Kennett, Cut-Off Channel and Sapiston (see Figure 1).

2. CURRENT ISSUES IN THE LARK UNIT

A summary of the issues is given below and the details are given in section 3. In brief, there appears to be a higher demand for water abstraction and dilution needs than the available supply.

2.1 Depletion of water levels and river flows

There is public concern about the current low flows of the river.

During the current drought years of 1989, 1990 and 1991 the river flow was severely reduced and some tributaries became dry. As a consequence there were spray irrigation bans during the summers of 1990 and 1991. The details are given in Table 1 and Figure 2. In 1992, the farmers have voluntarily agreed to restrict their abstraction by 50 per cent.

2.2 Reduction of river quality

The quality of the river water does not reach N.R.A. objectives. The lack of dilution flow in the river during drought conditions exacerbates the problems.

2.3 Increasing demand for water abstraction

The N.R.A. has received applications from Anglian Water Services Ltd., and spray irrigators requiring more abstraction licences.

3. DESCRIPTION OF THE LARK GROUNDWATER UNIT

3.1 Definition of the Unit

Figure 1 shows the area of the Lark Groundwater Unit (Unit 8). The north west boundary has been defined by the base of the Totternhoe Stone horizon within the Chalk. The remaining boundaries are groundwater divides derived from the groundwater heads in 1976 shown on the "Hydrogeological map for East Anglia" produced by British Geological Survey.

The Unit covers part of the following surface water catchments; the River Lark (6/33/37), the River Kennett (6/33/38), the Lower Lark (6/33/39), the River Sapiston (6/33/41) and the Cut Off Channel (6/33/56).

3.2 Geology and Hydrogeology

The geology is shown in Figure 3 and described below in order of importance with respect to water resources.

The principal aquifer which lies under the whole unit is the Chalk. This is a fine grained, fissured, white limestone with bands of flint nodules. To the west of the unit, the Chalk is at outcrop. The Chalk yields water effectively with the majority of water flow occurring through the fissures.

The east and upper part of the river catchments are covered by increasing thicknesses of Boulder Clay. Boulder Clay consists of unstratified clay, containing fragments of flint and chalk, all of variable thickness and consistency. It is semi-permeable.

There are several deposits of Sands and Gravels in the unit. Firstly, Glacial Sands and Gravels in the upper part of the catchment occurring beneath and on top of the Boulder Clay and at outcrop along the valley sides. Crag, consisting of unconsolidated or poorly consolidated ferruginous sands and gravels with shells, occurs beneath the Boulder Clay east of Bury St. Edmunds. The Sands and Gravels, and Crag, form local aquifers and can easily store and transmit water. The second type of Gravels are the Valley Gravels. These occur in the middle and lower stretches of the river valleys. These can be important locally as aquifers.

Finally, the rivers run in a bed of Alluvium. This consists of silts, clays and some sand layers. the main river Lark runs along a line of a buried channel up to 30 metres deep filled with sands and silts.

The general direction of Chalk groundwater flow in the unit is South-East to North-West, or from the Boulder Clay covered areas to the outcrop and subsequently to the rivers and spring flows. The groundwater levels are given in Figures 4 and 5, and Table 2.

3.3 Hydrology

The river flow regime for the Lark can be examined using available records from gauging stations, current metering, analysis using the Great Ouse Resource Model (G.O.R.M).(WRC Report CO2504-M, April 1990) and analysis using the Regional Groundwater Model.

3.3.1. Gauging Stations

There are four gauging stations in the Lark catchment. The table below gives the details. The flow duration curves are given as Figures 6 to 9.

TABLE 3 . Flow Measurement in the Lark Unit.

Name of Station	National Grid Reference	Period of Record	Average Flow (tcmd)	95%ile (tcmd)	Base Flow Index
Fornham St. Martin (Lark)	TL847 672	1985 - 1991	23.85	0.77	0.50
Temple (Lark)	TL758 730	1960 - 1991	110.76	42.42	0.77
		1985 - 1991			0.79
		1975 - 1984			0.77
Isleham (Lark)	TL648 760	1936 - 1985	156.21	36.80	0.64
		1975 - 1984			0.59
Beck Bridge (Lea Brook/Kennett)	TL662 733	1962 - 1991	21.51	1.64	0.72
		1985 - 1991			0.67
		1975 - 1984			0.70

Note: The 95%ile is the flow that is exceeded for 95 per cent of the time.

The low flows recorded at Isleham are less than at Temple Weir due to leakage through the raised river banks into the lower lying fen areas and the release to the Cut Off Channel via the Lark Head Sluice of approximately 4.3 tcmd. The release to the Cut Off Channel is made to maintain a level of water to safeguard the fishery and other users. The Cut Off Channel losses water to the Chalk aquifer.

The Base Flow Index is the ratio of the flow in the river derived from the aquifer to the total river flow. Rivers with a high baseflow component will therefore have a higher BFI. The index ranges from zero (no baseflow) to one (all baseflow). The BFI given in the table above has been calculated using the "Low Flow Studies" (1980) method of hydrograph separation.

The BFI has been calculated on "un-naturalised" flows i.e. those where the abstractions and discharges have not been added or deleted respectively. As an example, the Fornham St. Martin site is above Bury Sewage Works but below the discharges made by British Sugar (winter) and Greene King (summer). From the analysis of the un-natural record, there appears to be a higher baseflow component in the lower stretches of the Lark than at Bury St. Edmunds, which is on the edge of the Boulder Clay cover. This may be due to the regulating effect of the discharge from Bury St. Edmund's Sewage Treatment Works, or the natural geological difference, or both.

The river flows in the drought period have fallen below the lowest ever previously recorded. This is illustrated at Temple Weir Gauging Station in Figure 10.

3.3.2 Current Metering

Ten sites were identified as current metering sites in order to measure the flows in the tributaries and main stream. These sites were visited regularly between June 1988 and the present as part of the drought monitoring and data collection for the groundwater model. The locations of the sites are given in Figure 11 and the hydrographs are presented as Figure 12.

3.3.3 Great Ouse Resource Model

The Great Ouse Resource Model (G.O.R.M.) was developed by Water Research Centre between 1987 and 1990. The whole of the Great Ouse river system has been divided into reaches defined by nodes at each end of each reach. The model calculates the flow at every node at weekly time intervals using information about recharge and aquifer characteristics as well as abstractions and discharges.

The inflow to a reach can be given as:

runoff + baseflow + effluent returns - surface water abstractions.

The inflow is then added to the flow from the upstream node, progressively adding the flows downstream. Account is made of aquifer storage and transmissivity values as well as groundwater abstractions when the model calculates the baseflow element.

The model has been calibrated with abstraction data for the period 1970 to 1986. Abstractions are allowed to vary through year, for example the spray irrigation quantity is taken during the summer only. Effluent returns to the river have been calculated for the historical record (using the consented flows multiplied by a factor derived from metering trials). The effluent returns vary seasonally and increase from year to year similar to abstractions. The 2011 effluents have been estimated. Figure 26 illustrates the match between modelled flows and actual flows for Temple Weir. The model under estimates the low flows for the Lark and hence needs recalibration.

The model can be used to produce the flow record given different abstraction regimes e.g. abstraction at full licensed quantity or predicted abstractions at the year 2011.

Figures 13 and 14 show the flow duration curves produced by the G.O.R.M. for the Lark catchment. The model does not include post 1986 data and hence the current drought conditions and current level of abstractions are not reflected. The current conditions could be between the 'actual' and 'full licensed' curves.

Upstream of Bury, the historical actual flows are shown to be very similar to those if the river were natural, i.e. there has not been any significant deterioration due to abstraction or that the abstractions match the discharges. However, if the total licensed quantity is taken, the river could potentially run dry. During average flow conditions, the reduction of total flow caused by abstraction at full licence conditions would be 9 per cent. During the lowest flow conditions the reduction would be 80 per cent.

At Isleham, the actual flow is less than the naturalised flow for all the time. This indicates there has been a net reduction due to abstraction and the potential of reducing flows further is also apparent, if total licensed quantity is taken. During average flow conditions, the reduction of total flow by abstractions at full licence conditions would be 15 per cent. During the lowest flows the reduction would be 54 per cent.

The model suggests, therefore, that abstractions could cause a proportionally greater reduction of flows in the upper part of the Lark compared to the lower Lark during critical low flow conditions.

3.3.4 The Groundwater Model

The regional groundwater model, fully described in section 4.2.2, also examines the leakage flow between the aquifer and the river. The baseflow is calculated for selected sites such as Beck Bridge, Temple Weir, Fornham St. Martin and Isleham. The model needs to be improved in order to study this groundwater - surface water interaction more accurately.

3.3.5 Hydrology Summary

In summary, the Lark has a high baseflow element from the Chalk aquifer and the smaller Sand and Gravel aquifers. The runoff from the Boulder Clay covered part of the catchment is significant in recharge events, both as direct input to river flow and as recharge via infiltration to the Chalk aquifer.

During a drought period, the river flows are sustained by the baseflow element only. Some tributaries are vulnerable since they do not have the contribution of groundwater as baseflow. Most of the tributaries during the current drought period from August 1988 to date have declined.

The Culford Brook does not intercept the Chalk aquifer, however, minor Sand and Gravel aquifers sustain flow for a limited period.

The River Kennett also does not intercept with the Chalk groundwater levels during drought conditions until Freckenham (TL665 715). In addition, there are no minor aquifers to help sustain flow in the upper reaches. Hence, parts of the river regularly are dry.

Figures 4 and 5 show the approximate maximum (March 1988) and minimum (September 1991) chalk groundwater levels. The chalk provides a base flow below Rushbrooke via the buried channel deposits. The gradient of chalk groundwater levels down the main river Lark valley does not change significantly between maximum and minimum conditions. This is because the river continues to act as the base level for groundwater discharge.

The main variation can be seen in the groundwater gradients to the south of the main river valley. This influences the flow of the tributaries such as the Kennett, Tuddenham and Cavenham. The spring line has probably remained in a similar location but the gradient is steeper, and hence the flow is greater, in maximum conditions compared to minimum conditions. This is illustrated for the river Kennett in Figure 15.

Photographs from 1991 are given in Figures 16 and 17.

3.4 Navigation

The practise of making the River Lark a navigable river was permitted by an Act of Parliament in 1699. The length of river under the classification of "The River Lark Navigation" runs from Eastgate Bridge, Bury St. Edmunds to Great Branch Bridge near the confluence with the Ely Ouse River. The total distance is 40 kilometres.

At present 16 kilometres is navigable from Branch Bridge (TL573 844) to West Row Bridge at Judes Ferry (TL677 748). This is maintained by the National Rivers Authority as required under the Anglian Water Act 1977.

The navigation was completed in 1715 to Fornham as the Bury St. Edmunds Borough Council would not agree to allow the navigation into the town. The navigation was extended to it's highest point at St. Saviour's Wharf in Bury St. Edmunds (TL856 652) in 1889. By 1900 the traffic had ceased largely due to the arrival of the railway in 1852. Throughout the history of the navigation the majority of the river traffic was confined to the lower Lark up as far as Mildenhall.

A report written in 1931 by the Ministry of Agriculture and Fisheries summarised the position with respect to maintaining the river as a navigation:

"(1) The naturally navigable portion in the Fens from the mouth at Prickwillow to near West Row. There is one lock on this section, viz. at Isleham, and it is still navigated by large barges. The width is about 100 feet.
(2) The middle section from West Row to Lackford bridge which could be navigated by small boats without much expense if the locks and banks were kept in order. There are three locks at the three mills on the stretch and four stanches to navigate some shallow portions.
(3) The uppermost portion from Lackford to Bury which is navigable only at great expense as silting is rapid, the banks are sandy and soft, the stream very narrow and water insufficient."

The report mentions siltation due to the slowing down of the current because of the locks and canalising of the river. Weed growth was a problem causing floods in some sections.

In conclusion, it is only the lower part of the River Lark that has been a successful navigation.

3.5 Water Quality

The river is classified according to River Quality Objectives (1986). The river has been divided into a series of stretches and the uses of the river have been listed (given in Table 4). The uses imposed on a stretch of river determine the quality that should be maintained. The conditions of any discharge are set accordingly. The N.R.A. requires that there should be "no deterioration" of quality and where quality is inadequate for the recognised uses on the river, it aims to improve the quality as appropriate.

During the present drought conditions, the river Lark fails to meet its objectives in some stretches. This is best examined by using the old National Water Council classification which identifies the stretches of river as good, fair etc. The classification is given below in Table 5 and Figure 18 shows the 1990 status of the Lark.

Figure 19 and Table 6 show the discharges made to the River Lark system

Bury St. Edmunds Sewage Treatment Works has a dry weather flow of 12 tcmd and although it improves the flow, it reduces the quality classification of the river from 1A to 1B. The river below Bury St. Edmunds used to be a trout fishery but in the drought conditions, it is only classed as a coarse fishery.

At Isleham, the total dry weather flow of effluents is 15 tcmd compared with the recorded 95%ile flow at Isleham of 36.8 tcmd. The classification changes from 1B to 2 at Mildenhall. The Sewage Treatment Works at Mildenhall, which has a dry weather flow of 4.6 tcmd, could be improved.

Table 5	National Water Council River Quality Classification	
1A	Good Quality	Water of high quality suitable for potable supply abstractions, high class fisheries (trout) and high amenity value.
1B	Good Quality	Water of less high quality than Class 1A but usable for substantially the same purposes as Class 1A.
2	Fair Quality	Waters suitable for potable supply after advanced treatment but supports reasonable coarse fishery.
3	Poor Quality	Waters which are polluted to an extent that fish are absent or only sporadically present; may be used for low grade industrial abstraction purposes.

3.6 Wetland S.S.S.I.s and Other Sites of Conservation Interest

Figure 20 shows the location of the wetland sites of conservation interest. The S.S.S.I. sites come under the control of English Nature whereas the Wildlife Sites are under the supervision of Suffolk Wildlife Trust. The future licence policy has to take account of these sites.

3.6.1 S.S.S.I. Sites

a. Cavenham Heath S.S.S.I. TL755 733.

This is a large and varied area of heath, grassland, woodland and fen which straddles the flood-plain of the River Lark. The flood plain of the River Lark is largely occupied by cattle-grazed meadow grassland, much of which has been partly drained, either deliberately or as a result of lower water levels in the river. There are areas of marshy grassland as well as dry woodland and wet woodland. Cavenham/Ickingham Heaths are notable for a number of nationally and locally rare plants. These include Breckland Wild Thyme, Spring Speedwell and Maiden Pink. The generalised cross section, given in Figure 21, shows the geology underlying the site to be complex.

b. Bradfield Woods S.S.S.I. TL925 577.

The woods which comprise Bradfield Woods S.S.S.I. are of ancient origin and contain extensive areas of plateau alder, acid pedunculate oak-hazel-ash with wet patches of ash-maple. The site is on the boulder clay cover at the top of the catchment divide to the south west. The wet areas and pond are likely to be rely on surface water drainage or perched water systems and not in continuity with the Chalk aquifer.

c. Hay Wood, Whepstead S.S.S.I. TL810 578.

Hay Wood is a small ancient wood lying on poorly drained boulder clay soils. The wood contains small-leaved lime, wet ash-maple and elm.

d. Rex Graham Reserve S.S.S.I. TL737 746.

This is a disused chalk pit. the floor and lower slopes are covered by damp, calcareous grassland.

e. West Stow Heath S.S.S.I. TL784 714.

This site contains a wide range of grassland and heath vegetation as well as an area of wet woodland. Three nationally rare plants are found in association with the acidic and calcareous grassland areas; Glaucous Fescue, Breckland Wild Thyme and Spring Speedwell.

The wet woodland occupies the Letch Moor part of the site. The ground is wet and there are large areas of standing water. The area is directly adjacent to the River Lark.

f. Wilde Street Meadow S.S.S.I. TL710 791.

This is an example of calcareous grassland and calcareous loam grassland which grades into damp pasture. There is a sizeable population of Green-winged Orchid. This site lies on Chalk outcrop close to the Cut-Off Channel.

3.6.2 Wildlife Trust Sites

The following sites are under the control of Suffolk Wildlife Trust and, according to the Trust, have a "wetland" aspect.

a. Worlington Moat TL691 734
b. Red Lodge TL696 700
c. Hurst Fen and Howlett Hills TL726 765
d. Mitchell's Farm Meadows TL777 721
e. Berner's Field TL794 744
f. Norah Hanbury Kelk Memorial Meadow TL714 741
g. Barton Mills Meadow TL730 737
h. Pattie Carr's Meadow TL858 590
i. Hengrave Wet Meadows TL827 691
j. Hengrave Hall Lake & Moat TL825 685
k. Lackford Wildfowl Reserve TL802 709
l. Ducksluice Farm Meadow TL833 686
m. Timworth Wet Meadow TL865 696

3.6.3 Breckland Environmentally Sensitive Area

Figure 20 also shows that the north-western part of the area is within the Breckland Environmentally Sensitive Area. The Breckland area is distinguished by light sandy soils, belts of Scots Pine and areas of heathland with a rich variety of flowers, birds and other wildlife. The Ministry of Agriculture operate a scheme whereby farmers can come to an agreement (in exchange for a grant) to farm in such a way as to preserve the Breckland landscape. The river valleys are considered to be an integral part of the landscape and farmers can agree "to maintain wet grassland", ponds and ditch systems.

The River Lark was surveyed in 1990 as part of the Rivers Environmental Database Survey programme. The survey extended from the main river limit (TL8645 5961) near Hawstead Hall to the start of the fenland section (TL6488 7604) to the north of Waterside. The survey provided detailed plant and bird data for each 500 m section of the river.

3.7 Fisheries

Fishery data are collected as part of routine fish population surveys. In 1985 all of the tributaries i.e. the Tuddenham Stream, the Culford Stream and the Cavenham Stream were found to support natural as well as introduced breeding populations of brown trout. In 1989, the Culford stream was identified for special consideration to protect the numerous spawning sites of brown trout.

However, the tributaries have suffered due to low flows during the drought conditions since 1988. This results in loss of habitat, i.e. spawning grounds and nursery areas, and subsequently the reduction of fish populations. The main adult populations may have returned into the main river but the reproduction cycle may not have been repeated in certain areas. The fish live between six and ten years and are able to reproduce once they are two to three years old. If the adverse conditions persisted for more than four years there would be a generation missing from the natural brown trout population. There is some evidence from the 1992 fish population survey to support this. Adult brown trout were recorded in the main river Lark, the Tuddenham and Cavenham Streams but not recorded in the Culford stream.

The loss of flow and poor water quality also means loss of invertebrates as well as fish populations.

The lower reaches of the Lark supports a valuable coarse fishery. The stretch between Mildenhall Gas Pool to the junction with the Ely Ouse, approximately 20 kilometres in total, is defined as a cyprinid (coarse) fishery under the E.E.C. Council Directive on the quality of fresh waters needing protection or improvement in order to support fish life (No. 78/659/EEC).

In addition, the N.R.A. uses the stretch of the Cut-Off Channel between the rivers Lark and Wissey as a nursery area for coarse fish. It is, therefore, important to maintain water level along this stretch. This could present conflict in low flow conditions when the water from the river Lark may be needed to stay in the river as well as be diverted to the Cut-Off Channel.

Table 4 indicates the fishery designation of the river with reference to water quality objectives.

4. WATER RESOURCES

4.1 The Water Resource Balance

The water resource balance for an aquifer unit is presented as follows:

INFLOW = OUTFLOW +/- CHANGE IN STORAGE

INFLOW = (Rainfall - Evaporation - Runoff) x Area of Groundwater Unit

OUTFLOW = (Abstraction - Discharges) + Baseflow

STORAGE = Water stored in the aquifer

This can also be examined in terms of DEMANDS vs. SUPPLY

The following section examines the method of estimating the "Effective Resource" or INFLOW to the catchment. Section 5 then looks at the demands for the water or the OUTFLOW from the system.

4.2 Estimating the Effective Resource

Two methods have been used to estimate the water resources available for groundwater abstraction. The first is based on Wright's method detailed in his paper "Combined use of surface and groundwater in the Ely Ouse and Nar Catchments.", Water Resources Board, March 1974. The second approach has been to calibrate a regional groundwater model.

The calculated "gross" resource is then reduced by 20 per cent to reflect the inadequacy of the Chalk storage to fully even out the year to year fluctuation in recharge (drought years to wet years) and becomes the "effective resource". The 20 % is unavailable for reliable abstraction but will instead contribute to river flow. A separate allocation is also made for the river (section 5.2).

4.2.1 Wright's Method

The area of the Lark Groundwater Unit has been divided into "Chalk outcrop" and "Chalk overlain by Boulder Clay". Wright looked at the relationship of infiltration and rainfall. He did this by using known factors of geology, rainfall and river flows and produced the following relationships by multiple regression analysis.

The infiltration through Chalk: $I = 0.81 \times R - 308$ (mm/a)
The infiltration through Boulder Clay over Chalk:
$$I = 0.202 \times R - 70 \text{ (mm/a)}$$
where R = average annual rainfall (mm/a)

The following assessment was made using Wright's Method for the Cambridge Water Plan, 1984 :

TABLE 7 : Lark/Kennett Resources

Sub Catchment No.	Chalk Area (km2)	I (mm/a)	Boulder Clay Area	I (mm/a)	Recharge (tcma)
37	171	183	176.5	49	39940
38	51	183	44	51	11570
56	39.5	166	-	-	6560
			Gross Resource = 58070 tcma (or 159 tcmd)		

The "effective resource",therefore, becomes 46456 tcma or 127 tcmd.

