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John Bromley's Report
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SUMMARY OF THE WORTON RECTORY/PROJECT 39 STUDIES

Introduction

Along much of the length of many of Britain's major river systems the valley floors and floodplains are blanketed by thin but extensive sheets of gravel and sand laid down during and since the Pleistocene period. Shallow wells and boreholes sunk into these deposits have, throughout the ages, provided a safe and reliable source of drinking water to local communities scattered along their outcrop. The aquifers formed by the thin sand and gravel deposits offer particular attractions. Groundwater is invariably encountered at shallow depth thus making it easy and cheap to abstract, while its unconfined nature ensures regular recharge from either river or rainfall. At the same time the coarse clastic, unconsolidated nature of the sediment gives a high permeability thus offering the guarantee of good yields. But the qualities that make the aquifers so attractive also render them particularly vulnerable to pollution and disturbance through man's activities.

Until the industrial revolution the impact of man's activities upon this natural groundwater system was localised and widely scattered. But since this time the expression of urbanisation, industrialisation and changing agricultural practices have relentlessly increased pressures on the delicate floodplain environment. Pollution and canalisation of rivers, expanding urban areas, the advent of widespread application of nitrogen-rich fertilizers and the ever-increasing demands of the construction industry for sand and gravel have all had considerable impact upon this small but important source of groundwater.

Because groundwater resources held by these aquifers are small in relation to those available from other more widespread and thick formations in the U.K., they have received relatively little serious hydrogeological study. Most studies have concentrated on the potential for sand and gravel extraction. In response to this lack of knowledge the Institute of Hydrology launched a research programme in 1978 to identify the properties and processes operating within the groundwater regime of floodplain gravel aquifers. The area chosen for investigation was that region of the Upper Thames valley between Wallingford and Oxford. Several specific objectives were defined at the outset:-

* To define the aquifer geometry and outline the sedimentological history that led to its final form.

* To develop techniques of sampling a saturated and unconsolidated aquifer with minimum disturbance.

* To understand the controls on the distribution of permeability and storage within the gravels and to determine the relationship between grain size distribution and permeability.

* To identify the process of recharge and discharge within the system and to quantify these elements.

* To assess the impact of Man upon the environment.

* To understand the relationship between surface and groundwater.

Exploratory work was carried out in areas between Wallingford and Oxford from 1978-1984. During this period techniques of sampling the aquifer with minimum disturbance were developed and considerable expertise and knowledge of the floodplain environment built up. As a direct result of expertise accumulated during this research programme the Institute were approached in 1984 by ARC Ltd. with a request to undertake a study on their behalf. The request was to assess the potential impact of a proposed gravel extraction scheme upon ancient water meadows on the floodplain in the vicinity of Worton Rectory Farm to the west of Oxford. Because of their unique nature the water meadows of Yarnton and Pixey Meads have been declared sites of special scientific interest (S.S.S.I's) and thus protected by law from damage or interference either directly or indirectly. Over the centuries the Meadows have established a fine balance with local ground and surface water conditions. Extraction of gravel on a large scale in areas adjacent to the Meads poses the threat of disturbing the local groundwater pattern to the extent that rare plant species could be deprived of the water table conditions necessary for their survival. To assess the potential impact of the planned extraction scheme a 2 year study of the Worton Rectory region commenced in September 1984 running on conjunction with the ongoing research work covering a larger area (see Fig. 1). The two projects are progressing hand in hand and demonstrate how research and repayment projects can help mutually support each other.

This report summarises the work accomplished to date on both the research and Worton Rectory projects and explains how the two studies are being integrated.

Physical setting

Landform and Boundaries

The section of Thames valley floodplain covered by our research project is located immediately to the west of Oxford at a point where the Thames passes around the northern and eastern flanks of Wytham hill. As it does so the river changes course from an easterly to a southerly direction. Our study concentrates upon the area extending from the confluence of the Evenlode and Thames near Cassington southward to the urban sprawl of New Botley, which is built up across the floodplain connecting Botley with Central Oxford (Figure 1).