4.2.2 The Groundwater Model

The regional groundwater model consists of a recharge model and a finite difference groundwater model which uses the successive over relaxation technique to solve simultaneous equations. The change in groundwater heads and flows across the unit are calculated from changes in recharge and abstraction. The calculations are made at every node of a 1 km^2 grid placed over the catchment (see Figure 22). The model uses 1970 to 1989 records of abstraction and estimates of recharge and calibrates against known groundwater heads and river flows. The model fit is adequate; however, there is need of refinement and updating to include the current drought conditions.

The monthly recharge is calculated using a Penman - Grindley type soil moisture balance of daily rainfall and potential evapotranspiration figures.

There are three components which form the total recharge in the model; recharge through Chalk areas, recharge through Boulder Clay covered areas and the infiltration of Boulder Clay runoff. This latter component describes the runoff from the upper, Boulder Clay covered catchment which infiltrates as it flows across the Chalk outcrop. This latter infiltration component was adjusted in the model to obtain the best model fit. In reality this infiltration may be transmitted quickly down the catchment due to the higher transmissivity values of the chalk in the valley.

An interpretation of the model results gives the following average figures (based on 1970 to 1989 data). These are subject to review after a more detailed study of the recharge mechanisms in the model.

TABLE 8

Component	Area of Unit (km^2)	Recharge (tcmd)
Recharge through Chalk Area	279	117
Recharge through Boulder Clay Area	225	15
Infiltration from Boulder Clay	-	34
	Gross Recharge	166

The effective resource would, therefore, be 133 tcmd.

4.2.3 Effective Resources Comparison and Summary

The main difference between the two methods is the area used to describe the Lark unit;

TABLE 9

	Chalk (km^2)	Boulder Clay over Chalk (km^2)	Total Area (km^2)
Cambridge Water Plan	261.5	220.5	482
Groundwater Model	279	225	504

There is also a need to update the analysis. The Cambridge Water Plan was completed in 1984 and the groundwater model uses 1970 to 1989 data.

The rainfall from individual gauge records have been weighted by the fraction of the area represented by the gauges and then summed. The area was determined by a technique of Theissen polygons. The following table summarises this analysis:

TABLE 10

Station	proportion of total area	Annual Average Rainfall (mm/a) 1961 - 1990	Rainfall Weighted by area
Prickwillow	.085	578	49.13
Elvelden	.103	653	67.26
Honington	.020	576	11.52
Sugar Factor	.164	581	95.28
Hawstead	.152	608	92.42
Lidgate	.148	594	87.91
Exning	.063	537	33.83
Isleham	.072	543	39.10
Brooms Barn	.192	583	111.94
Wattisham	.001	569	0.57
Sum/Average	1.000	582.2	588.96

It is appropriate to use the method of resource calculation which offers the best confidence together with the most up to date rainfall information and best estimate of geological areas. Hence, the Wright's Method (the groundwater model still needs refinement) together with the information in Table 10 and the areas used in the groundwater model should be used.

TABLE 11 :

Chalk Area (km^2)	I (mm/a)	Boulder Clay Area (km^2)	I (mm/a)	Recharge (tcma)
279	169	225	49	58186 (or 159.41tcmd)

The Effective Resource is, therefore, taken as 127.53 tcmd.

5. DEMANDS FOR WATER

5.1 Abstraction Demand

Figure 23 and Table 20 show the historical record of licensed abstractions (not actual abstractions) for the Lark Unit. The quantity licensed for public water supply increased from 15747 to 19373 tcma between 1966 and 1992. The quantity licensed for spray irrigation increased from 597 to 3854 tcma in the same period and the quantity licensed for industrial use increased from 2194 to 6211 tcma.

The impact of any abstraction depends on the use of the water and the destination of the resulting effluent. The table below gives examples of the type of impact with respect to water resources : (i.e. Low means that most of the water is returned to the river)

TABLE 12

Abstraction Type	Destination of Effluent	Impact
Public Water Supply	Within Catchment	Low
Public Water Supply	Export from Area	High
Spray Irrigation	Evapotranspiration	High
Gravel Washing	Recirculation	Low
Agriculture	Within Catchment	Low
Industrial	Within Catchment Export in product	Low High

5.1.1 Public Water Supply Demand

Figure 24 shows the location of the public water supply boreholes operated by Anglian Water Services Ltd. There is no surface water intake directly from the river for public water supply.

The boreholes sources are used to supply the population centres within the unit from Bury St. Edmunds to Mildenhall and Isleham as well as the smaller towns and villages. The boreholes are also used to supply areas outside the catchment. The "exports" were calculated as part of the Cambridge Water Plan (1984) and a forecast from these figures has been made to estimate the quantity exported during 1991; a total of 1.57 tcmd is estimated to be exported to the south east from Rushbrooke source, 4.7 tcmd from Barrow Heath to south of the Lark, 2.9 tcmd from Moulton to supply Newmarket and finally a total of 11.11 tcmd from Beck Row, Isleham, Eriswell and Twelve Acre Wood sources to supply Ely. A total estimated export of 21.27 tcmd.

The table below lists the actual abstraction from the public water supply boreholes. The total abstracted is 41.26 tcmd (1991). Refering to the estimation of exports, the total return to the catchment is 19.99 tcmd or 48 %. The sum of the dry weather flows given in Table 6 equals 19.92 tcmd.

The quantity of effluent returned to the river can also be estimated using the population figures for the unit and multiplying by the estimated quantity returned per person. The total population of the Lark Unit is 76,630 (forecast figures taken from the Cambridge Water Plan,1984). The quantity returned is estimated as 90 per cent of the Average Daily Demand . The Average Daily Demand is given as 0.278 m^3/d/person (Cambridge Water Plan, 1984), total demand results as 21.284 tcmd and the effluent would be 19.16 tcmd. This is comparable to 19.99 tcmd given in the previous paragraph.

The table also shows the current licence details for the sources. Anglian Water Services Ltd abstracted 78 % of their licensed quantity in 1991.

TABLE 13 Source	1991 Actual Abstraction (tcma)	Quantity Licensed (tcma) Per Source	 Within Aggregate
Bury St. Edmunds	2409.044	2700.000)	8000.00
Risby	628.997	1493.000)	
Rushbrooke	1514.802	1792.000)	
Barrow Heath	2493.106	3318.000)	
Moulton	1456.699	2045.000	
Tuddenham	1.119	273.000	
Isleham	1488.066	1650.000	
Beck Row	2004.894	3905.000	
Eriswell	2309.549	2818.500	
Twelve Acre Wood	753.629	682.000	
TOTAL	15059.905 or 41.26 tcmd		19373.000 or 53.08 tcmd

Anglian Water Services Ltd. have currently applied for the following changes to their licences:

TABLE 14 Anglian Water Services Ltd. Licence Applications (January 1992)

Application No.	Details
R84	Application to include a new borehole, called St. Helena Farm, on to licence No. 6/33/39/12 (Beck Row) but no increase in quantities. Beck Row is used to supply Ely outside the Lark unit.
R97 & C467	To include a third borehole at Twelve Acre Wood and to increase the daily rate from 4546 to 7000 m^3/day and the annual rate from 682 to 1650 tcma. This increase is likely to be for supplies outside of the Lark unit although the source does supply Mildenhall within the unit. **
R116	To increase the daily quantity at Moulton from 6.545 to 8.1 tcmd.
R117	To increase the daily quantity at Rushbrooke from 5.7 to 7.3 tcmd.
C466	To increase the annual quantity at Eriswell from 2818 to 4000 tcma. The increase to 4000 tcma was given on a temporary basis in 1991 but within an overall aggregate. Eriswell is used to supply Ely outside of the unit. **
CN601	To develop a new site at Nowton to meet increased demands of 5 tcmd, 1500 tcma in Bury St. Edmunds.

Anglian Water will accept the increases marked with ** (in Table 14) within an overall aggregate of 9000 tcma linking together abstractions at Isleham, Beck Row, Twelve Acre Wood and Eriswell. Therefore, the only increase required is at Nowton to meet increase in demands at Bury St. Edmunds. The current aggregate of the sources around Bury St. Edmunds is 8000 tcma. Anglian Water have indicated they would agree if Nowton was included within the aggregate and the aggregate was increased to 9000 tcma. Total increase required by Anglian Water would be 1000 tcma or 2.74 tcmd.

The Regional Groundwater Model, described in section 4.2.2, has been used to demonstrate the effect on groundwater heads and river flows from the proposed individual increases in abstraction.

Firstly, the model was run with the abstractions set at the 1990 levels (a total of 45.1 tcmd). This run was used as the base level in order to compare subsequent runs. The second run increased the level of abstraction to full licensed levels in 1991 including the Anglian Water aggregates of 8000 tcma for the Bury sources and 7000 tcma for the Mildenhall sources (a total of 47.45 tcmd). The results were similar to the base run results.

A third run was made with the public water supply sites (all at Beck Row and none at St. Helena Farm) at maximum output, including the currently applied for licence increases and without the aggregates (a total of 62.55 tcmd). This results in a reduction of flow of between 10 and 15 tcmd at Isleham. In particular, the Mildenhall sources are shown to affect the river flow below Temple Weir and Beck Bridge.

A fourth run included the abstraction from public water supply at maximum as run three but allowing a quarter of Beck Row to be abstracted at St. Helena Farm and allowing the abstraction at Bury to be increased by 4.4 tcmd (a total of 66.95 tcmd overall). The river flow below Temple Weir is slightly affected whereas the flow at Isleham is similar to run three. The main change is seen at Fornham St. Martin, here the flow is reduced by approximately 5 tcmd compared to the first run.

Other model runs, indicate that abstraction from three sources around Bury St. Edmunds would capture more baseflow to Fornham St. Martin than the one Bury Source. This could reflect the higher transmissivity values in the valley which would spread the effect of the Bury abstraction further down the valley below Fornham St. Martin.

In conclusion, the model can be used to show <u>where</u> the change in groundwater heads and river flows will occur according to different patterns of abstraction. The model also confirms that if an extra "x" tcmd is abstracted from the chalk, an equal "x" tcmd is lost to the baseflow of the river.

5.1.2 Other abstraction demand

Figure 23 and Table 20 show the historical record of licensed abstraction per type of use. Table 15 gives the details of the current applications for groundwater and surface water (non public water supply) abstraction.

The total increase in groundwater abstraction currently applied for is [redacted] 1363 tcma or [redacted] 3.74 tcmd.

Impact of these depend on the water use. The applications for Spray Irrigation would have the highest impact as the water is lost to the system via evapotranspiration. The lowest impact would be gravel washing where only 10 percent is considered lost by evaporation.

5.2. Environmental Demand for Water

The environmental demand for water consists of two elements; the level and flow needed to maintain wetland sites of conservation interest and the "in river needs".

The wetland sites exist, in certain cases, because of supporting groundwater levels and flow. Therefore, the protection of wetlands will exclude areas of the unit where abstraction boreholes can be sited. Ideally, there will be defined protection or catchment zones.

The "in river needs" can be defined as the flow, level and quality of water necessary to satisfy:-

a. the aquatic and riparian communities,
b. the requirement for effluent dilution,
c. the needs of surface water abstractors,
d. navigation, and
e. flushing of silt.

In some other catchments, an extensive ecological and hydrological study has been carried out, to examine the existing ecology of the river system and define the minimum water level, flow and quality required to maintain the system. Such a study has not been carried out for the Lark catchment.

There is a need to define the quantity that should be reserved for the river system from the overall available groundwater resource. In the absence of an extensive ecological study, the natural 95 percentile flow (i.e that which would have occurred before abstractions existed) is considered to be a first approximation to the quantity needed to preserve minimum flows. The natural flow can be calculated using the Great Ouse Resource Model as detailed in section 3.3.3.

There are two further considerations. Firstly, the discharges made to the river and secondly, the transfer out of the river at the Lark Head sluice to the Cut Off Channel. The transfer to the Cut Off Channel has been included as part of the natural flow, this means that it has been accepted that the flow of the lower Lark will always be less due to the diversions made to the Cut Off Channel.

In conclusion the quantity of water required for the river can be given as:

$$RA = Z - 0.75E$$

where, RA = the quantity of water that needs to be reserved from the overall groundwater resource for the river system

Z = the naturalised 95 percentile flow (this includes the regular transfer to the Cut Off Channel (CO) of 4.3 tcmd).

E = sum of the effluents made to the river

0.75 E = an estimate of how much of the effluents are reliably made to the river (arbitrary but is a concession that some of the effluent may seep to ground and not contribute directly to river flow, and that not all effluents are reliably made, i.e. depends on water demands, industrial activity and limitations on water supplies during drought periods.)

The results for the whole Lark Unit:

Z = 62.21 tcmd (output from G.O.R.M.s model node 3903 near Isleham) (this includes 4.3 tcmd to Cut-Off Channel)

E = 25.77 tcmd, this is made up from 19.99 tcmd discharge from Public Water Supply i.e. that which is not exported (see Section 5.1.1.), 3.53 tcmd the sum of industrial dry weather flows (see Table 6), 0.37 tcmd the sum of Private Water Undertaking Licences and 1.88 tcmd the sum of Agricultural Licences.

0.75 E = 19.33 tcmd

RA = 62.21 - 19.33 = 42.88 tcmd

The calculated "RA" describes the allocation of groundwater made for the main river. There is no measure of water needed in the tributaries. In dry conditions, such as those experienced in the last three years, it is the tributaries that have shown the worst signs of stress. An attempt to address this is given below.

The unit has been divided into four smaller sections. The divisions were made with regard to surface hydrology and groundwater flows. Figure 25 shows the definition of the sections; A covers the Upper Lark around Bury St. Edmunds which is largely a Boulder Clay covered area, B is Mid Lark across the Chalk Outcrop and C is Lower Lark. The Kennett catchment forms D.

TABLE 16

ALL FIGURES IN TCMD (unless otherwise indicated)	Upper Lark A	Mid Lark B	Lower Lark C	Kennett D
95 %ile Natural Flow (Z) (G.O.R.M.S. node in model)	10.37 (3706)	22.46 (3703 -3706)	17.28 (3903-(3703 +3802))	12.10 (3802)
Effluents (E) 0.75 E	12.13 (1) 9.10	4.36 (2) 3.27	7.17 (3) 5.38	2.11 (4) 1.58
River Allocation (RA)	1.27	19.19	11.90	10.52

Notes: P.W.S. = Actual 1991 return for Public Water Supply sources, Exports = estimate for 1991 from Cambridge Water Plan, P.W.U. and Agric = sum of total licensed quantities, Ind. = Sum of dry weather flows for industrial discharges

(1) P.W.S.: Bury + Rushbrooke = 10.75 tcmd, Exports = 2.57 tcmd, P.W.U. = 0.26, Agric. = 0.22, Ind.= 3.47 tcmd

(2) P.W.S.: Tuddenham + Risby + Barrow Heath = 8.56 tcmd, Exports = 4.7 tcmd (to Rede Reservoir), P.W.U. = 0.06, Agric. = 0.38, Ind. = 0.06

(3) P.W.S.: Isleham + Beck Row + Eriswell + Twelve Acre Wood = 17.97 tcmd, Exports = 11.11 tcmd (to Ely), Agric. = 0.31

(4) Public Water Supply : Moulton = 3.99 tcmd, Exports = 2.9 tcmd (to Newmarket), P.W.U. = 0.05, Agric. = 0.97

NOTE : All figures from the G.O.R.M.s model are **underestimates** as it has been recognised that the model needs recalibrating for the Lark catchment.

6. BALANCE OF RESOURCES AND DEMANDS

6.1. The Whole Lark Unit

The following table summarises the information for the whole of the Lark Unit from sections 4 & 5.

TABLE 17		
Resource	Tcmd Gross	Effective
Wrights Method (1984 Cambridge Water Plan)	159.0	127.0
Regional Groundwater Model Recharge	166.0	133.0
Updated Wrights Method	159.41	127.53
ADOPTED FIGURE OF EFFECTIVE RESOURCE (X)		127.53
Total Abstraction Demand		
Groundwater abstraction licensed (Y) *		83.13
Surfacewater abstraction licensed		4.29
Applications for Public Water Supply from groundwater		2.74
Applications for non P.W.S. supply from groundwater		3.74
Applications for non P.W.S. supply from surface water		0.63
Environmental Demand		
River Allocation (RA) (62.21 ** - 19.33)		42.88

*only includes 10% of gravel washing licence total (90% recirculated)
**All figures from the G.O.R.M.s model are underestimates as it has been recognised that the model needs re-calibrating for the Lark catchment.

The future DEFICIT or SURPLUS (D/S) can be calculated as follows:

D/S = X - Y - RA

X = The Available Resource

Y = Quantity Licensed, Groundwater only. Surface Water Licences are assumed to work to M.R.F. conditions.

RA = the flow that needs to be reserved from the overall resource for the river system

The calculation made for the whole of the Lark Unit is:

D/S = 127.53 - 83.13 - 42.88 = 1.52 tcmd

Therefore, there is a slight surplus.

However, this is a figure for the whole of the Lark and it is necessary to examine the pattern within the Unit.

6.2. Sub Units of the Lark

The unit has been divided into four smaller sections. The divisions were made with regard to surface hydrology and groundwater flows. Figure 25 shows the definition of the sections; A covers the Upper Lark around Bury St. Edmunds which is largely a Boulder Clay covered area, B is Mid Lark across the Chalk Outcrop and C is Lower Lark. The Kennett catchment forms D.

The table below shows the assessment of surplus or deficit for each sub unit.

TABLE 18

ALL FIGURES IN TCMD (unless otherwise indicated)	Upper Lark A	Mid Lark B	Lower Lark C	Kennett D
Total Area (km^2)	138.0	154.0	76.0	136.0
Chalk Area	13.0	109.0	76.0	81.0
Boulder Clay Area	125.0	45.0	-	55.0
Total Resource (using Wrights Method)	22.78	56.52	35.20	44.90
Available Resource (X)	18.23	45.22	28.16	35.92
Total Groundwater Licensed (Y)*	25.32	22.59	25.61	9.61
River Allocation (RA)	1.27	19.19	11.90	10.52
Surplus/Deficit (D/S)	- 8.36	3.44	- 9.35	15.79

* only includes 10 % of gravel washing licence total (90% recirculated)

This analysis shows that the Upper and Lower Lark areas are in deficit whereas the mid Lark and Kennett are in surplus. The calculations are simplistic and contain arbitrary assumptions. However, there is a strong indication that the water resources of the Lark unit are fully committed. The Isleham P.W.S. source has been included in section C, but the source may derive water from section D or even from the Lodes Unit adjacent to the Lark. The apparent surplus in the Kennett is needed to make up the apparent deficit in the lower Lark and is not available for abstraction purposes.

6.3 Summary of Water Resources and Demands

a. The groundwater resources of the Lark Unit are committed. This conclusion is sensitive to the amount of allocated to the river. The recommendations for future work address this issue.

The gross average resource has been allocated as follows, including the small surplue of 1.52 tcmd:

TABLE 19 Allocation of Resources

Unavailable resource (20%)		31.88
Licensed Abstraction	Public Water Supply	53.08
	Spray Irrigation	10.56
	Industrial	17.01
	Gravel Washing (10% taken only)	0.23
	Agricultural	1.88
	Private Water Undertaking	0.37
River Allocation-includes reliable effluents of 20.65.		42.88
Deficit		1.52
	Gross Resource	159.41

b. Some areas of the unit are over licensed. In particular the Upper Lark around Bury St. Edmunds and the Lower Lark near Mildenhall.

c. 31 percent of the total licensed abstraction potentially returns to the river Lark (25.77 tcmd effluents compared to 83.13 tcmd licensed abstractions). Only 75 percent of this is considered to be reliable. Currently, approximately 50 per cent of the public water supply is exported from the unit and all of the spray irrigation water is considered lost (a total of 10.56 tcmd is licensed).

d. The existing problems of low flow, reduced quality and loss of fisheries in the unit are due to abstraction exceeding effluents and recharge, during an extended drought period since August 1988. As an example, despite effluent returns, the flows at Temple Weir gauging station fell to 21 tcmd during summer 1991. This is 65 per cent of the given naturalised 95 percentile of 32.83 tcmd.

e. Total licensed quantity compared to gross resource; 83.13/159.41 x 100, gives 52.1 per cent developed. In some studies 20 per cent development has been used as a 'trigger' for river support.

7. OPTIONS

The options for dealing with each of the perceived problems are discussed :

7.1. The protection of water levels and river flows

The resource balance calculations have indicated that the groundwater resources of the Lark are committed. These calculations have reserved groundwater resources (in addition to reliable effluents) equivalent to a river flow of 42.88 tcmd. This is still a first approximation, based on the natural 95 percentile flow.