From the point at which the Thames makes its right angled turn southward at King's Lock the study area also extends northward to encompass part of an abandoned floodplain of the river Cherwell which has since changed its course and now flows to the east of Oxford. This floodplain forms a 1 km wide corridor extending southward from Kidlington merging with and joining the Thames floodplain approximately 1 km north of King's Lock.

Figure 2 shows the boundaries of the study region which covers an area of 13.5 km^2. Those boundaries which parallel the river coincide approximately with the 60 m contour. This represents the highest elevation of the Thames floodplain deposits in the area. To the west and south within the elbow formed by the Thames the land rises rapidly away from the floodplain to the 148 m high Wytham Hill. Eastward the region is flanked by a spur of higher ground forming the interfluve between the Thames and Cherwell. It is on this ridge that Oxford has been sited and developed. To the north between Cassington and Yarnton the land slopes up from the floodplain to elevations over 106 m along the watershed between the Thames and Evenlode.

Boundaries drawn across the floodplain to the west, north and south have less physical meaning but are located in the positions shown in Figure for the following reasons:-

* The western boundary is located at the Thames Evenlode confluence in order to exclude any consideration of the Evenlode catchment.

* The northern boundary is drawn across the abandoned Cherwell floodplain at a point where it begins to narrow significantly and become confined in a narrow channel.

* The southern boundary is marked by the urban region of New Botley, which is built across the floodplain, connecting Botley with Central Oxford.

Within these boundaries the floodplain is everywhere very flat-lying. Elevations range from 56.1 m AOD at New Botley in the south to 60.2 m AOD at the northern boundary near Yarnton. The low lying flat nature of the terrain renders it particularly vulnerable to severe flooding and as a result settlements are few and far between. Where settlements are present they tend to be restricted to slightly elevated and drier locations. By far the largest settlement is Wolvercote which is situated on a slight rise of exposed gravel on the eastern banks of Wolvercote Mill stream. Elsewhere the only other settlements are farms such as Church Farm, Manor Farm and Medley Manor Farm located on islands of gravel between the Thames and Seacourt stream. At these points the gravel appears from beneath the overlying alluvium to form slightly elevated areas.

Among the parcels of land particularly liable to flooding are the sites of special scientific interest mentioned earlier. These are the water meadows of Yarnton and Pixey Meads, Portmeadow and Wolvercote Common.

The first two are located adjacent to the Thames around the elbow formed by the river at King's Lock. These are ancient water meadows supporting a combination of flora which is extremely rare and is dependent upon the special conditions to be found in the floodplain environment. Because the Meads have never been ploughed and are only used for haymaking and grazing they remain in their natural state, as yet unaffected by man's activity. In recent years control of river flow has resulted in the Meads being flooded less frequently than in the past, but to date no permanent damage seems to have resulted. It is these sites that are most threatened by the proposed gravel extraction scheme planned for the Worton Rectory area (Figure 1).

Further south lie the two other regions of special scientific interest. These are Portmeadow and Wolvercote Common, which lie on the eastern bank of the Thames to the south of Wolvercote. Like Pixey and Yarnton Mead, these areas have never been under the plough but have only even been used for grazing. Portmeadow has belonged to the City of Oxford since at least 1087 while Wolvercote Common has belonged to the people of Wolvercote since 1884. Both are of immense scientific interest and the Nature Conservancy Council places great importance on their preservation. Our research work includes all four sites of scientific interest but the work being done to investigate the potential effects of gravel extraction in the Worton Rectory area is only concerned with Yarnton and Pixey Meads.

The Watercourses

The most important and conspicuous geographical feature of the floodplain is the complex system of watercourses that extend along its length. Many of these rivers and streams are in intimate connection with groundwater and thus do much to mould the pattern of groundwater flow. But the pattern of rivers and streams that we see today are not entirely natural. Over the past 1000 years or so the requirements of water power for mills and the necessity of draining waterlogged agricultural areas has led to extensive modification of the natural regime. In this section the present day pattern of watercourses is described and discussed, followed by a brief account of how they have been modified in the historic past.

The main river, the Thames, flows around Wytham hill first eastward and then southward with the change in direction taking place at King's Lock. From upstream of King's Lock a secondary channel, the Wolvercote Millstream, branches away and loops around Pixey Mead before rejoining the main river at downstream of Godstow lock 1.4 km downstream.

A second major watercourse is Seacourt stream. This leaves the Thames 0.8 km upstream from King's Lock, at Hagley Pool. From here it flows southward keeping to the extreme western edge of the floodplain. Eventually, in the vicinity of New Botley, but outside the southern boundary of the study area, the Thames and Seacourt become connected by a complicated network of three streams, the Bulstoke stream, Botley stream and Osney ditch (Figure 2).

A third watercourse of significance is the Kingsbridge brook. Although much smaller in scale than either the Thames or Seacourt the Kingsbridge brook plays a vital role in both the surface and groundwater flow patterns of the region. It rises near the Oxford canal on the abandoned Cherwell floodplain from where it flows along an erratic southerly course to the Wolvercote Millstream. Where the two meet, 0.7 km upstream from Wolvercote Mill, the brook is carried under Wolvercote millstream via a siphon. After passing through the siphon the brook flows parallel to the millstream for 0.7 km before the two meet at Wolvercote Mill.

The overall relationship between water levels in the three major watercourses is shown in Figure 3. Under normal circumstances we might expect the major channel to occupy the lowest part of the floodplain with other secondary channels feeding it. But in our study area this is not the case. Figure 3 clearly illustrates that it is the Seacourt stream, rather than the Thames, which occupies the lowest part of the floodplain. Water levels taken along the Seacourt, which feeds from the Thames via a weir, show it to be up to 1.2 m lower than the Thames at certain points. Levels measured at the weir between the two rivers during 1984 and 1985 show a difference in levels from 0.8 m to 1.2 m. In groundwater terms the difference in levels is of great importance. It means that throughout the region the Seacourt offers a potential groundwater discharge poibt much lower than the Thames itself. Indeed groundwater level maps compiled for 1984 and 1985 confirm the Seacourt 'Valley' to be a major discharge source.

In the same way the Kingsbridge, downstream from the point where it passes beneath the Wolvercote Millstream, offers a similar low level groundwater discharge point. This man-made section of stream, from the siphon to Wolvercote Mill, is cut at a much lower level than surrounding watercourses. For instance in Figure 3 water levels for Dec-Jan 1979 in the Thames, Kingsbridge Brook and Wolvercote Millstream are 58.0 m, 57.1 m, and 58.4 m respectively. Hence the brook offers a groundwater discharge point 0.9 m lower than the Thames and 1.3 m lower than Wolvercote Millstream. As a consequence groundwater levels are pulled down dramatically along this stretch of Kingsbridge brook, and a steep water table trough is formed.

Although the relatively high level of the Thames precludes it as a major groundwater discharge source it renders it particularly effective as a potential source of recharge. Groundwater maps for 1984 and 1985 demonstrate that some sections recharge the aquifer to a significant degree whereas the equally elevated Wolvercote Millstream provides no, or very little recharge.

Apart from the major streams and rivers, the study region is also criss-crossed by an intricate series of drainage ditches (Figure 4). Although individually small the drains together exert a great influence over both ground and surface water flow patterns. Throughout the winter the ditches, together with the Kingsbridge brook and Seacourt stream, act as the major discharge sources. In summer other processes take over to a large extent but nevertheless some of the large ditches continue to carry water even through the driest periods. Another purely man-made feature is the Oxford canal which closely follows the eastern boundary of the study region along its entire length. The canal, opened in 1789, is the most elevated water course in the area. Over much of its length it stands over 1 m higher than the Thames and 2 m higher than the Seacourt. Clearly it does not act as a groundwater discharge source and from the evidence available neither does it provide significant recharge. As a recipient for surface water however it is very important since it accepts much of the storm water flow from West Oxford and Kidlington.