Information is required about the ecology of the river system in order to better identify the critical flows, levels and quality necessary to maintain the ecology and other "in river needs" as discussed in section 5.2. These conditions might then be protected and maintained by one or all of the following methods (it is recognised that these methods would need to be researched further in order to identify the feasibility and cost);

a. The introduction of structures in the river,

Tilting gate structures, designed to retain the level of water in low flow periods but also to allow flood flows to pass easily, have been introduced into some rivers. The character of the River Lark may be enhanced by the introduction of similar gates in the upper sections above the navigable stretch. However, there may be land drainage implications and the structures will affect the range and type of habitats in the river and migration of fish.

b. Reducing the wetted area of the river,

It is suggested, but not proven, that the cross section of the river channel has been deepened during the process of opening up the river as a navigation. If the channel is narrowed, locally the level will be increased. In addition, the seepage loss through the banks will be lessened in the low flow situation. The channel cross section should incorporate a narrow channel for low flows but a wider section for flood flows.

In some sections of the river Lark, routine maintenance dredging has already taken this into consideration by restoring natural river widths and leaving shoals/point bars insitu.

c. Lining sections of the river,

This has been included as an option but is not recommended. Lining the banks and bed of the river will interfere with the river to/from groundwater interaction. Since most of the low flows are baseflow from the groundwater, the lining of the bed would prevent the inflow of water to the river.

d. Restoration of In River Channel Features

The morphology of many river channels including the Lark have been severely degraded by the actions of flood defence works. This has largely involved increasing channel capacity and the creation of more uniform channel shape and slope. The restoration of appropriate channel features, such as riffle/pool systems will not only help to restore channel and habitat diversity but will also help to restore more natural flow conditions. This is more environmentally sympathetic than the introduction of structures as described in 8.1.a.

The reintroduction of riffle forming material has already taken place at limited locations within the river Lark (upstream of Temple Weir Gauging Station) and this has been very successful.

e. Providing augmentation water from boreholes or inter basin transfers,

This option has been widely adopted in the Anglian Region. One example is in the River Rhee catchment where water from chalk boreholes is used to supplement the flows and levels in the perennial tributaries and wetland sites.

Boreholes could be sited into the Chalk near the perennial sources of the Lark tributaries and water pumped in during low flow periods. The boreholes would be unable to support stretches where the river is usually intermittent due to the fluctuation of groundwater levels. Figure 27 shows the stretches of river which are known to be perennial. The boreholes would need to be located in order to maximise the "Net Gain" (the gain of the river flow over recirculation losses back to the groundwater).

The practise of using augmentation boreholes is effectively using the Chalk aquifer as a store of water, i.e. borrowing the water from the aquifer in order to supplement the river. The aquifer then needs to be replenished during subsequent years otherwise the overall balance would not be maintained. There must be sufficient overall resource to provide such replenishment, which in the Lark Unit is very limited. The feasibility of river support will depend on the reallocation of water reserved for the river to meet identified critical flow regime (in particular low flows but could also be used to supply high flush flows during the winter). In some areas it may only be possible if the water is imported to the catchment.

f. Including cessation clauses in licences to protect low flows

During the drought years 1990 and 1991 (and possibly to come in 1992), the abstraction for spray irrigation was restricted to protect low flows in the river system. It is suggested that abstraction licences contain clauses by which the abstractor reduces or stops abstraction dependant on the level or flow in the nearby water course (the monitoring point would need to be remote from all abstractors). The abstractor would know the risks and be able to assess whether to accept the licence conditions. The N.R.A. would need to "police" the abstractors to ensure that the condition was complied with. It would be simpler if trigger levels were identified at the nearest gauging station to make control easier. A suitable level could be the 1 in 12 year 7 day minimum flow. 1 in 12 would reflect the level of service inherited in this Region to spray irrigation abstractors.

Any condition on a licence must be defendable, if necessary in a Public Inquiry, and able to be policed.

g. Revoking licences

The N.R.A. has the authority to revoke abstraction licences under the Water Resources Act 1991. If the source has not been used for seven years, the revocation is without compensation.

This has not been investigated in this report. The actual abstraction would need to be compared to licensed abstraction in order to decide whether the practice of revocation would be significant in terms of releasing water resources.

7.2. <u>Protection of river quality</u>

The options available to improve the river quality are;

a. To impose more stringent conditions in discharge consents,

This would have the effect of improving the treatment of effluent and hence there would be less need for dilution. This has already been recognised for Mildenhall Sewage Treatment works, and may be possible elsewhere.

The method of defining consent conditions is based on the long term flow characteristics of the river, represented by the mean and the 95 percentile flow. Future discharge consent conditions are likely to be harsher following this current drought since the long term statistics for the river will be reduced.

b. To introduce structures in the river,

The introduction of "wing dykes" or weirs which only go across part of the channel may be beneficial in terms of mixing flow.

c. Providing augmentation water from boreholes or inter basin transfers,

This would provide extra dilution water during low flow periods (see section 7.1.e). As a generalisation, it is almost always more economic to improve effluent treatment than to provide additional dilution flows.

7.3. <u>Protection of Fisheries</u>

The loss of flow during the drought conditions has resulted in some loss of fish and invertebrates. There would be a need to maintain the level and the flow in the tributaries in order to prevent such loss. The exact level, flow and quality of water needed would be identified by an "in Rivers Needs" study. The methods given in Section 7.1 would then apply.

7.4. <u>Protection of Wetlands</u>

a. Increase monitoring of sites,

There is a need to understand the hydrology and hydrogeology of many of the wetland sites. The programme of monitoring and studies should be maintained or accelerated to obtain this understanding.

b. Definition of Catchment Areas,

The identification of catchment areas which supply water to the wetland site would follow from the monitoring work at the sites. Abstraction should be controlled by either refusal of applications or the use of conditions on the licence to protect the wetland status of the sites if it occurs within a defined catchment area.

7.5. <u>The Increasing Demand for Water Abstraction</u>

Section 5 describes the present demands for water in the Lark Unit and the current list of applications for more water for public water supply, spray irrigation, industry and gravel washing. In addition, demands will increase further into the future.

However, the resources are fully committed. The following options are available;

a. Total embargo of the Lark Unit,

As already stated the water resources of the Unit are committed. It has also been shown that some areas of the unit are over licensed. It would be necessary, therefore, to prevent any increase in water abstraction from the unit at least until research has proved the resource calculations to be different.

b. Issue of licences with strict cessation clauses to protect low flows,

This is described in section 7.1.f.

c. Future assessment of resources,

The assessment of available resources used in this report is still simplistic with arbitrary assumptions. There is a need to refine the method of calculation.

It is suggested that research is completed with respect to; the calculation of recharge to the chalk, the storativity of the chalk (how much of the store is available), the limitations imposed by the need to protect wetlands, the naturalisation of river flows, the interaction of groundwater abstraction and river flows (the Regional Groundwater Model and G.O.R.M. could be updated, refined and calibration reviewed), to review the critical flow, level and quality of the river that should be maintained (carry out an "in river" needs study) and finally to assess the feasibility of augmenting the river flow.

Such assessment <u>may</u> indicate more water available for abstraction.

d. Revokation of Licences

This is described in section 7.1.g.

8. RECOMMENDATIONS

The recommendations have been divided into investigation work that should be carried out in the next five years and an interim licensing policy that will be used until the further investigations have been completed.

8.1 Interim Licensing Policy

The following are recommended. These are in addition to any statutory requirements under the Water Resources Act 1991. The groundwater embargo should remain in force unless and until the investigations detailed in the next section show that additional water is available.

a. Surface Water

Some winter water is available during periods of high flow and abstractors are encouraged to store this water in reservoirs for summer use. Summer water is not available.

b. Groundwater

The groundwater resources of the Lark unit are fully committed.

All applications for increase of annual groundwater abstraction will not be recommended with the exception of the following cases; the abstraction is small (less than 20 cubic metres per day) for which no alternative supply is available, or the abstraction is part of an arrangement which provides for overall net benefit to the environment.

Renewals of time-limited licences for the same quantities should be for ten years duration.

c. Current Licence Applications

i. Anglian Water Services Ltd. - Eriswell and Twelve Acre Wood

The increases required by Anglian Water Services Ltd. at Eriswell and Twelve Acre Wood should only be issued under an aggregate of the total of existing sources at Beck Row, Eriswell, Twelve Acre Wood and Isleham; 9055 tcma (i.e. no increase in total licensed quantity). In addition, compensation flow may be required to maintain levels in the Cut Off Channel and other local derogation issues sorted, including the protection of wetland sites and local groundwater abstractors.

ii. Anglian Water Services Ltd. - Nowton

The new source at Nowton, required by Anglian Water Services to meet demands within the catchment at Bury St. Edmunds, can only be licensed within the existing aggregate of 8000 tcma.

iii. Anglian Water Services Ltd. - Moulton and Rushbrooke

The daily increases at Moulton and Rushbrooke can be granted subject to ensuring no local derogation occurs.

iv. Others

The licence applications given in Table 15 should be determined in accordance with the above licensing policy.

8.2 Further Investigations

The following investigations should be carried out within the next five years. An indication of when the work should be done is given in brackets.

a. "In River Needs" study should be undertaken for the whole of the river system including the part of the Cut Off Channel between the Lark and the Little Ouse. (1993 - 1994)

b. Demand Forecasts should be updated and reviewed.(1992 - 1993).

c. Effluent Return information should be updated and reviewed. (1992 - 1993).

d. Investigation of Recharge Mechanisms. The Recharge model and the Regional Groundwater model should be updated, refined and calibration reviewed. The role of the aquifer storativity also needs to be examined in relation to the practice of reducing the gross resource by 20 percent to become the effective resource (see section 4). (1992 - 1994)

e. Impact of Actual and Licensed Groundwater Abstractions on River Flows. This can be examined by the use of the Groundwater model. All the abstractions should be included and the model updated and calibrated to reflect the current drought conditions. The river to/from groundwater interaction needs to be reviewed and refined. In addition, the G.O.R.M. model should be updated to include the current drought information and the current level of abstractions. (1992 - 1994)

f. Definition of Wetland catchment areas. (1992 - 1996)

g. Restoration of In River channel features and creation of narrow low flow channel. (1992 - 1996)

h. River Augmentation investigation - to meet in river needs identified by a. (1994 - 1996)

i. Revocation of Licences. Examine the scope of unused resources with a view to revoking or reducing licences. (1992 - 1993)

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July 1992

References

Aleobua, B O Y (1987). Aquifer River Interaction in the Lark Catchment of East Anglia. An assessment by means of mathematical modelling using Finite Differences. University of Birmingham, Birmingham.

Butcher R W, Pentelow F T K and Woodley J W A (1930). An investigation of the River Lark and Effect of Beet Sugar Pollution. Ministry of Agriculture and Fisheries. Fishery Investigations Series 1. Vol III no. 3.

Cambridge Water Plan (1984), Anglian Water, Cambridge Division.

Cambridge Water Plan (1985) Parts I and II, Anglian Water, Cambridge Division.

Clarke D A (1986). Lark Groundwater Model Progress Report No. 1. Report PW10, Anglian Water, Cambridge Division.

Clarke D A (1985). Lark Catchment Resources, First Preliminary Report. Anglian Water, Cambridge Division.

Clarke D A (1985). Lark Catchment Resources, Second Preliminary Report. Anglian Water, Cambridge Division.

Green J (1985). Groundwater resource assessment and stream flows in the Bury St. Edmunds area. University of Birmingham, Birmingham.

Ministry of Agriculture, Fisheries and Food (1990). Breckland Environmentally Sensitive Area. Explanatory Leaflet No. BD/ESA/1

Oakes D and Keay D (1990). A resource Model of the Great Ouse River System. Water Research Centre Report No. CO 2504-M, Henley.

Weston D E (1979). The Lark Navigation. St. Andrews Press, Bury St. Edmunds.

Wilson E (1991). The River Lark Project Model Manual. University of Birmingham, Birmingham.

Wright C E (1974). Combined use of surface and groundwater in the Ely-Ouse and Nar catchments. Water Resources Board, Reading.

TABLE 1

Year	Action Taken
1990	Total bans of surface water abstraction from the River Lark and tributaries (except River Kennett) were imposed on 6th August; total bans for abstraction from the River Kennett followed on 8th August. The bans were imposed becasue the flows in the Ely Ouse pond (the section of river impounded above Denver Sluice) has fallen to zero and the the levels were falling significantly, up to 10 cm per day. Irrigation in all upstream catchments was restricted, therefore, to prevent environmental problems in the pond.
1991	The action taken was in accordance with the "Good Irrigation Practice" bookle issued by Ministry of Agriculture, Fisheries and Food, 1991. The following occured: 1. For Catchments 37 and 38 (Lark, Kennett, Cavenham and Tuddenham rivers): 11th June : Amber alerts issued regarding the cessation ofboth surface and groundwater abstraction for Spray Irrigation (S.I.). 5th July : 50 % restriction imposed for groundwater S.I. abstractions 31st July : 50 % restriction for surface water abstraction. 15th August : total ban of all S.I. abstraction with a zone along the river (see Figure). The remainder of the catchment remaining at 50 %. 2. For remainder of catchments 37,38,39,41 and 56: 22nd and 23rd August : 50 % restrictions for groundwater S.I. abstractions imposed. 23rd August : total ban imposed within the zone along the river (see Figure). The remainder of catchments stayed as 50 %.
1992	Consultation group has been set up with the farmers and they have agreed to a voluntary restriction of 50 %. Future bans will depend on the resources situation.

TABLE 2 Table of Groundwater Level Information

Well Ref No.	National Grid Reference	March 1988	September 1991
		metres O.D.	
TL65/43	TL603 593	31.57	12.01
TL65/44	TL626 590	41.44	21.95
TL65/50	TL630 596	39.72	20.94
TL65/53	TL606 568	38.03	19.99
TL65/55	TL649 599	42.25	22.80
TL65/56	TL633 565	56.24	51.44
TL65/64	TL696 568	67.27	59.76
TL65/67	TL643 516	70.45	69.10
TL66/2	TL619 601	34.04	-
TL66/4	TL699 617	57.64	46.05
TL66/55	TL662 637	27.08	15.58
TL66/87	TL613 667	8.93	7.69
TL66/88	TL672 667	22.03	15.01
TL66/89	TL653 681	16.03	12.71
TL66/93	TL647 660	19.76	-
TL66/94	TL600 640	17.89	12.17
TL66/95	TL669 607	53.76	35.98
TL67/77	TL674 724	7.59	5.68
TL67/117	TL677 705	9.83	7.76
TL75/1	TL716 541	70.94	<70.60
TL75/9	TL785 598	65.91	65.65
TL75/68	TL728 597	55.55	47.54
TL75/71	TL720 550	68.52	66.20
TL75/72	TL720 550	88.39	86.37
TL76/2	TL713 699	16.73	<13.67
TL76/6	TL755 614	53.07	52.08
TL76/7	TL784 674	27.12	<21.40
TL76/9	TL785 655	30.12	19.90
TL76/29	TL756 686	22.27	-
TL76/59	TL719 671	26.90	19.80
TL76/110	TL733 650	35.87	25.39
TL77/1	TL711 723	9.28	6.96
TL77/2	TL712 723	9.26	7.22
TL77/3	TL703 718	9.58	< 7.03
TL77/4	TL786 749	35.13	<25.75
TL77/6	TL747 788	11.96	< 6.90
TL77/13	TL779 790	23.79	<10.60
TL77/20	TL712 722	9.36	7.33
TL77/46	TL770 716	15.18	14.14
TL77/48	TL706 794	2.20	1.54
TL77/53	TL735 759	6.51	4.51
TL77/55	TL709 719	9.56	7.37
TL77/56	TL710 717	9.74	7.49
TL77/103	TL763 763	15.16	6.47
TL77/124	TL764 734	-	9.35
TL77/126	TL711 723	-	7.23
TL78/2	TL781 832	7.51	< 4.31
TL78/5	TL797 853	7.89	3.89
TL78/6	TL797 824	17.61	7.06
TL78/7	TL779 819	11.23	< 5.30
TL78/41	TL727 844	100.03	99.85
TL78/54	TL756 835	5.28	2.80

TABLE 2 contd.

Well Ref No.	National Grid Reference	March 1988	September 1991
TL85/1	TL834 567	73.54	73.14
TL85/2	TL894 596	41.16	<37.63
TL85/73	TL821 574	74.40	73.94
TL85/75	TL873 559	55.79	55.22
TL85/76	TL873 559	87.92	86.10
TL86/1	TL832 627	37.35	<31.16
TL86/3	TL823 645	36.66	29.57
TL86/4	TL886 680	64.36	59.03
TL86/5	TL891 611	39.26	31.87
TL86/6	TL816 662	30.98	<25.58
TL86/8	TL800 656	33.59	-
TL86/12	TL810 685	21.31	<17.36
TL86/22	TL884 647	38.03	30.00
TL86/23	TL899 647	45.94	31.86
TL86/31	TL893 617	40.75	32.08
TL86/53	TL836 611	38.35	33.05
TL86/72	TL849 674	27.93	25.28
TL86/116	TL895 662	39.32	32.06
TL86/169	TL870 693	30.08	26.09
TL86/170	TL852 608	36.81	32.07
TL86/171	TL852 638	31.97	26.15
TL87/8	TL893 779	18.96	15.70
TL87/10	TL854 706	25.50	<22.90
TL87/13	TL873 789	16.32	<14.02
TL87/14	TL887 715	31.24	-
TL87/15	TL896 780	21.12	19.58
TL87/24	TL850 777	21.97	16.40
TL87/114	TL827 727	23.23	20.49
TL87/132	TL820 785	26.60	18.98
TL87/133	TL821 760	31.81	23.49
TL96/2	TL936 618	45.70	43.89
TL96/3	TL992 645	39.18	38.95
TL96/5	TL917 643	46.47	38.44
TL96/6	TL974 623	55.46	47.52
TL96/7	TL954 644	44.72	44.07
TL96/9	TL992 685	52.54	42.76
TL96/10	TL929 688	40.90	38.72
TL96/164	TL921 631	48.10	40.85
TL97/1	TL986 782	24.73	23.01
TL97/4	TL950 703	29.68	<24.14
TL97/5	TL964 731	30.06	25.05
TL97/6	TL951 798	18.03	15.21
TL97/14	TL909 781	17.02	14.65
TL97/15	TL904 792	15.89	13.85
TL97/17	TL912 745	22.67	20.95
TL97/138	TL935 794	17.32	14.55
TL97/139	TL900 796	16.71	13.81
TL97/140	TL955 792	19.02	15.68
TL97/141	TL969 794	21.82	17.81
TL97/142	TL915 783	17.20	14.84
TL97/143	TL943 772	26.03	23.27
TL97/144	TL993 764	31.46	26.34
TL97/145	TL926 759	20.19	18.77

TABLE 2 contd.

Well Ref No.	National Grid Reference	March 1988	September 1991
TL97/146	TL953 758	27.22	26.62
TL97/147	TL967 754	28.47	26.71
TL97/148	TL977 745	31.51	26.78
TL97/149	TL992 749	32.08	26.71
TL97/150	TL946 737	26.34	23.84
TL97/151	TL917 725	24.90	23.16
TL97/152	TL937 723	27.29	23.93
TL97/153	TL978 725	35.19	29.00
TL97/154	TL998 723	15.43	18.85
TL97/155	TL999 777	25.01	23.24

TABLE 4

RIVER	STRETCH	STRETCH LENGTH (km)	RECOGNISED RIVER USE
R.Lark	Pinford End Bridge - Gt.Welnetham	3.5	LW,MA
Stanningfield Tributary	Stanningfield Tributary	4	MA
R.Lark	Gt. Welnetham - Culford Stream	13	F_2, SI,LW,H
Rush Brook	Rush Brook	2.5	LW,MA
R.Linnet	Chedburgh - Chevington Trib	2	LA
R.Linnet	Chevington Trib - Lt Horringer Hall	4	MA
R.Linnet	Horringer Hall - R.Lark	6	F_2,MA
Trib R.Lark	BSC Factory - R.Lark	0.5	MA
Trib R.Lark	Fornham - R.Lark	0.1	MA
Culford Stream	Honnington - Great Livermere	2	SI,LW,MA
Culford Stream	Great Livermere - R.Lark	10	F_1,SI,LW,MA
Wordwell Brook	Wordwell Brook	2	F_2,LA
R.Lark	Culford Stream - Mildenhall Gas Pool	11	F_1,SI,LW,HA
Cavenham Stream	Barrow - Cavenham Village	10	MA
Cavenham Stream	Cavenham Village - R.Lark	2	F_1,HA
Tuddenham Stream	Headwaters - Tuddenham Mill	2	SI,LW,HA
Tuddenham Stream	Tuddenham Mill - R.Lark	2	F_1,SI,LW,HA
R.Lark	Mildenhall Gas Pool - Ely Ouse	20	F_2,SI,LW,HA
R.Kennett	Headwaters - Badlingham Manor Bridge	21	MA
R.Kennett (or Lee Brook)	Badlingham Manor Bridge - R.Lark	5	F_2,SI,LW,HA
Chippenham Lodge Tributary of R.Kennett (or Lee Brook)	Chippenham Lodge Tributary of R.Kennett (or Lee Brook)	2	MA

KEY :

F_1	fisheries supporting a breeding population of trout/grayling
F_2	fisheries supporting a breeding population of non-salmonid fish
IWS	industrial water supply
SI	spray irrigation
LW	livestock watering
HA	high amenity
MA	Moderate amenity
LA	low amenity

TABLE 6 : Discharges made to the River Lark System

Ref. No.	Site Name	Nat. Grid. Reference	Dry Weather Flow (m^3/d)
A. Sewage Treatment Works (Anglian Water Services Ltd.)			
110	Rougham	TL883 628	337
111	Isleham	TL645 757	261
112	Mildenhall	TL689 744	4600
113	West Stow	TL810 708	810
114	Bury St. Edmunds	TL844 680	11000
115	Gt. Welnetham	TL876 602	190
116	Hawstead	TL847 596	220
117	Prickwillow	TL596 827	100
119	Chippenham	TL665 702	51
120	Gazeley	TL711 633	200
121	Lidgate	TL714 584	85
122	Tuddenham	TL739 708	1100
123	Barrow	TL781 638	363
125	Chedburgh	TL795 588	400
126	Stanninfield	TL877 568	83
274	Kentford	TL704 665	<50
275	Kirtling	TL692 569	<50
477	Prickwillow	TL606 829	<20
B. Trade Effluents			
A	British Sugar	TL853 654	3000
B1	Greene King	TL854 635	1591
B2	Greene King	TL856 635	545
C	Chafers	TL792 575	68
D	Sappa Chicks	TL840 678	91

TABLE 5 Current Non-PWS Abstraction Applications in the Lark Unit

A. Existing Licence Quantity in tcma
B. Quantity applied for in tcma
C. Different between A. and B.
D. Further Impact on Resource.

App. No.	Name (Use)	Lic. No.	A.	B.	C.	D.
C/445	Taylor Farms (Spray Irrigation)	38/38	0	275	275	275
C/335	Anne Unwin Farmers (Spray Irrigation)	37/287	91	182	91	91
C/557	Peach Malt Ltd. (Industrial)	37/11	25	36.36	11.36	11.36
-	C. Palmer & Sons (Spray Irrigation)	-	0	60	60	60
C/432	Allen Newport Ltd. (Gravel Washing)	-	573	812	239	23.9*
C/89	R.C. Browne & Sons (Spray Irrigation)	-	0	275	275	275
C/429	Elveden Farms (Spray Irrigation)	37/304	945.6	945.6	0	0
C/333	R.H. & R.A.Brittain (Gravel for Spray Irrigation)	-	0	11	11	11
C/302	T.D. Barclay & Sons (Spray Irrigation)	37/308	340.8	454	113.2	113.2
-	T.C. Cobbold (Spray Irrigation)	-	0	250	250	250
C/10	Tarmac Roadstone (Spray Irrigation)	-	0	120	120	120
-	G.A. Thornally (Spray Irrigation)	-	0	113.6	113.6	113.6
-	West Suffolk Health (Hospital, licensing existing use)	37/179	0	95	95	0
C/590	P.Palmer (Agricultural)	-	0	5	5	5
C/594	R. Taylor (Agricultural)	-	0	4.3	4.3	4.3
C/610	Rushbrooke Farms (Spray Irrigation)		91	91	0	0
C/613	Maynard House Orchards (Spray Irrigation)		9.1	9.1	0	0
C/536	N.W. Peachy (Horticultural)		0	5	5	5
	[redacted]		[redacted]			
-	Crandene Nuseries (Horticultural)		0	5	5	5
	TOTALS (TCMA)		[redacted] 2075.5	3748.9	1693.5	1363.4 +

+ 1363.4 [redacted] tcma divided by 365 is 3.74 [redacted] tcmd.

* Assume 10% of Gravel Washing as Impact

contd. on next page

TABLE 15 CONTD.

Applications not included in the groundwater assessment :

C/462	Taylor Farms (Surface)	-	0	230	230
C/509	N.H. Plummer & Son	-	0	196.8	196.8
-	Tarmac Roadstone (chalk for gravel washing)		0	385.0	385.0

TABLE 20 : HISTORY OF LICENSED GROUNDWATER ABSTRACTION

YEAR	PWS	PWS INCL.AGG	IND	SPRAY	AGRIC/AMEN	WASH	PWU	TOTAL with AGG PWS
1966	12055	15747	2194.238	597.188	300.164	0	0	18838.59
1967	12055	15747	2727.828	987.958	464.586	819.434	38.764	20785.57
1968	12055	15747	3260.453	1291.879	610.034	886.807	38.764	21834.937
1969	12055	15747	3262.817	1169.057	610.034	2005.148	38.764	22832.82
1970	12055	15747	2904.22	1198.471	609.376	2005.148	38.764	22502.979
1971	15783	15747	3489.012	1164.167	603.826	2005.148	38.764	23047.917
1972	15783	15747	3403.285	1165.084	599.753	2005.148	38.764	22959.034
1973	18116	15747	3403.285	1219.455	595.63	2005.148	38.764	23009.282
1974	20604	17207	4893.224	1263.098	594.44	2005.148	38.764	26001.674
1975	20604	17207	4586.862	1585.173	563.174	2006.558	38.764	25987.531
1976	20604	17207	4586.862	1544.43	560.329	2006.558	38.764	25943.943
1977	19239	17207	4586.862	1514.981	551.918	2006.558	38.764	25906.083
1978	18694	17207	4627.772	1587.936	551.918	2008.562	38.764	26021.952
1979	18694	17207	4577.765	1652.572	551.918	2826.762	38.764	26854.781
1980	18694	17207	4660.715	1878.079	580.558	2008.464	38.764	26373.58
1981	18694	17207	4699.438	1814.681	564.058	2008.464	38.764	26332.405
1982	18694	17207	4701.026	1802.299	594.253	2008.464	38.764	26351.806
1983	18694	17207	5178.056	2131.472	594.253	2008.464	38.764	27158.009
1984	19376	17207	5511.556	3201.026	594.253	2008.464	38.764	28561.063
1985	19376	17207	5697.724	3076.193	594.253	2008.464	38.764	28622.398
1986	19376	17207	5543.024	3110.338	593.798	2008.464	38.764	28501.388
1987	19376	17207	5542.86	4820.395	593.796	2010.734	38.764	30213.549
1988	19962	18066	5542.86	4815.105	593.796	2010.734	38.764	31067.259
1989	19962	18327	6211.46	5214.413	597.596	2010.734	38.764	32399.967
1990	22176	17318	6211.46	5269.759	753.373	1465.202	38.764	31056.558
1991	22176	17318	6211.46	5075.952	712.686	825.02	38.764	30181.882
1992	20676	19373	6211.46	3776.452	686.955	825.02	38.764	30911.651

TABLE 20 b Sub Unit Breakdown (1992) OF LICENSED ABSTRACTION

Sub Unit	P.W.S. (incl.Agg)	Industry	Spray	Agric/Amen	10% Wash	P.W.U.	Total
A	4000	4358.113	711.76	79.335	0	95	9244.208
B	4273	1725.502	2004.377	137.529	82.502	21.38	8244.29
C	9055	82.95	93.734	114.973	0	0	9346.657
D	2045	44.895	1043.801	355.118	0	17.38	3506.194
Total	19373	6211.46	3853.672	686.955	82.502	133.76	30341.349

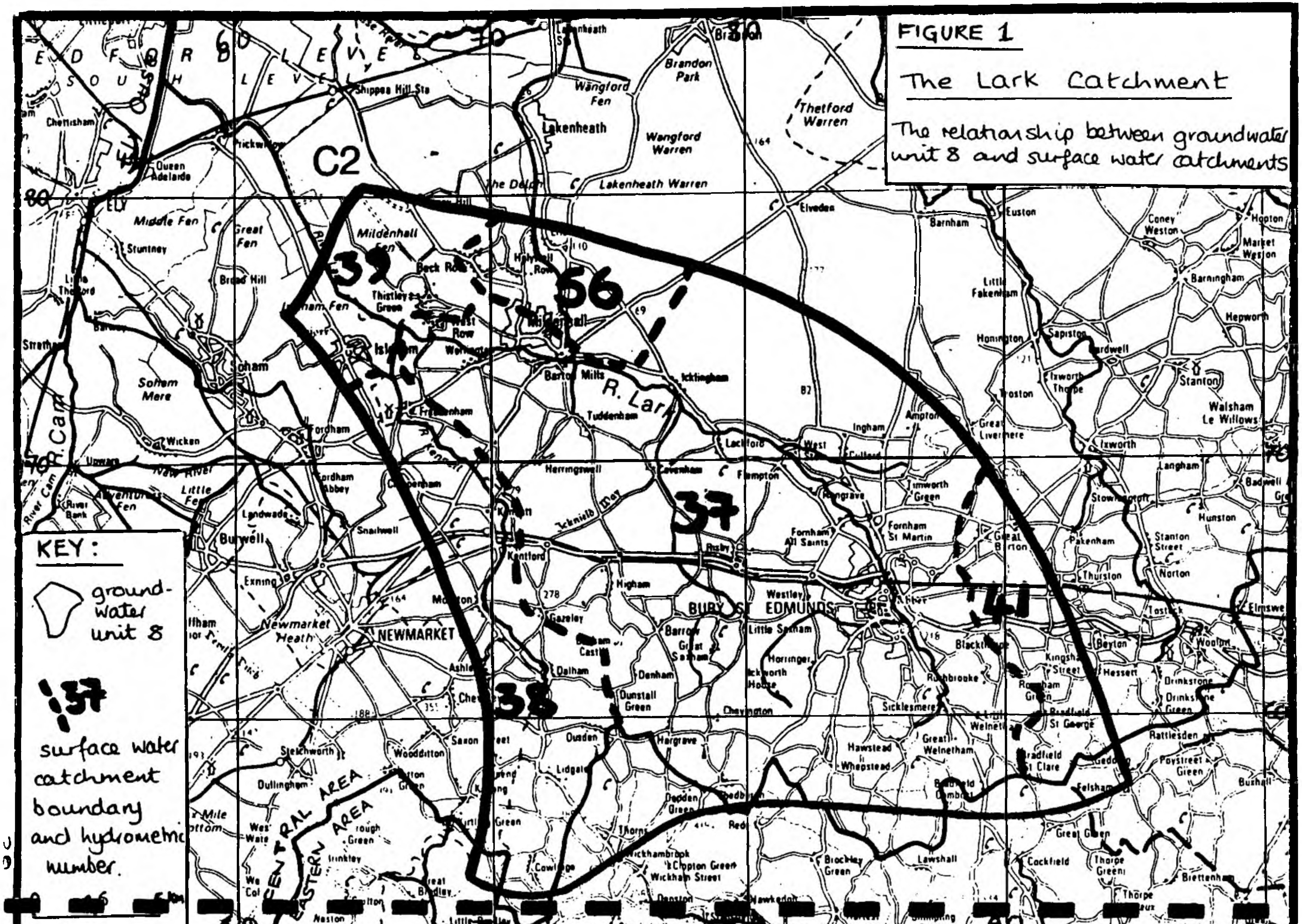
TABLE 20 contd. HISTORY OF LICENSED SURFACE WATER ABSTRACTION

YEAR	IND	SPRAY	AGRIC/AMEN	TOTAL
1966	0	613.449	4.682	618.131
1967	0	865.521	4.909	870.43
1968	4.682	873.977	202.301	1080.96
1969	0	977.629	202.301	1179.93
1970	0	916.395	202.301	1118.696
1971	0	930.529	202.301	1132.83
1972	0	916.337	202.301	1118.638
1973	0	952.706	202.301	1155.007
1974	0	979.982	202.301	1182.283
1975	0	1028.047	202.301	1230.348
1976	0	1028.047	202.301	1230.348
1977	0	1179.367	202.301	1381.668
1978	0	1286.315	202.301	1488.616
1979	0	1247.035	262.001	1509.036
1980	0	1033.675	202.301	1235.976
1981	0	1105.952	202.301	1308.253
1982	0	1334.111	202.301	1536.412
1983	0	1307.881	202.301	1510.182
1984	0	1392.361	202.301	1594.662
1985	0	1273.986	202.301	1476.287
1986	0	1410.386	18.2	1428.586
1987	0	1610.46	18.2	1628.66
1988	0	1601.27	0	1601.27
1989	0	1651.839	0	1651.839
1990	0	1682.259	0	1682.259
1991	0	1653.871	0	1653.871
1992	0	1566.52	0	1566.52

FIGURE 1

The Lark Catchment

The relationship between groundwater unit 8 and surface water catchments



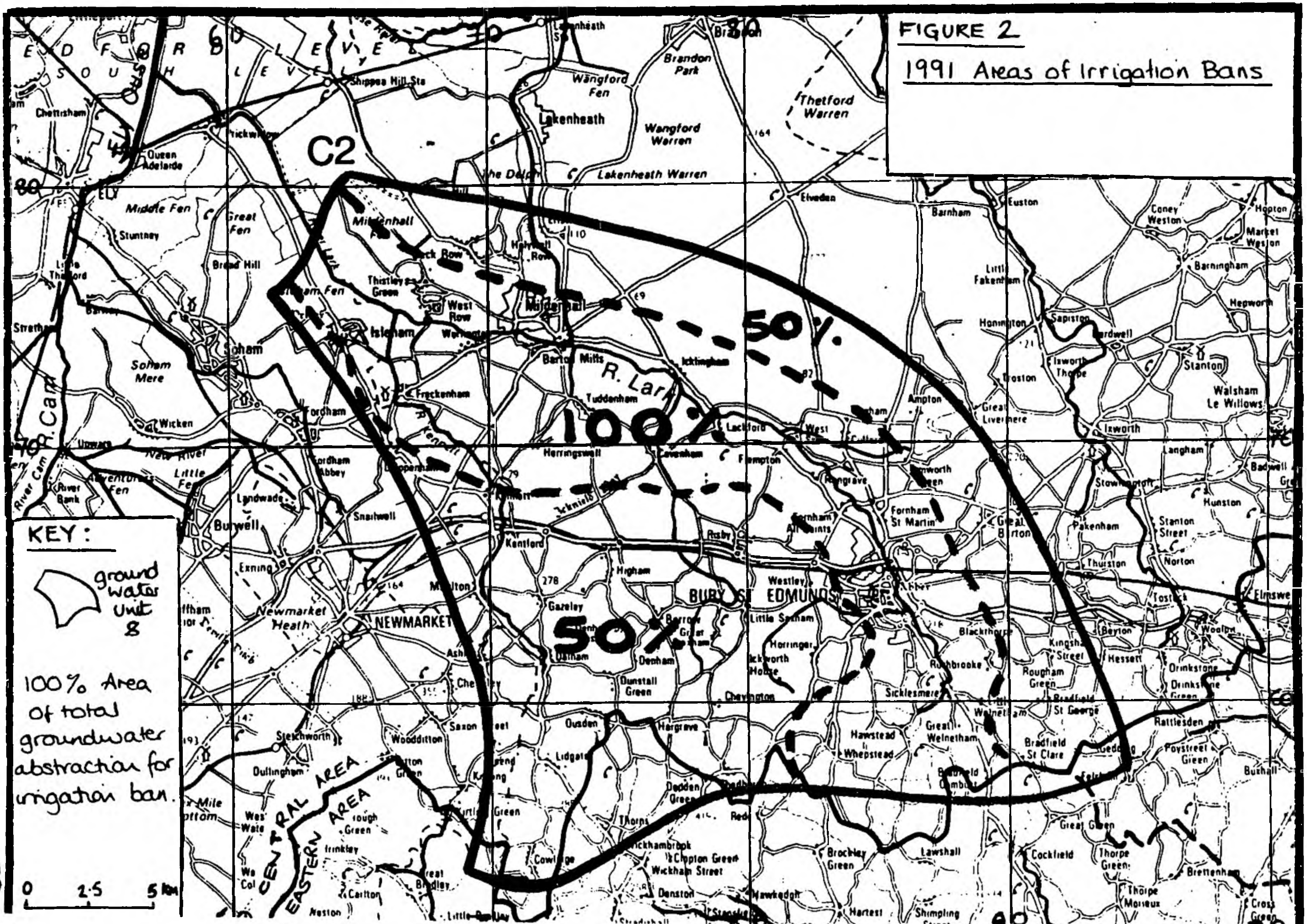
KEY:

groundwater unit 8

37 surface water catchment boundary and hydrometric number.

FIGURE 2

1991 Areas of Irrigation Bans



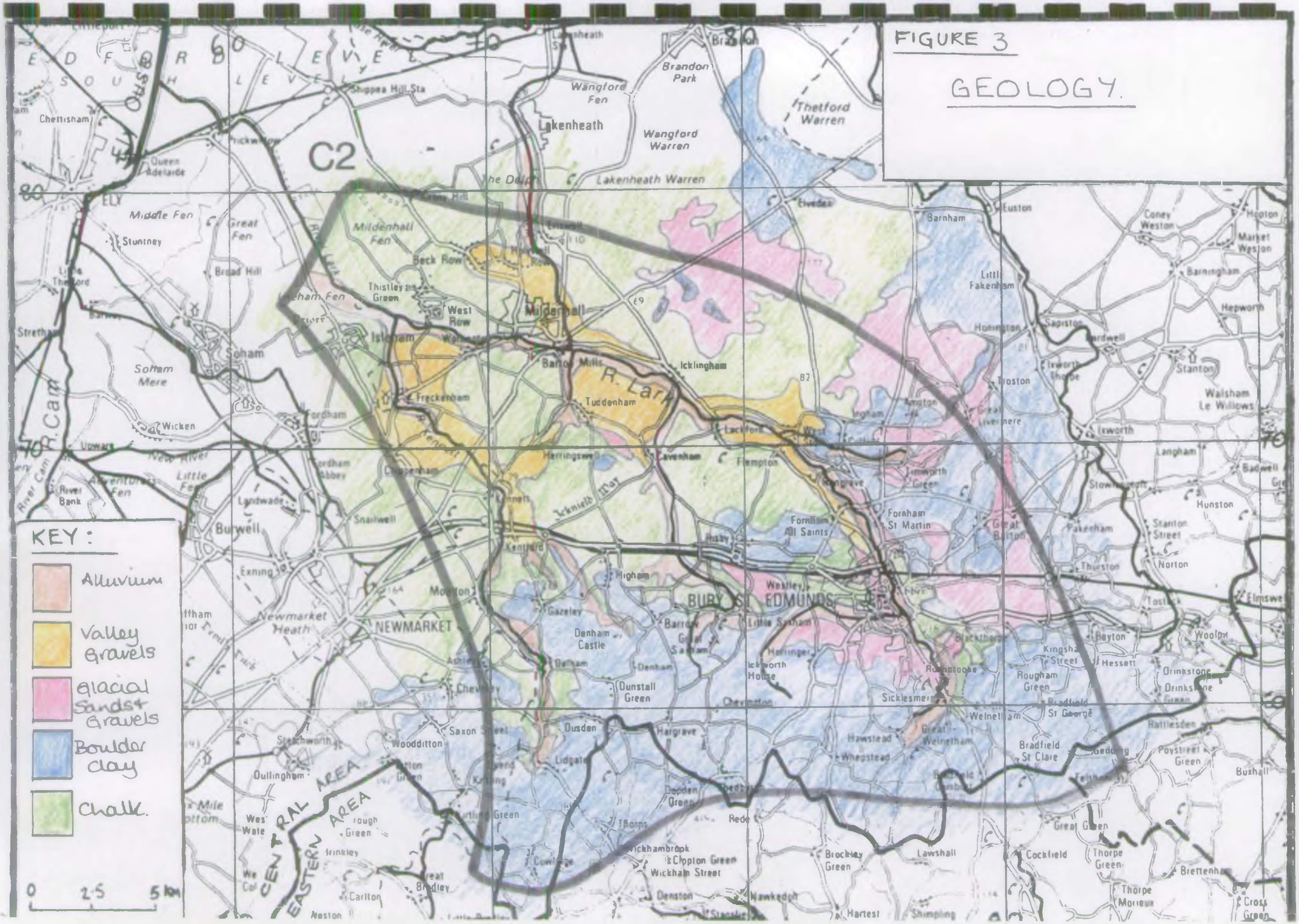


FIGURE 3

GEOLOGY.