The unusual and somewhat artificial nature of the surface water drainage is reflected in the configuration of the catchments they create. These are illustrated on Figure 4. Note that the Thames itself (catchment c) has a very restricted area confined to a narrow strip, never more than a few hundred metres wide, parallel to the river banks. An exception occurs to the south of Cassington where drainage ditches discharge directly into the river thus creating a much larger catchment (catchment C). In general the surface drainage of the region is commanded by three major surface water systems:

* The Kingsbridge Brook (catchments D and E): An extensive network of ditches draining the Worton Rectory area and the abandoned Cherwell floodplain all feed ultimately into the Kingsbridge Brook. The entire flow from this region is therefore required to pass through the siphon beneath Wolvercote Millstream.

* The Seacourt stream (catchment A): This is the largest catchment in the region. To the west the Seacourt receives much of the runoff from Wytham Hill while on the floodplain it is fed by an extensive series of ditches.

* West Oxford Catchment (Catchment F): The western half of this catchment is fed by runoff from Portmeadow and Wolvercote Common. On the eastern side it receives a portion of the storm water drainage from West Oxford, the remainder being fed into the Oxford Canal, which stands isolated above the natural drainage channels.

Historical development of Watercoursess

In this section we review the impact of man's activities in the historical past upon the course of rivers and streams throughout the study region. Pre-historic changes of the major streams in the geological past are referred to in Section .

Since about the 10th Century there seems to have been four major phases of water engineering. The first three appear to have been associated with the movement of river channels to provide water for mill power and to have been completed well before the Middle Ages. A fourth phase of work, related to drainage improvement, was completed only this century. Figure 5 illustrates the channel changes that have resulted from these activities. The changes to have taken place are as follows:-

1. The diversion of the main Thames Channel:

In the 10th century the main channel of the Thames south of Godstow Lock did not occupy its present position. Instead this section of river flowed along the present line of the Seacourt, downstream from Church Farm House (Fig. 5). We know this, partly through references made in 10th century documents. But more concrete evidence is given by the line of the modern (pre-197) Oxfordshire-Berkshire county boundary. Where the Thames offers itself the boundary between the two counties is invariably drawn along the line of the main channel. But in our study area it departs from the Thames to follow a rather unusual course. Between King's and Godstow locks the boundary breaks away from the Thames to follow an ancient drainage channel southward and join the Seacourt stream near Church Farm House (Figure 5). From this point it follows the Seacourt for 5.5 km before rejoining the Thames at New Hinksey. Since at all otherr places the Thames marks the boundary it is reasonable to assume that the river used to follow the line now taken by the boundary.

Further evidence comes from the geology of the area (see Chapter). A contour map of the top surface of the terrace gravel clearly shows a deep channel following the course of the present county boundary along the Seacourt upstream as far as Church Farm House, from this point the remnant of the 10th Century Thames.

By the early 18th Century maps show that the main channel had been moved to its present position. This move, to a higher part of the floodplain can only have been engineered by man. Why the channel was diverted is unclear but two possibilities present themselves:-

* It is known that in the 13th century the monks at Rewley Abbey, located near the southern boundary of the study area, were actively engaged on water engineering schemes to provide water for their mills. Part of this activity could have involved the diversion of the main Thames channel to flow past the mill.

* The diversion might have been undertaken to bring the Thames closer to the City of Oxford. This would have brought commercial advantages by allowing much easier access to river traffic.

2. Inception of the Seacourt stream:

At some point after the diversion of the main Thames stream, an artificial cut was made between Hayley pool and the abandoned Thames channel at Church Farm House (Figure 5). The cut was made to provide water for Wytham Mill. With over a one metre fall from the Thames to the new stream a substantial head of water was available to power the mill. Downstream the cut was continued to join the abandoned Thames channel to give rise to the present Seacourt stream. Evidence to substantiate this suggestion is not strong, but the manner in which the Seacourt is fed from the Thames, via a weir, strongly indicates a man-made origin.