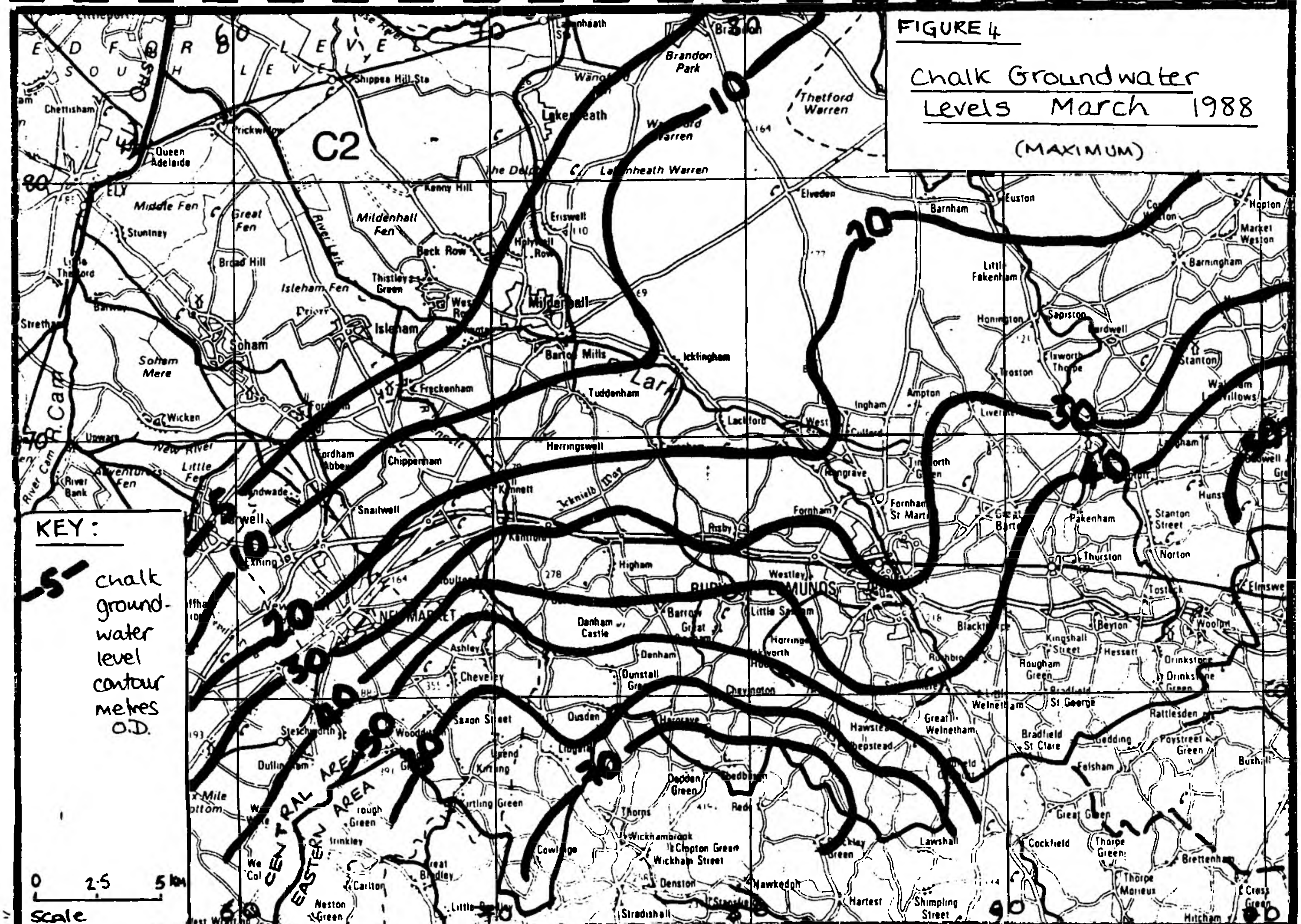


FIGURE 4

Chalk Groundwater Levels March 1988

(MAXIMUM)

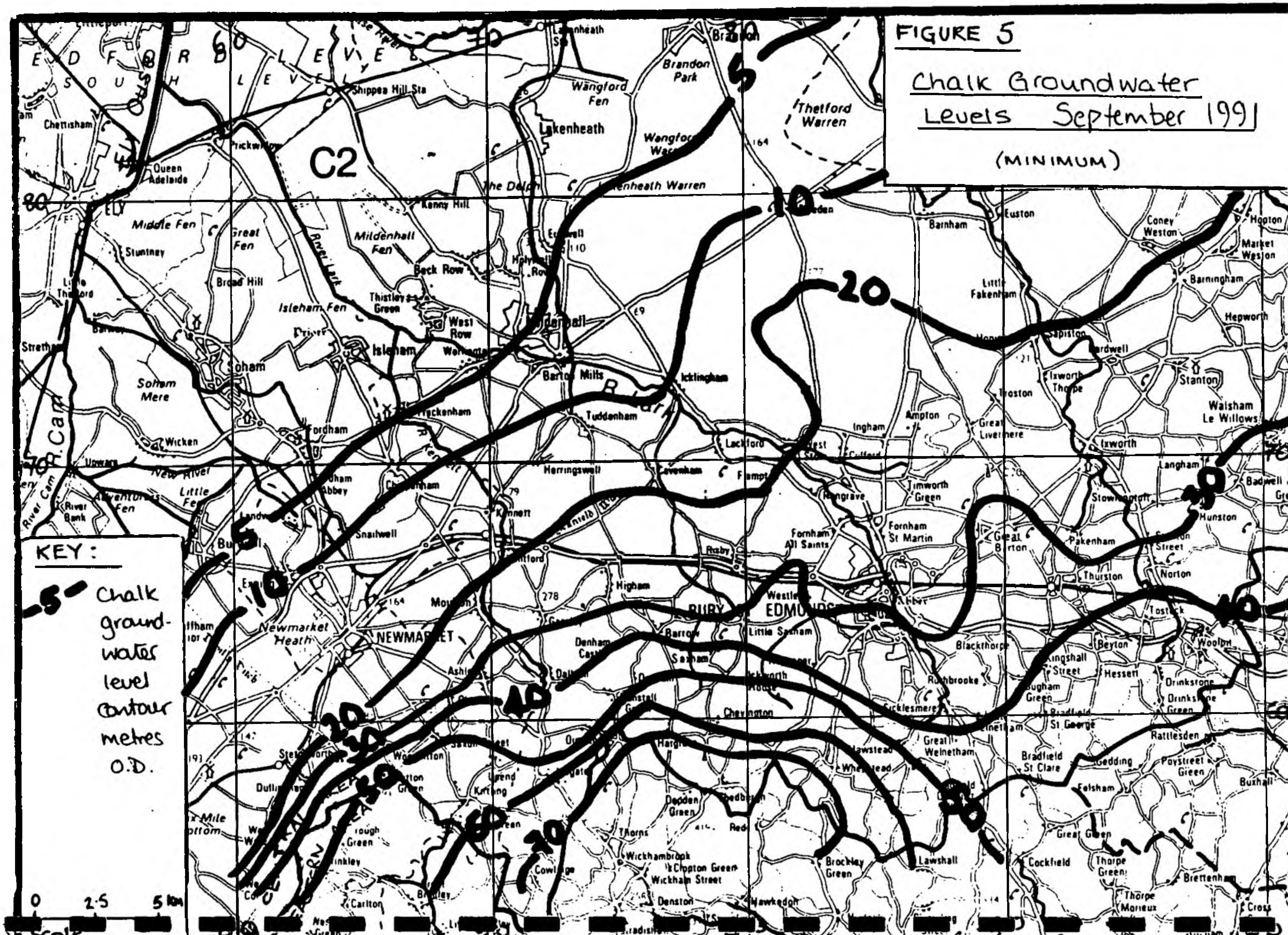


FIGURE 5
Chalk Groundwater Levels September 1991
(MINIMUM)
KEY:
-5- Chalk groundwater level contour metres O.D.
0
2.5
5 km
C2
5
10
20
30
40
50
60
70
80
Brandon
Brandon Park
Thetford Warren
Lakenheath
Wangford Fen
Mildenhall Fen
Isleham Fen
Soham
Soham Mere
Newmarket Heath
NEWMARKET
Tuddenham
Icklingham
Barton Mills
Ixworth
Pakenham
Thurston
Fornham St Martin
Fornham All Saints
Little Saxham
Bradfield St Clare
Lawshall
Brockley Green
Cockfield
Barnham
Euston
Hepworth
Stanton
Walsham Le Willows

FIGURE 6 : FLOW DURATION CURVE

R. LARK, Fornham St. Martin.

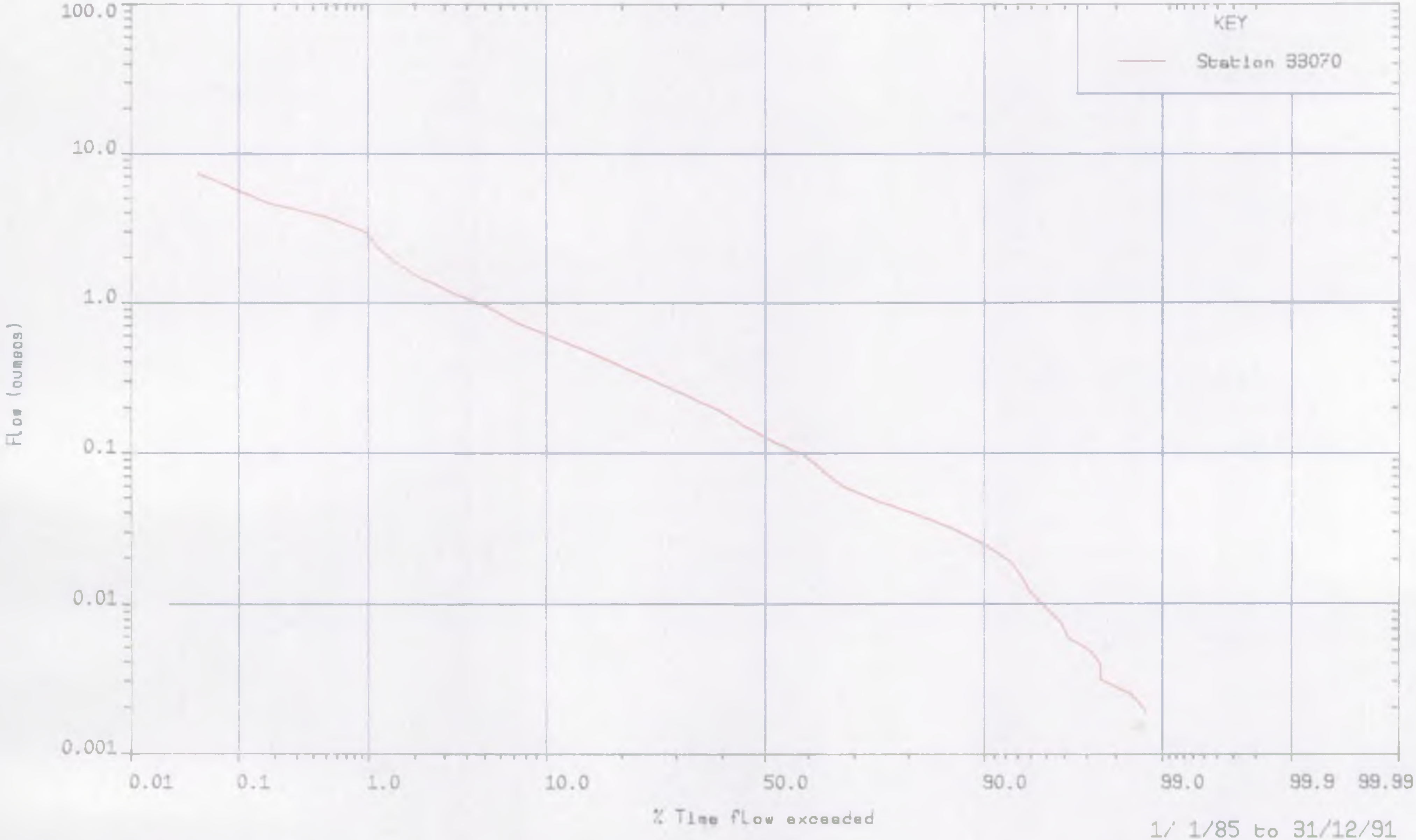


FIGURE 7 : FLOW DURATION CURVE
R. LARK, Temple.

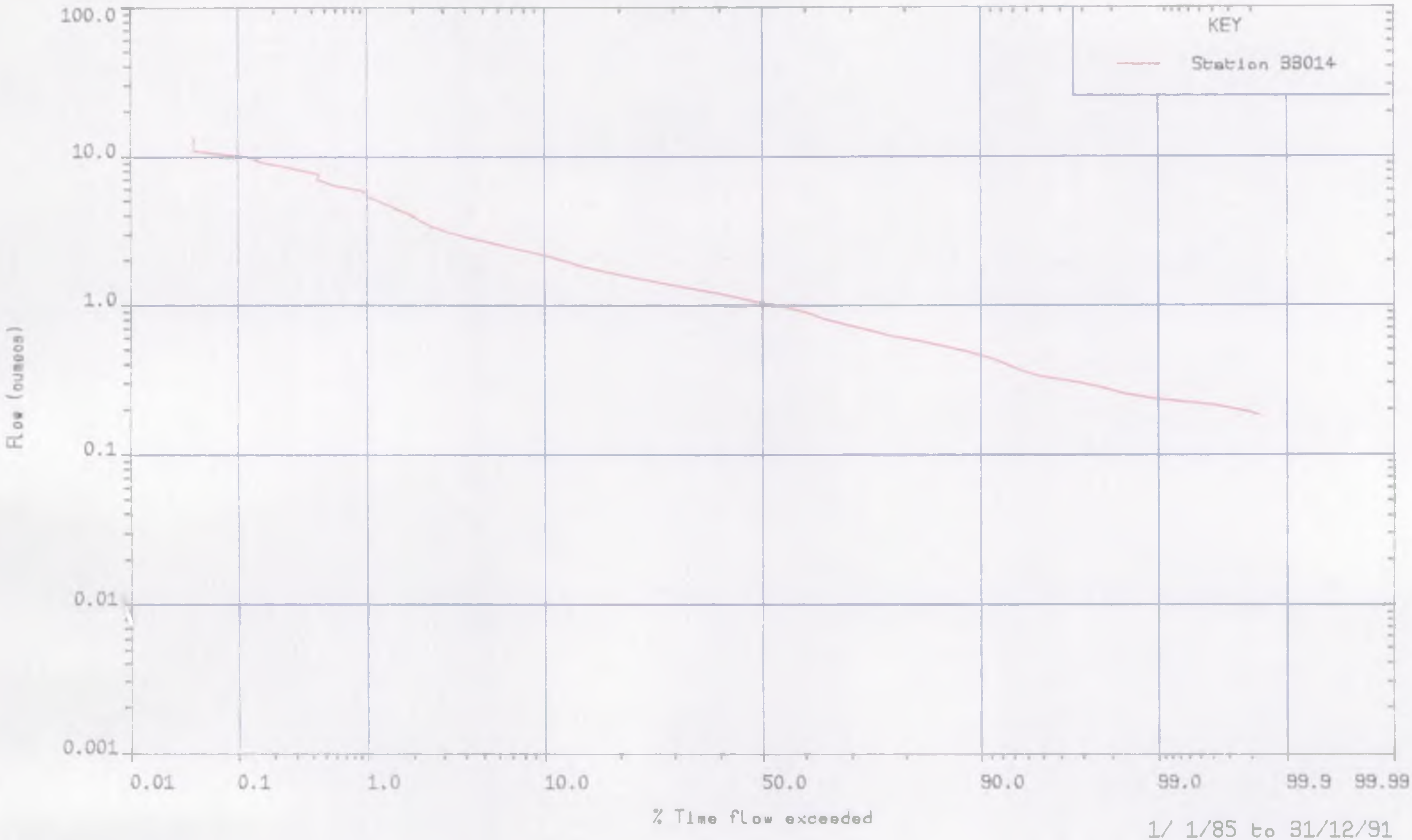
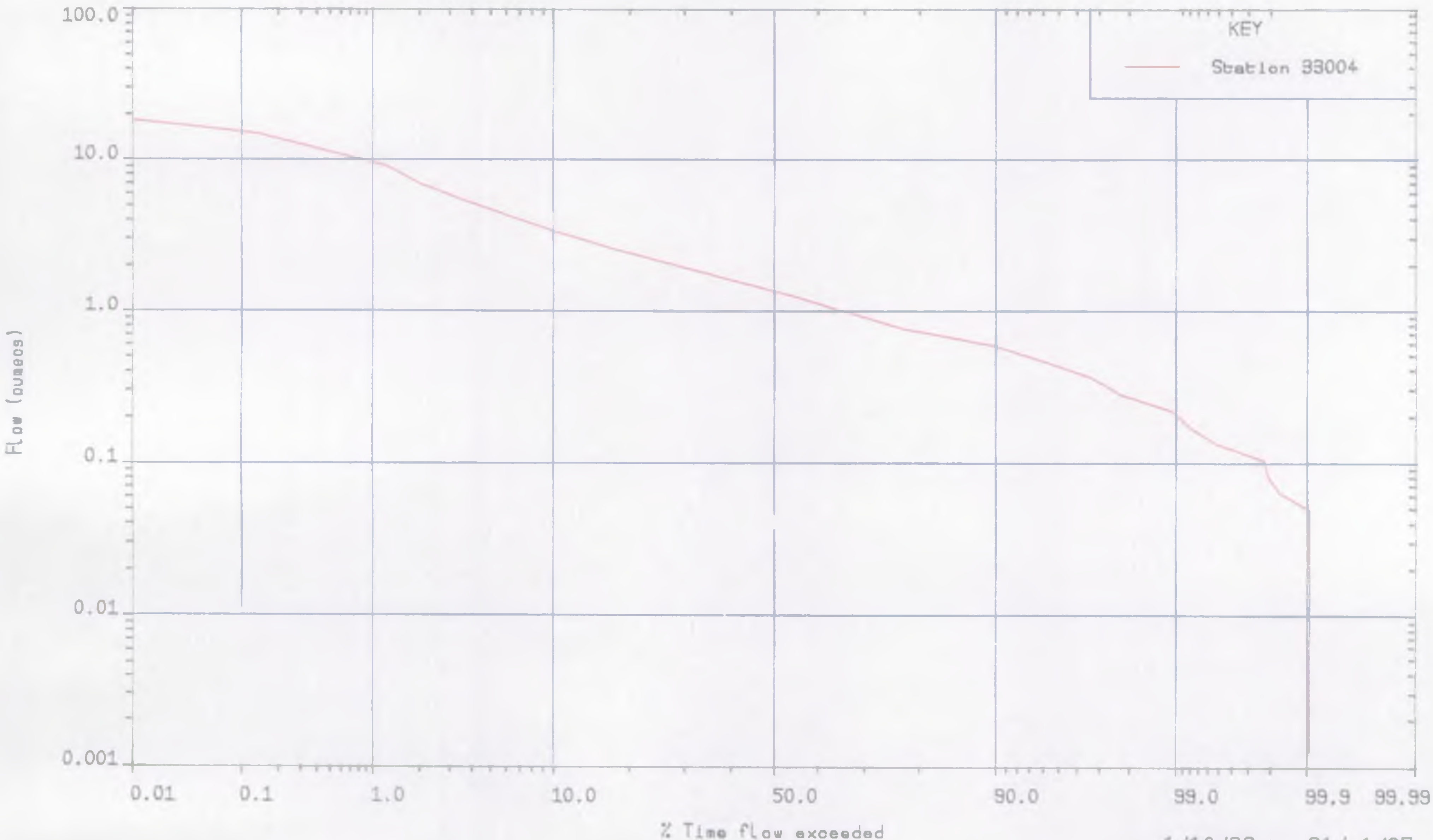


FIGURE 8 : FLOW DURATION CURVE

R. LARK, Isleham.



1/10/36 to 31/ 1/85

FIGURE 9 : FLOW DURATION CURVE

LEA BROOK, Beck Bridge.