3. The construction of the Wolvercote Millstream

The requirements of another mill, at Wolvercote seems to have led to a third phase of water engineering. This was the construction of part of the Wolvercote Millstream which loops around Pixey Mead leaving the Thames at King's Lock rejoining it at Godstow Lock. We suggest that an original mill stood by the proposed old line of the Kingsbridge brook, which flowed from the north to join the Thames at Godstow Lock (Fig. 5). Eventually rather than continuing to rely on the small and erratic flows offered by the brook, the attraction of cutting a millstream from the Thames at King's Lock to join the Kingsbridge brook upstream of the mill would have become irresistable. Such a scheme guaranteed not only larger and less erratic flows but a 2 m head of water to drive the mill (Figure 3). The existing course of Wolvercote Millstream is, therefore, man made to the north of the mill but is the natural course of the original Kingsbridge brook to the south.

Ordnance survey maps of the early 19th Century provide evidence to show that the northern section of the stream is indeed man made and not natural. These maps indicate Pixey Mead to be common to the parishioners of Begbroke and Yarnton. Yet the Wolvercote millstream separates these villages from the land. Clearly at one stage Pixey Mead must have been freely accessible to Begbroke and Yarnton. This would have been the case prior to the construction of the millstream. After the channel was cut Pixey Mead was effectively isolated from its commoners, although ownership of the land remained unchanged.

4. Lowering of Kingsbridge Brook:

A final important modification to the drainage system of the region was undertaken this century. In the 1940's the Kingsbridge brook was routed beneath Wolvercote Millstream through a siphon and a new channel was cut to carry the water back to the millstream near Wolvercote mill. By cutting the siphon the discharge point for the drainage system of the Kingsbridge brook catchment was lowered by 1.4 m. Drainage of agricultural land in the Worton Rectory area was considerably improved as a result.

Apart from these major engineering works small scale diversions of streams and the installation of a large number of drains throughout the area have been carried out over the centuries. Ordnance survey maps of the early 19th century show much of the present system of drains was already in existence. Very little change has since taken place. The surface water changes engineered by man have profoundly influenced the present day pattern of groundwater flow. In later sections it will be shown how the configuration of the groundwater table is partly moulded by man's post activities.

Surface Water Flows

Most surface water flow enters the region via the river Thames where it crosses the western boundary near Cassington. The river is continuously gauged at Eynsham, 2 km upstream from Cassington. Readings from this station together with those on the Evenlode at Cassington can be used to calculate the Thames discharge at the point where it enters the study area, downstream from the confluence of the two rivers. Data is currently available for the years 1979-1982; this is summarised in Table 1.

WATER YEAR (Oct-Sept)	TOTAL FLOW cumecs	MEAN FLOW cumecs	MAX FLOW cumecs	MIN FLOW cumecs
1979-80	6485	17.7	106.3	1.81
1980-81	7046	19.3	93.7	2.52
1981-82	7622	20.92	98.1	1.38

In addition daily head and tail readings for King's and Godstow Locks are available for the years 1980-81. An example is given in Figure 5A. Although these levels do not directly indicate the volume of flow they do give a good insight into the relative variability of discharge throughout the year.

No regular measurements are made along any of the other major rivers and streams. But in 1981 and 1984 the Thames Water Authority took spot measurements along all major streams in the area. These were taken in September 1981 and August 1984 at times of exceptionally low flow (Figs. 5B and 5C). Under these conditions the following relative flow distributions were recorded:-

1. Of the total flow entering the study area via the Thames between 20-30% is diverted along the Seacourt stream.

2. At King's Lock 30-40% of the remaining flow is taken by the Wolvercote Mill Stream. From this channel less than 4% is lost by outflow through Dukes cut to the Oxford Canal.