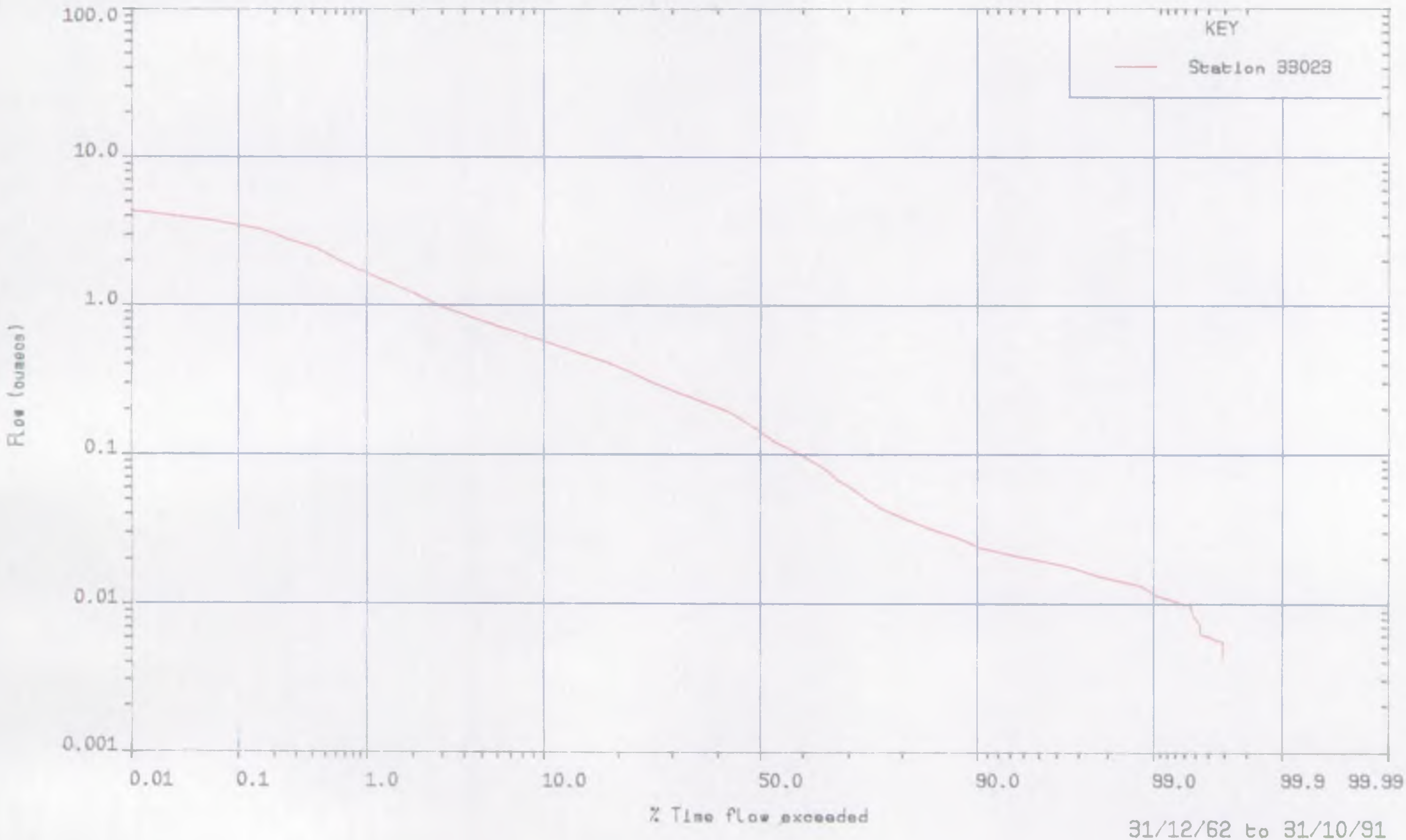
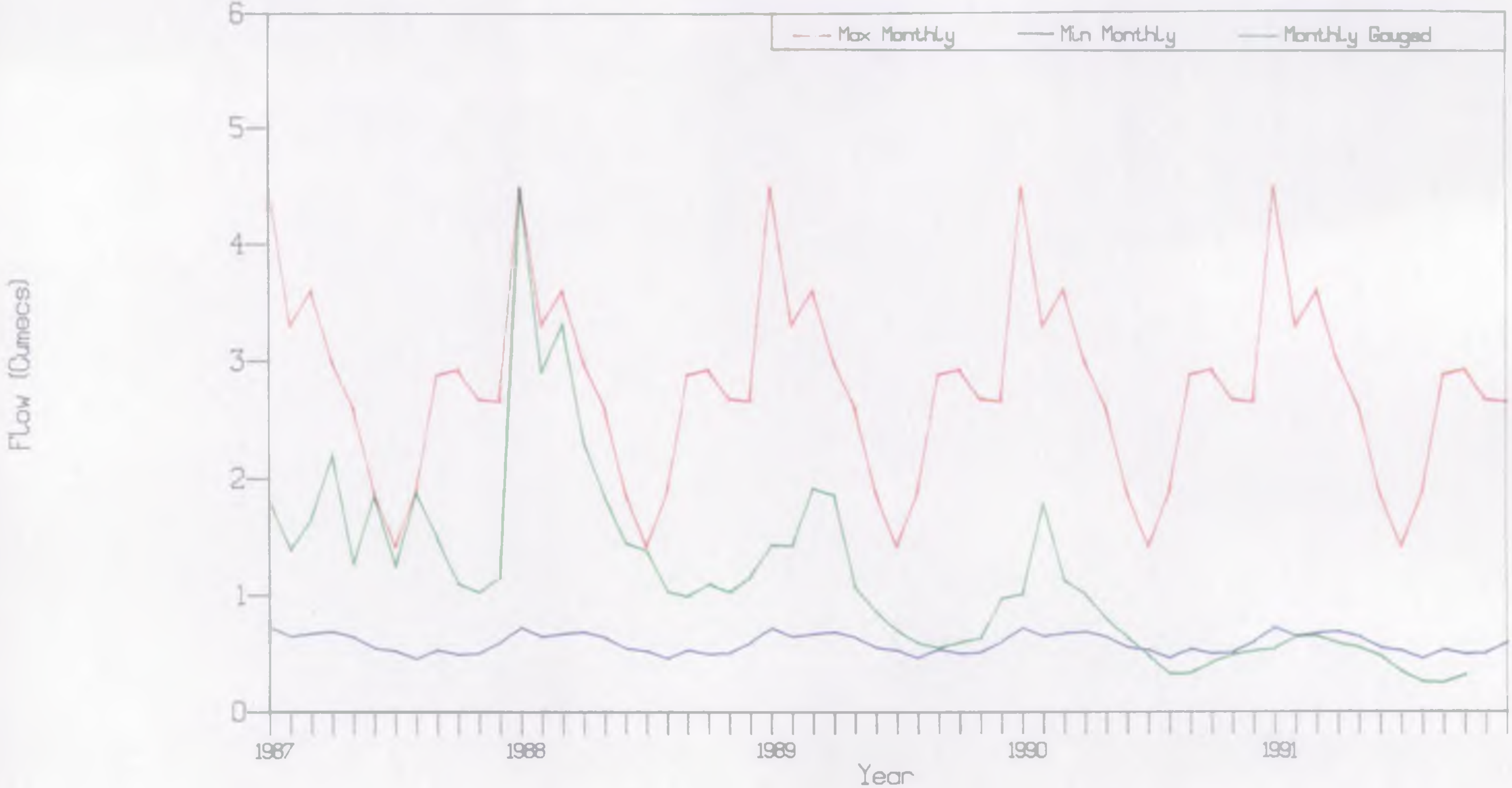


FIGURE 10

River Lark, Temple Weir.
Monthly Mean Flows 1987-1991.



Max and Min Monthly Flows taken from 1960 - 1988

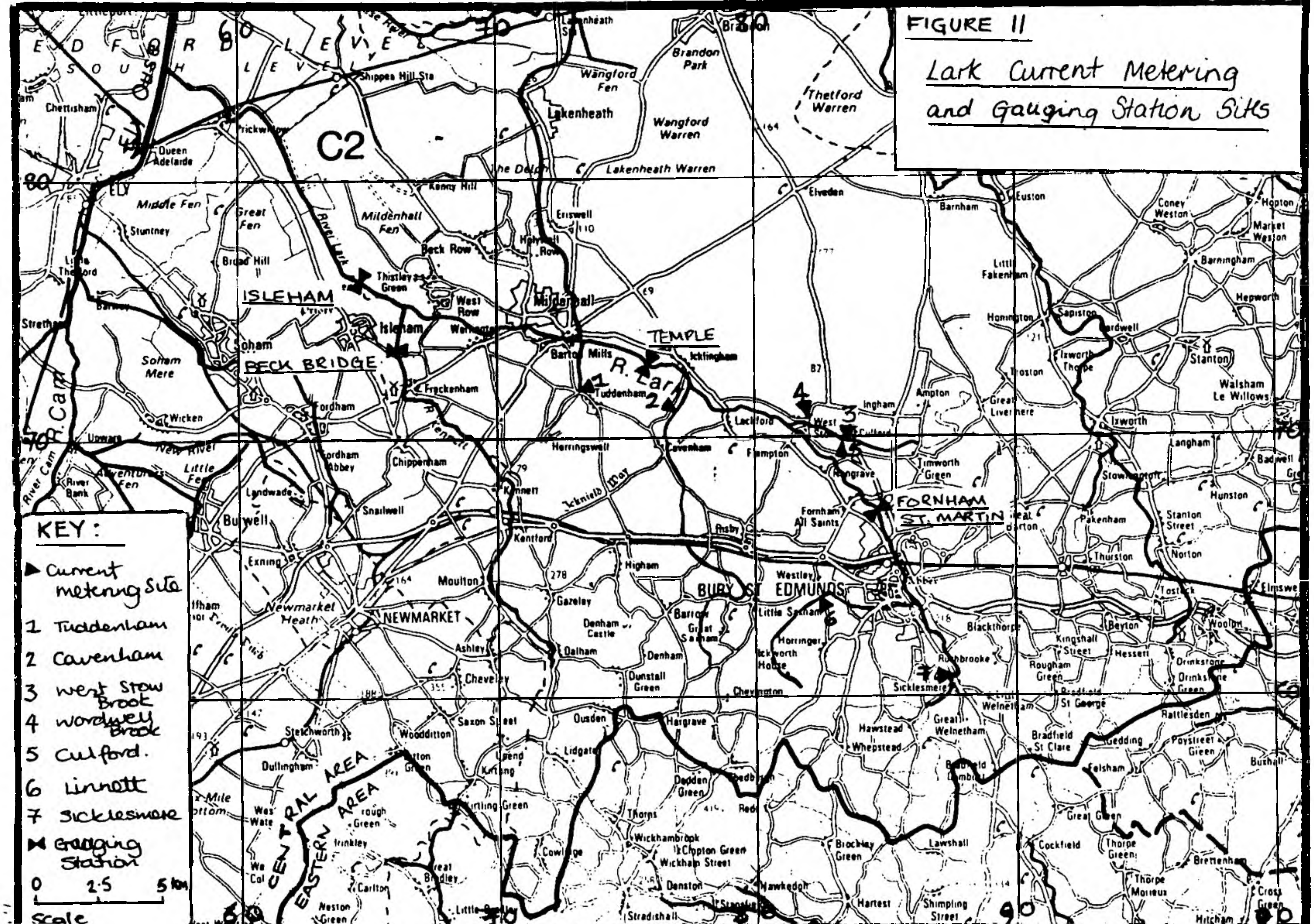
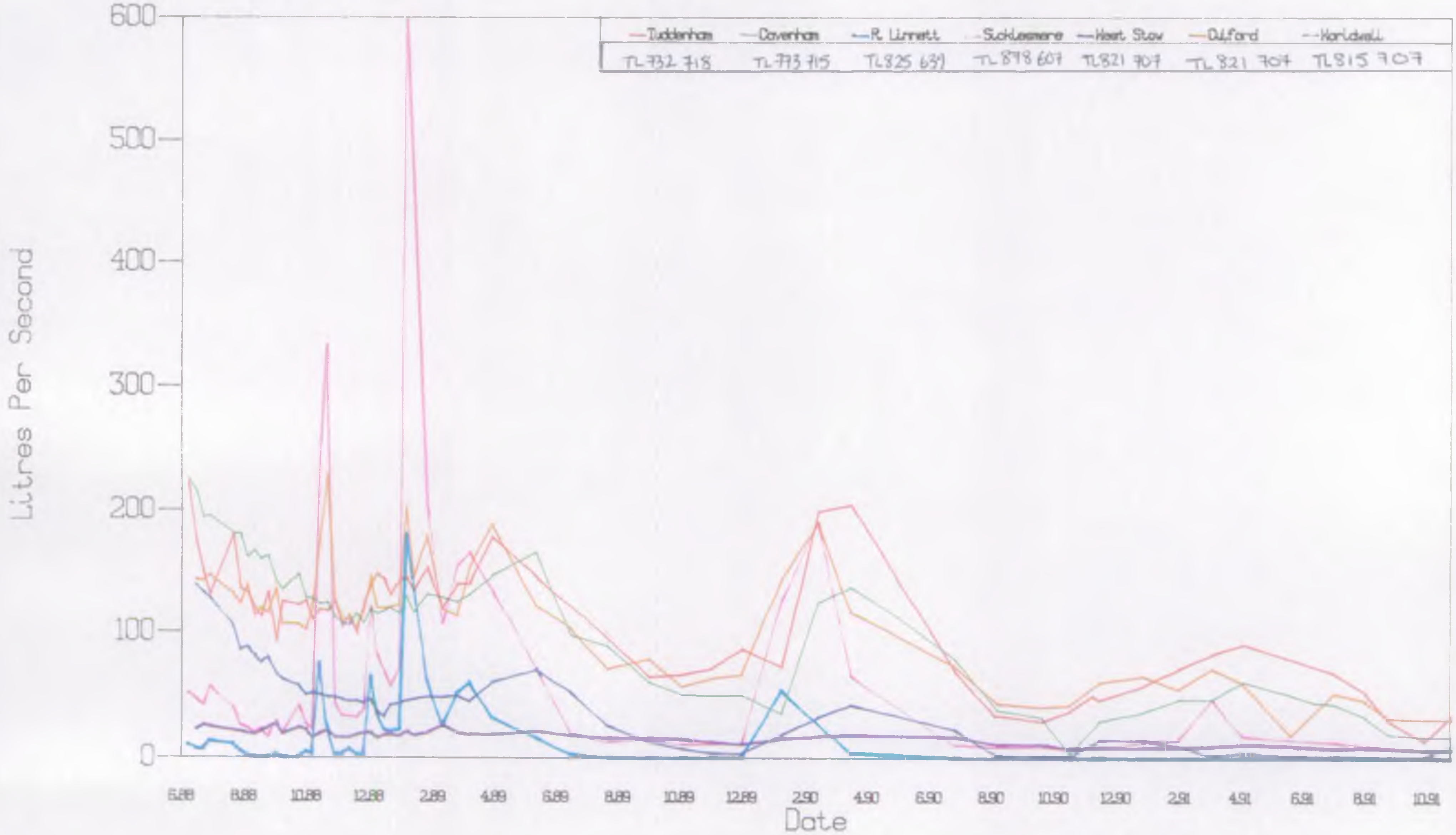


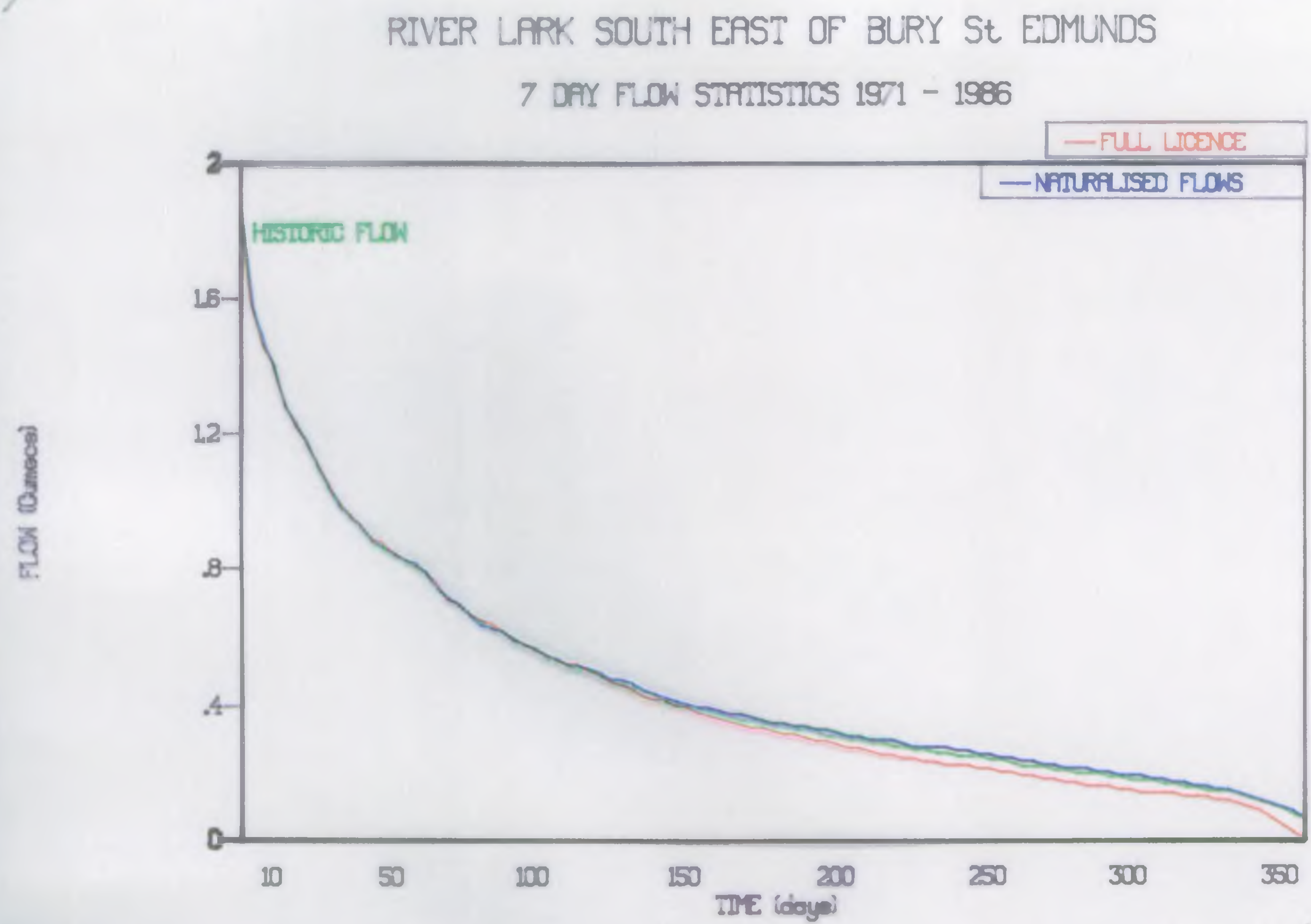
FIGURE 11

Lark Current Metering and Gauging Station Sites

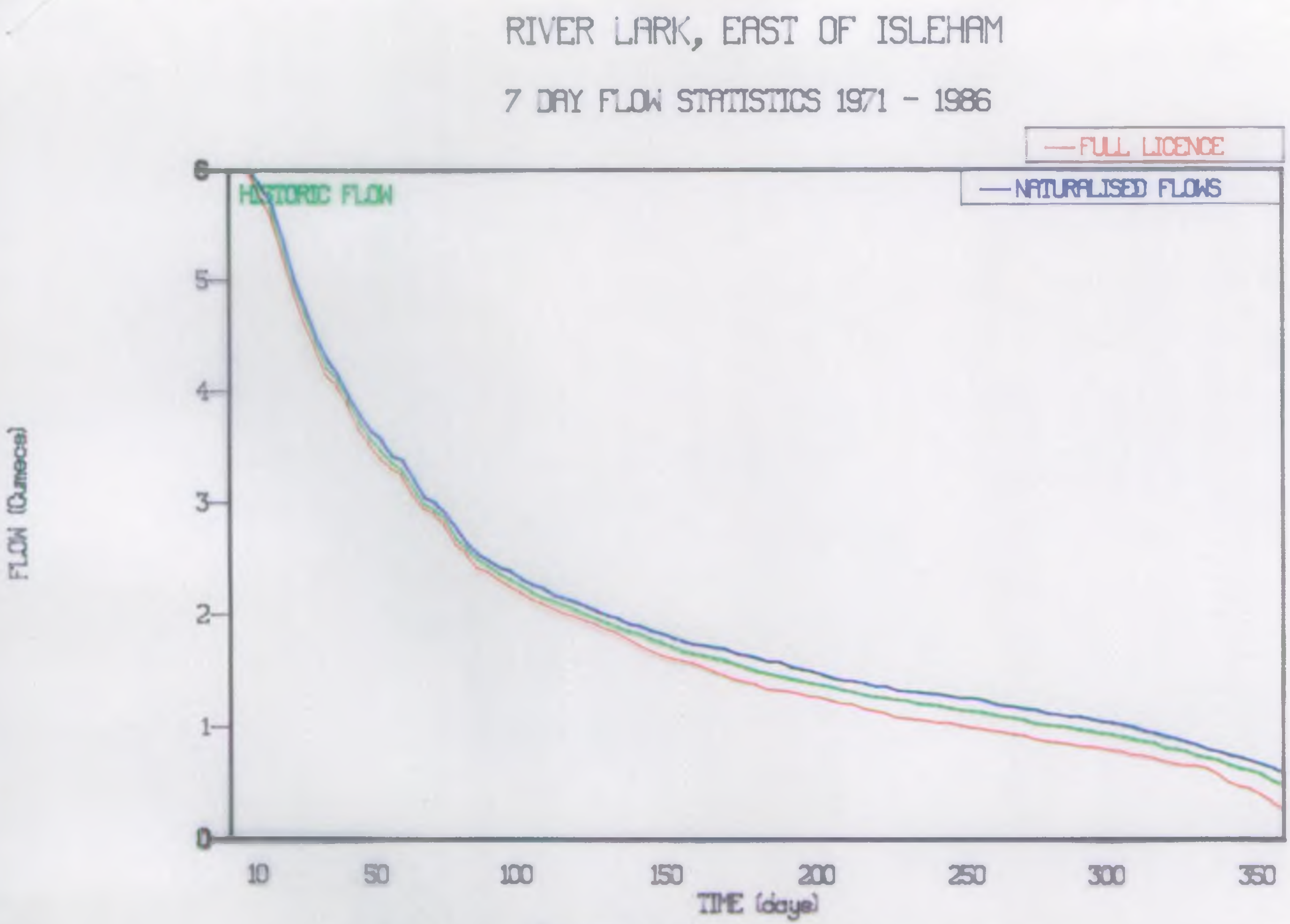
FIGURE 12:

River Lark Current Metering





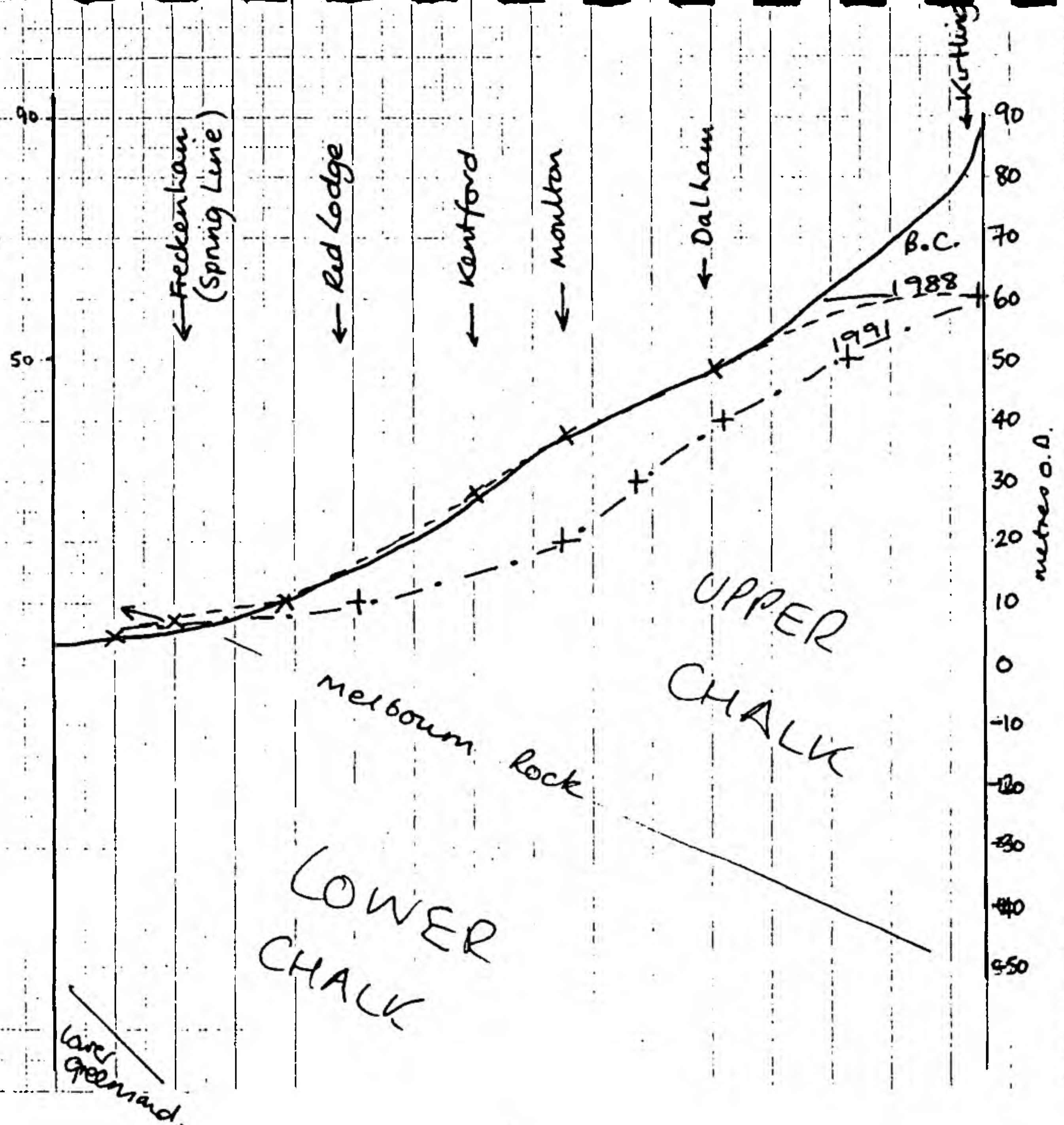
GORM model FLOW DURATION CURVES



GORM model FLOW DURATION CURVES

FIGURE 14

FIGURE 15



X = March 1988 chalk water level

+ September 1991 chalk water level.