3. The Oxford canal itself has a small flow. On the two occasions measured flow was less than 4% of the Thames at Cassington during the same periods.

Although these figures cannot be extrapolated to high flow conditions they nevertheless provide a guide to the relative importance of the various channels in terms of flow volumes.

A second series of measurements were made along the Seacourt stream by the Institute of Hydrology in May 1985. These were carried out to determine whether the volume of groundwater recharge or discharge to the stream was sufficiently large to have a measurable impact on flows along its length. In the event stream flow proved to be constant at all points varying only between 0.524-0.618 cumecs; this variation being within the expected error of measurement. It is therefore evidence that if groundwater discharge or recharge is taking place along the Seacourt the volumes are small im comparison to total surface flow.

Finally, the Institute has also monitored the discharge of 4 small ditches and streams since the beginning of 1985. Two of these are located on an important groundwater discharge source, the Kingsbridge Brook, where to date flows of between 0.08 and 0.55 cumecs have been recorded. These results, however, are discussed in more detail in Section .

HYDROGEOLOGY

Introduction

A fundamental requirement of the study is to define the dimensions and geometry of the floodplain aquifer and to specify the boundary conditions that operate at the margin of the system. Without this three-dimensional picture of the groundwater body, subsequent analysis of other aspects of the hydrogeology is meaningless.

In our study region the sands and gravels of the 1st(floodplain) terrace form the major aquifer. These deposits infill a shallow valley cut into the Oxford Clay forming a ribbon like aquifer up to 2 km in width, following the course of the Thames. Total thickness nowhere exceeds 7 m and is very small in comparison to the width and length. It follows from this configuration that on a regional scale groundwater flow need only be considered as a 2-dimensional problem.

In this region the Oxford Clay, into which the gravel-filled valley is cut, exceeds 120 m and as a result provides an effective lower aquiclude to the system. In addition it provides a lateral seal at many places since the clay also forms the sides of the valley.

Aquifer lithology is mainly a mixture of sandy gravel and gravelly sand although there is a range of material from silt to medium gravel. Permeabilities and specific yields are consequently high. Overlying the gravel is a variable sequence of alluvial silts and clay, ranging between 0.2 m and 3.2 m in thickness. Here permeabilities are an order of magnitude lower than the underlying gravel. Thus where water levels stand above the top of the gravel the alluvium acts as a confining or semi-confining layer. It also helps to restrict direct recharge from rainfall by promoting surface runoff or holding water on the surface.

In this section the dimensions, geometry and boundary conditions of the aquifer are described in detail to produce of three dimensional picture of the groundwater bearing formation.

Base of the aquifer and aquifer thickness

The morphology of the Oxford Clay surface upon which the floodplain gravel lies is shown in Figure 6. Elevations of this surface range from a minimum of 50.3 m in the south to 60 m along the margins of the area. On either side and parallel to the Thames the groundwater basin is bounded by abrupt steps in the Oxford Clay surface. The steps carry the height of the surface from below 55 m to over 60 m, and form the sides of the buried channel containing the floodplain gravel. (Figures 6 and 7). Between these steps the floor of the channel has a gentle topography but one which shows distinct features. Of those the most obvious is the valley which extends along the length of the area cutting across the present courses of both the Thames and Seacourt. Where the contours become more intricate in the Worton Rectory area this simply reflects the abundance of geological data in the region. We can only assume that this valley represents an ancient course of the Thames which existed prior to the deposition of the gravels.

From a hydrogeological point of view the feature is important because it is the major control on gravel thickness, which in turn controls the distribution of transmissivity. Gravel is thickest along the length of the old valley reaching a maximum of 6.3 m in the Godstow Lock area. Elongated patches of gravrl exceeding 5 m in thickness pick out the line of the valley in a striking manner (Figure 8). Elsewhere thicknesses tend to reduce progressively toward the margin of the basin.