Schematic Cross Section Along River Kennett Valley.

Sicklesmere : August 1991

Fornham Lock : September 1991

FIGURE 16

Barton Mills : September 1991

Cavenham Mill : August 1991

FIGURE 17

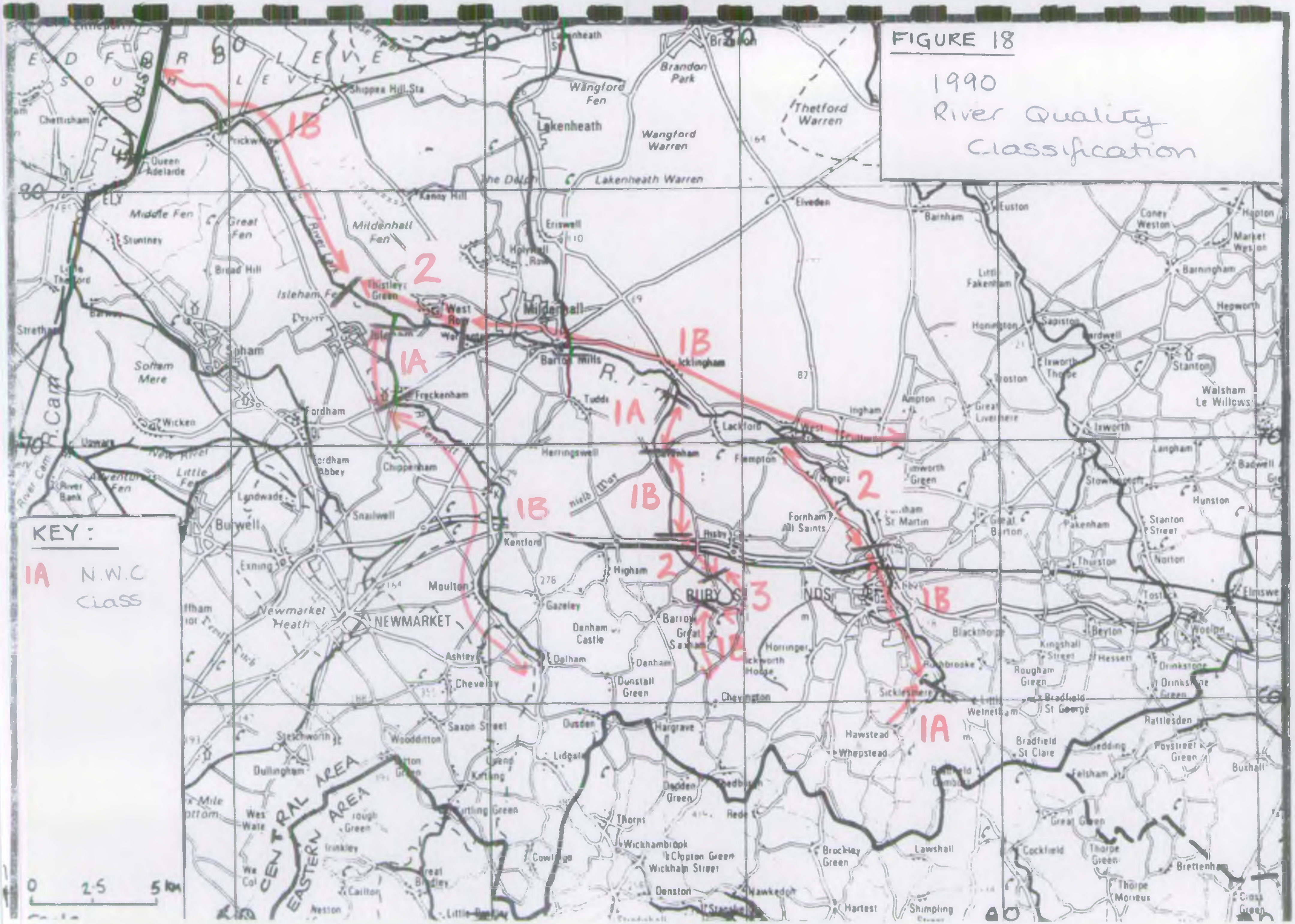
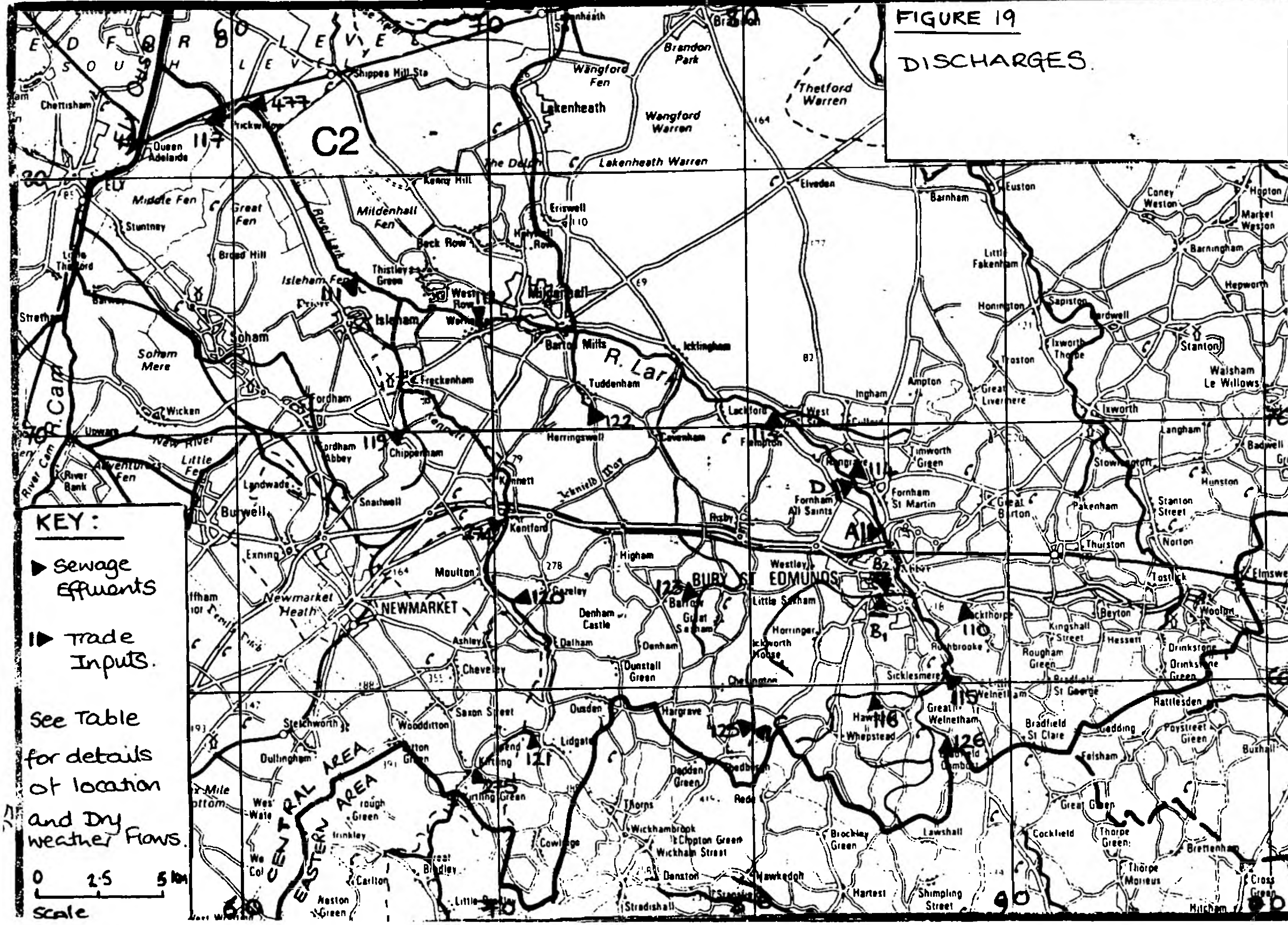


FIGURE 18

1990 River Quality Classification

FIGURE 19

DISCHARGES



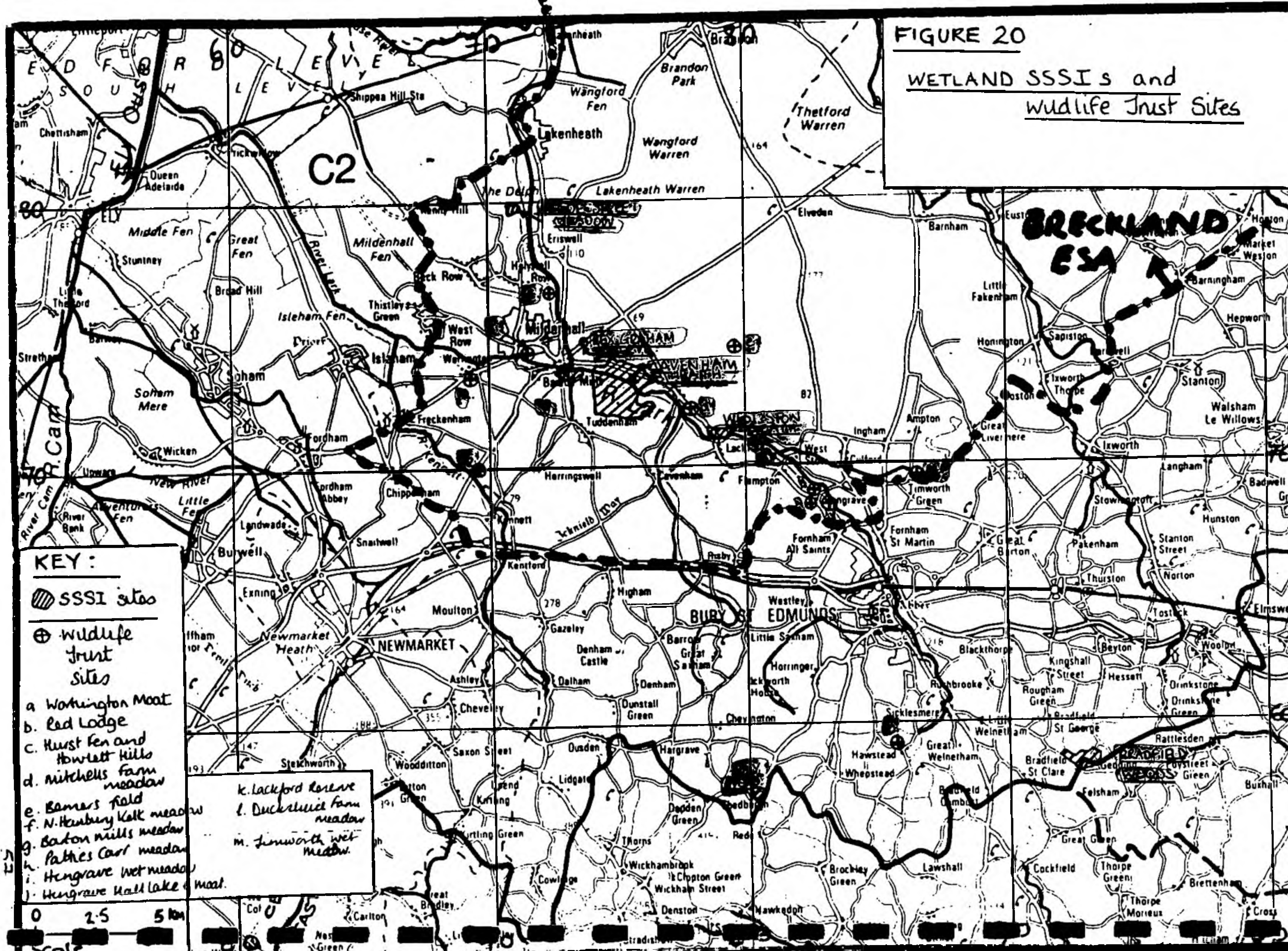
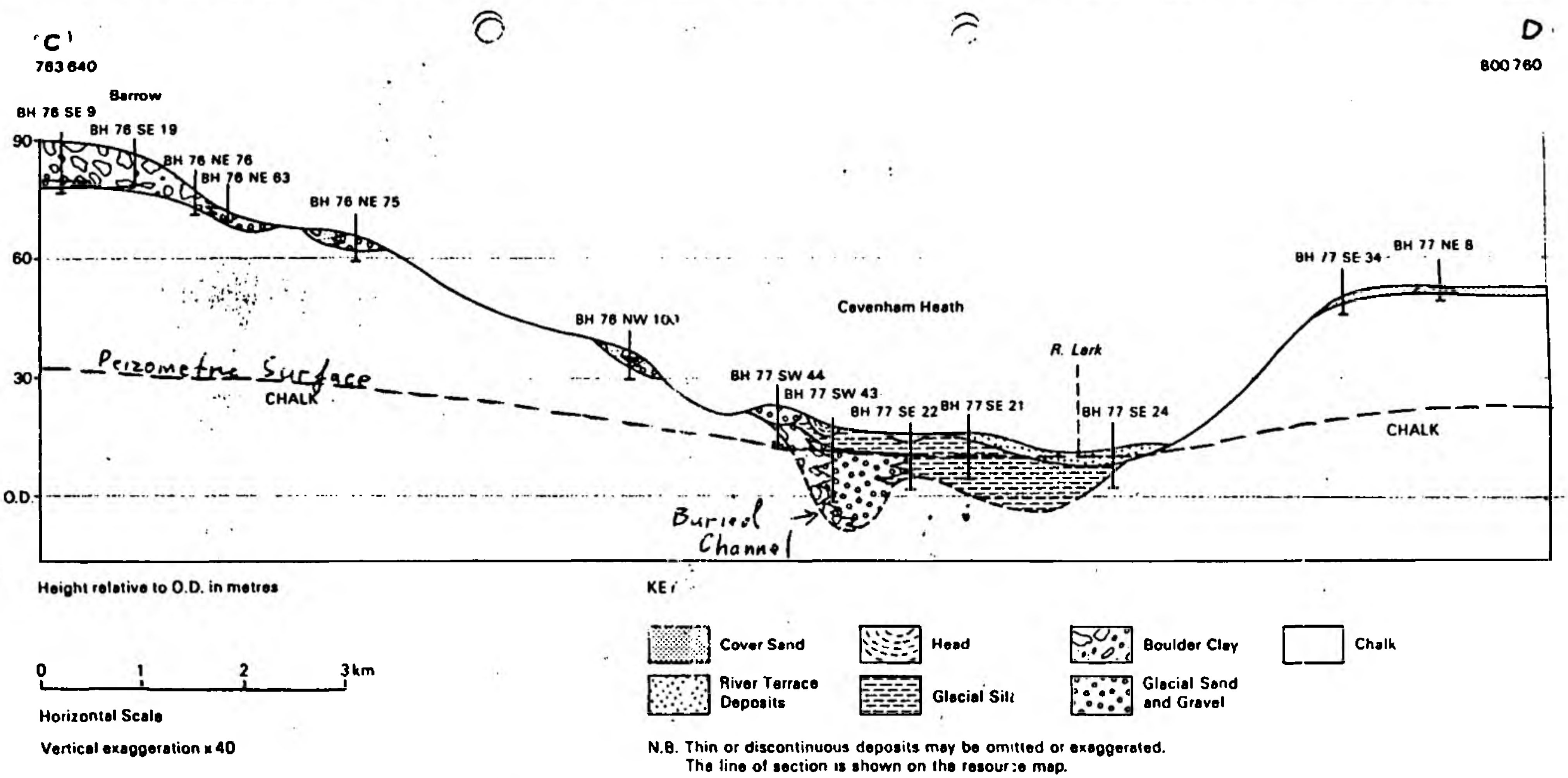


FIGURE 20

WETLAND SSSIs and Wildlife Trust Sites



Generalised geological section across the district showing the relationships between the principal Drift deposits.

From. Mineral Assessment Report 123
TL76, 77 Mildenhall and Barrow, Suffolk.

FIGURE 21.

FIGURE 22

Regional Groundwater Model Grid for Lark Unit

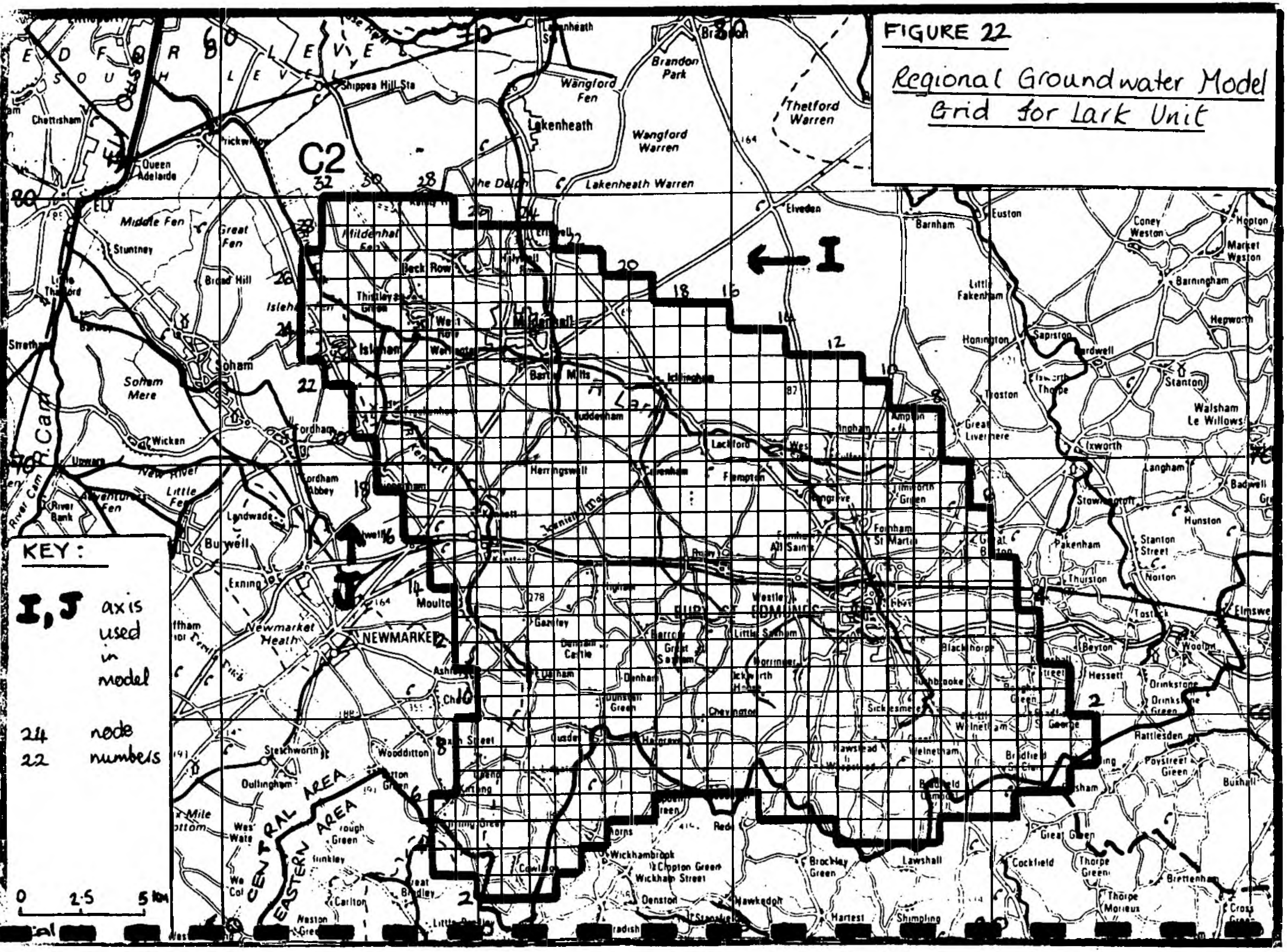
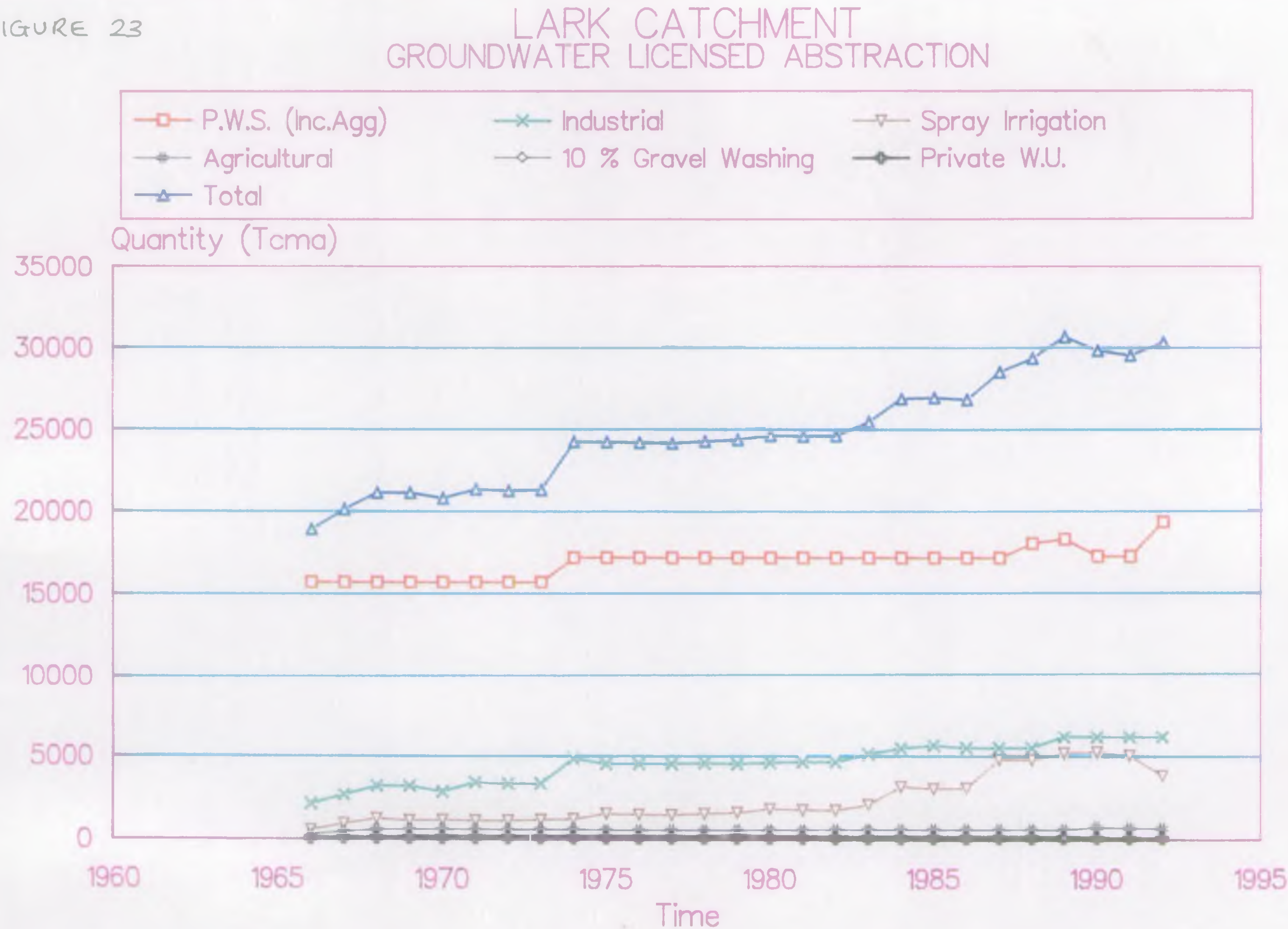


FIGURE 23



LARK CATCHMENT
GROUNDWATER LICENSED ABSTRACTION
P.W.S. (Inc.Agg)
Industrial
Spray Irrigation
Agricultural
10 % Gravel Washing
Private W.U.
Total
Quantity (Tcma)
35000
30000
25000
20000
15000
10000
5000
0
1960
1965
1970
1975
1980
1985
1990
1995
Time

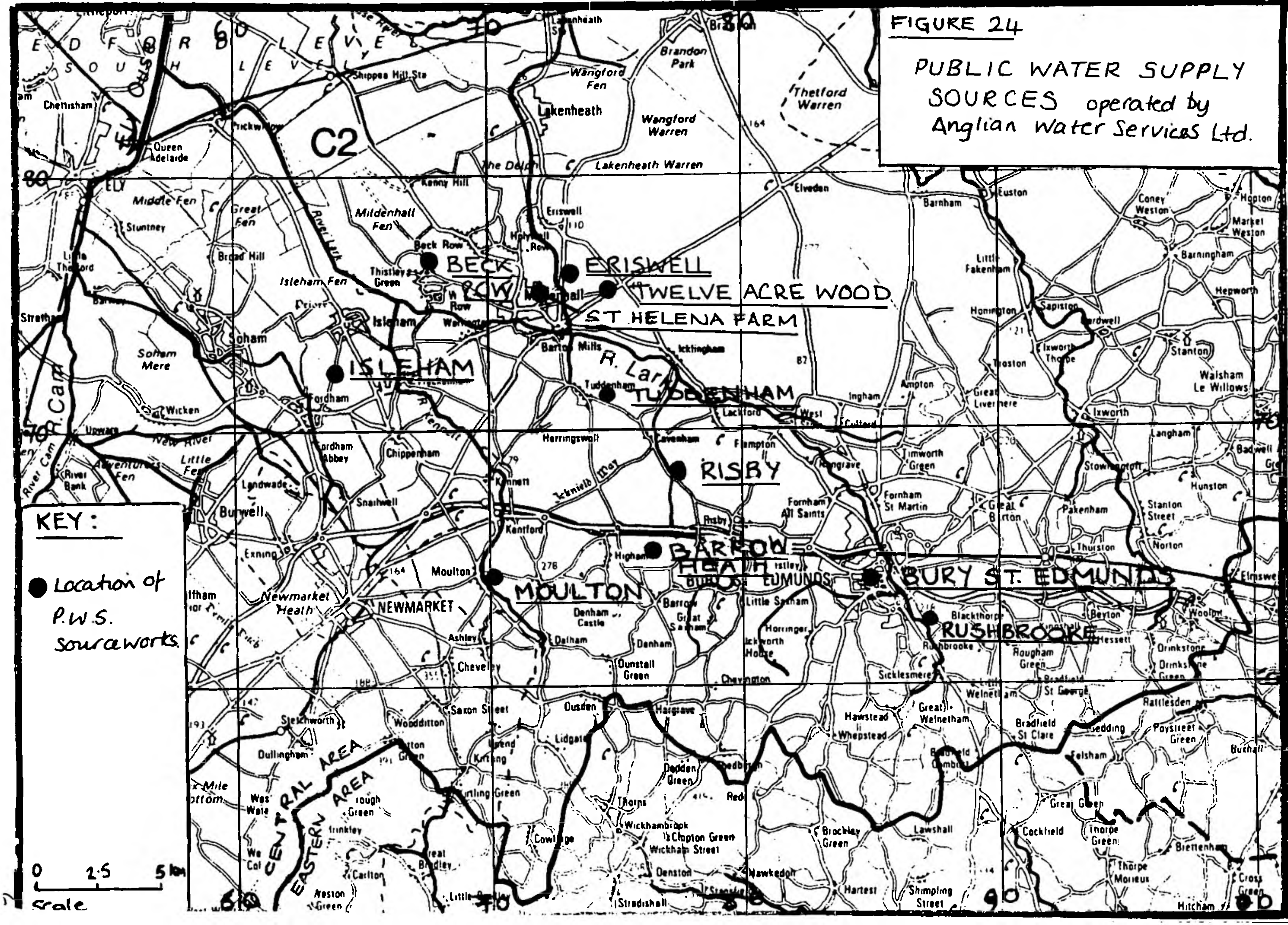


FIGURE 24

PUBLIC WATER SUPPLY SOURCES operated by Anglian Water Services Ltd.

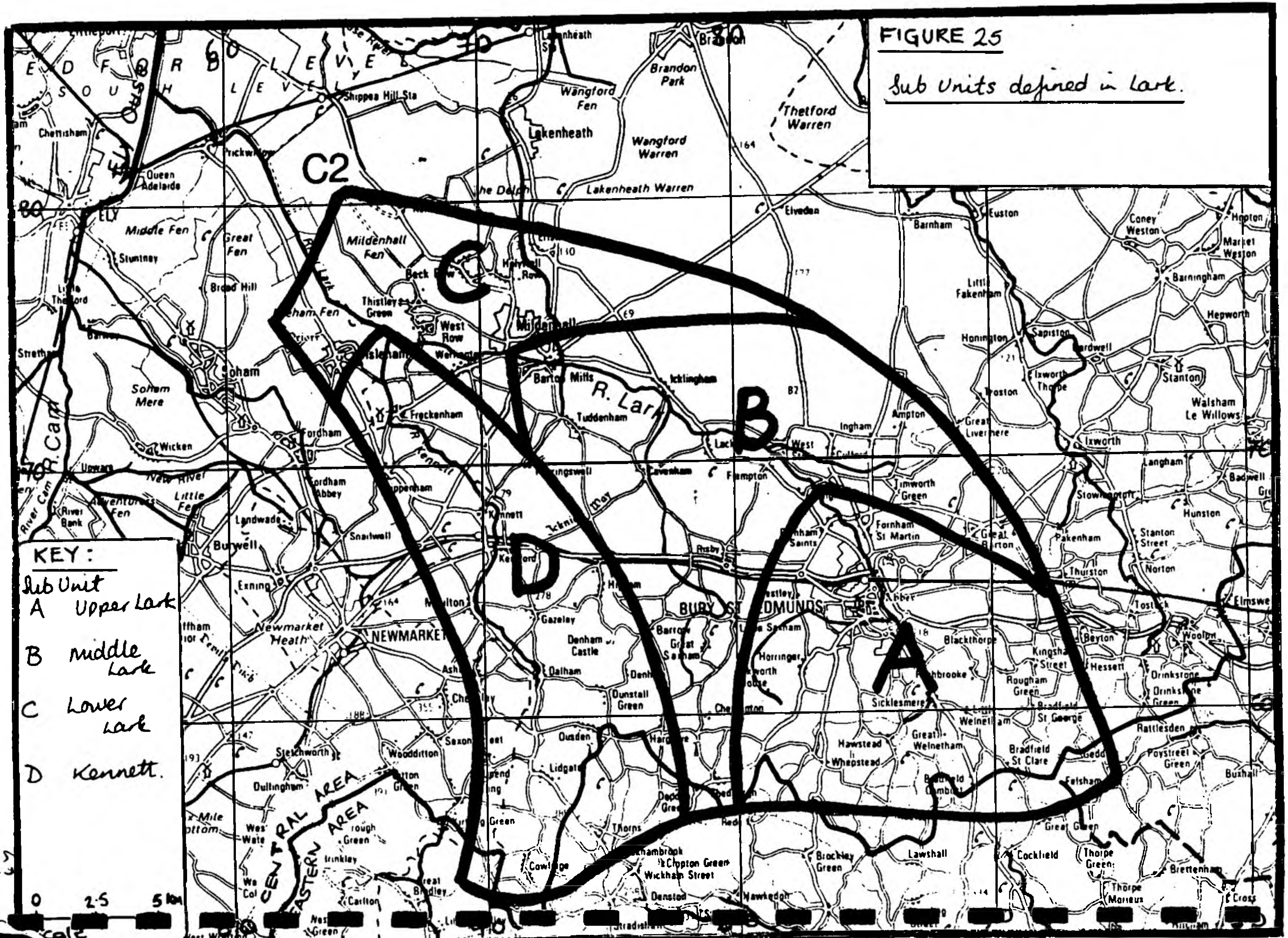


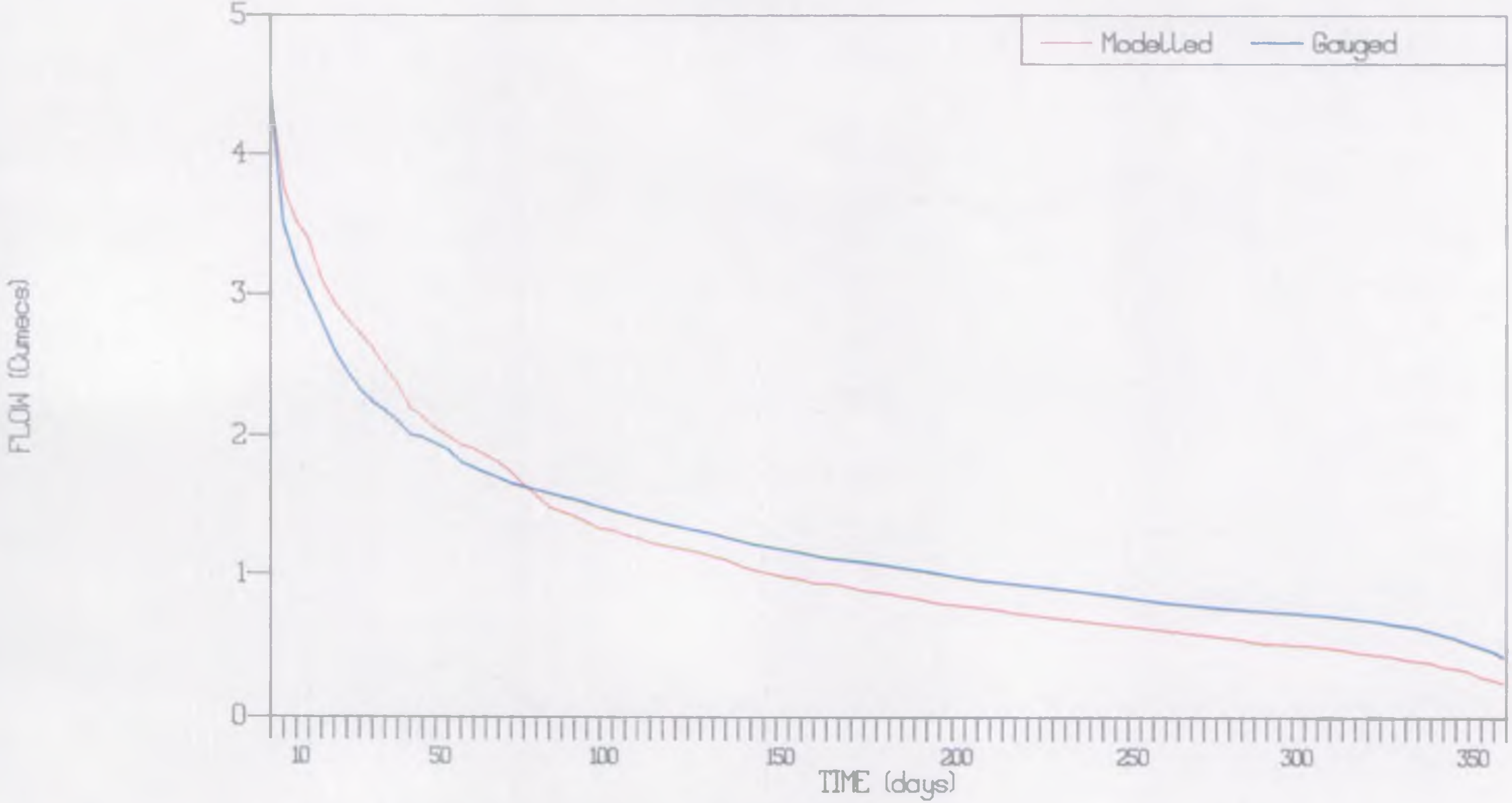
FIGURE 25

Sub Units defined in Lark.

Comparison of GORMs modelled to Actual Flows

RIVER LARK, EAST OF ICKLINGHAM

7 DAY FLOW STATISTICS 1971 - 1986



Flow Duration Curves, Gauged and Modelled Flows

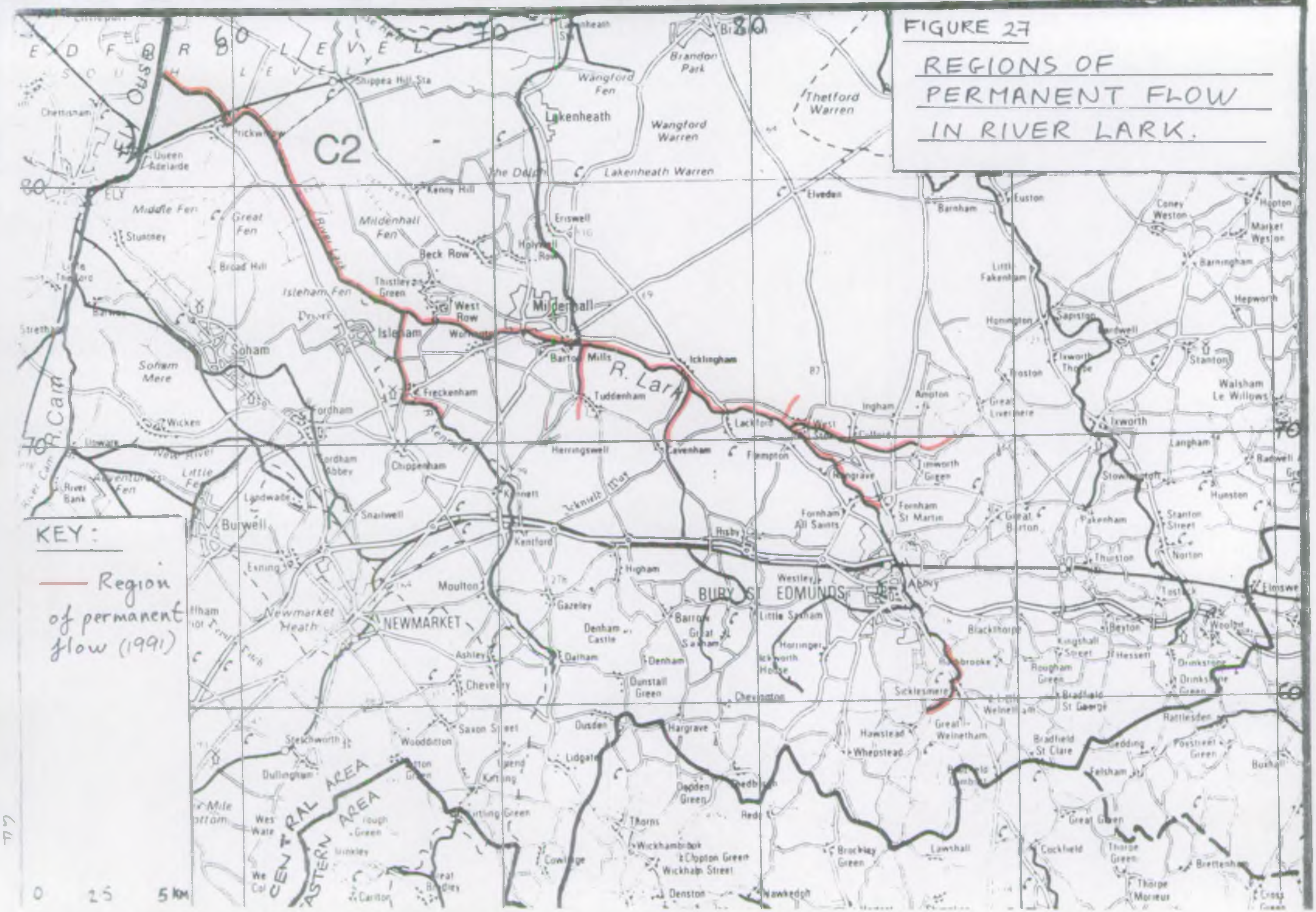


FIGURE 27
REGIONS OF PERMANENT FLOW IN RIVER LARK.