Where the pattern of thickness is more complex in the Worton Rectory area there is still a recognizable trend for greatest thicknesses to be concentrated along the line of the ancient valley, which here lies north of the present Thames.

To the north, on the abandoned Cherwell floodplain the pattern is also complex. Here the area of thickest gravel extends adjacent and parallel to the eastern margin, following the line of the Kingsbridge brook. At this point thicknesses exceed 4 m in isolated patches. The belt of thicker gravels here probably marks the course of an ancient Cherwell, which is partly picked out by the contour surface of the Oxford Clay (Figure 6).

The top surface of the Aquifer and thickness of alluvium

Alluvial silts and clays are draped over a complex gravel surface displaying several features of hydrogeological significance. The surface which ranges in ehight from 54.2 m to 59.9 m AOP provides a control on the thickness of overlying alluvium. In turn this partly determines the degree of aquifer confinement, with thicker alluvium giving rise to more confined conditions. From Figure 9 the major features of the gravel surface can be recognized.

* Dominating the pattern is a deep channel, which follows the approximate line of the 10th century Thames, referred to in Section . Along the southern part of the Seacourt as far upstream as Church Farm House and along the Thames upstream from King's Lock, the buried channel coincides exactly with the course of the 10th century river. But from the point where it breaks away from the Seacourt to where it rejoins the present

Thames at King's Loch, the correspondence is not so precise. Along this stretch the buried channel wanders first to the west and then to the east of the county boundary, which is taken to mark the position of the 10th century channel. A possible explanation is that the 10th century river was short-lived and itself the result of engineering work. Certainly the buried channel shown on Figure 9 must mark the position of a long established natural Thames channel that was in existence even before the 10th century.

The line of this channel is picked out again in Figure 10, where elongated strips of thicker alluvium are shown to be stretched along its length. Here thicknesses are almost everywhere greater than 2 m and in places exceeds 3 m as for example at the northern end of Pixey Mead. It is the large thickness of alluvium on Yarnton and Pixey Meads, caused by the presence of the buried channel, that ensures the existence of confined conditions in these areas throughout the year.

* A much shallower, but equally prominent channel extends northward along the course of the railway from Oxford station. This channel encompasses much of the southern and eastern parts of Portmeadow extending as far north as Wolvercote Common. Although the feature is shallow, alluvial thicknesses are increased sufficiently to ensure that much of the aquifer in this region remains confined throughout the year.

* Separating the two channels is a prominent ridge which extends from Wolvercote southward through Binsey and on toward New Osney. This dcovers most of the western and northern parts of Portmeadow and much of Wolvercote Common. Along the ridge alluvium is frequently absent and gravel crops out at the places indicated on the geological map (Fig.). Nowhere does the alluvium exceed 0.9 m. Here the aquifer is unconfined and offers considerable potential for direct recharge from precipitation.

A second ridge with similar conditions is present to the east of the University Field Station in the elbow of the main buried channel Figure 10).

* From the main buried channel of the Thames, upstream of King's Lock, a smaller channel branches off northward to follow a sinuous path toward the abandoned Cherwell floodplain. This most likely marks the old course of the river Cherwell. Alluvial thickness increases to over 2 m along the lower 750 m of channel, before it joins that of the Thames. Elsewhere thicknesses are not significantly increased.

Boundaries of the Aquifer

Quantitative calculation of groundwater flow through numerical modelling requires that the physical nature of all aquifer boundaries be defined. In our study area three types of boundary are recognized:

* No flow boundaries (ie a boundary across which no transfer of groundwater can take place).

  These occur in two situations in the study region:-

  1. At the base of the aquifer where the presence of Oxford clay beneath prevents the downward movement of significant quantities of water.

  2. Along those margins parallel to the river where the basin is cut into and abuts against outcrop of Oxford clay.

* Fixed head boundaries (ie where groundwater heads are known and can be fixed).

  These occur in two situations:-

  1. Where transverse boundaries are drawn across the floodplain. Along these boundaries heads are fixed to allow groundwater to flow either into or out of the area. The northern and western boundaries allow water to flow through the aquifer into the area, while the southern boundary permits an outlet of groundwater flow.

2. Where the margin of the basin abuts directly against higher (2nd) terrace gravels. Such boundaries exist at three locations.

   (a) To the south of Cassington
   (b) To the east of University Field Station
   (c) To the west of Oxford.

   These are shown in Figure 11.

* Water Table boundaries.

  Where the aquifer is unconfined the upper boundary is defined by the water table. Where confined the top of the gravel marks the boundary.

For two dimensional regional modelling only the marginal boundaries of the basin are defined. Upper and lower boundaries are not required.

The Water Table

Data Available

Systematic monitoring of both ground and surface water stations covering the entire study area began in February 1984. Prior to this in 1980-81 some long-term monitoring on a weekly basis had been carried out over the southern parts of the area. These levels are presented in Appendix I. But these sites do not cover the Worton Rectory region and so water table maps covering the study area as a whole cannot be presented for this period. Nevertheless the records for individual surface and ground water stations are valuable since they provide an extended record of water level fluctuations in the southern area.

From the time when monitoring of the region as a whole began in February 1984 water levels have been recorded approximately once every two months. The dates for which groundwater table maps are available are presented in Table 1 together with the number of surface and groundwater monitoring points used on each occasion. Variations in the number of stations used are due to periodic access problems and the occasional loss of both boreholes and surface water stages. Water level maps for March, June and July 1985 include an extra 12 boreholes within the City of Oxford. These are located on 2nd terrace gravels. Altogether a total of 10 groundwater level maps are available for the period February 1984 to July 1985.

In addition to the intermittent 'snap shots' provided by these maps, continuous records at both surface and groundwater sites are available for 6 sites. These are listed in Table 2. They include 2 boreholes and 4 surface water stages. Borehole WR29 is located within 10 m of the Thames and responds to variations of river level while WR18A is located in a well-drained part of Worton Rectory Farm. Surface water stages include two on the Kingsbridge brook, a groundwater discharge source of immense importance and two on major drains which feed the brook.

Water table configuration

Introduction

We are fortunate that our series of 10 water table maps compiled between February 1984 to July 1985 cover a reasonably extreme range of summer and winter conditions. Minimum water table elevations are recorded for July 16th 1984. Rainfall in June, July and August 1984 was only 43% of the average, while for July itself the figure was as little as 23% of the average for the month. Hence this minimum water table elevation can be regarded as typical for an unusually dry summer.

On the other hand the map for January 30th 1985 is typical of water table conditions following an extremely wet winter period. Not only was the preceding autumn unusually wet with rainfall being 135% of the average but the map was compiled following a 5-day period during which 23.8 mm of rain fell. Between these two extreme the remaining groundwater level maps illustrate a range of intermediate elevations.

We begin this section by first examining the groundwater configuration for July 1984. This is then compared with the map for January 1985 and differences in both the water table pattern and elevations for these two extremes is discussed.

Minimum Water Table conditions (July 1984)

The July 1984 groundwater table map presents a picture of the aquifer under stress, with water table elevations being at their lowest for the period of record (Fig. 13). Several features of interest emerge from the resulting groundwater level pattern:-

* The Seacourt groundwater trough

A distinct groundwater trough lies adjacent and parallel to the south western margin of the study area. Its position coincides approximately to that of the Seacourt stream. The coincidence of trough and stream channel is exact along its extreme northern and southern sections. But in the central stretch between Wytham and a point 1 km from the southern boundary the trough is offset from the stream channel by 200-300 m to the east.

Where the position of stream channel and trough coincide, between Hagley Pool and Wytham, the Seacourt curts deeply into the floodplain gravel offering a groundwater discharge point one metre lower than the Thames. Evidence of significant discharge along this stretch is given by the manner in which groundwater contours are pinched tightly upstream. A particular focal point is the weir over which the Thames cascades to feed the Seacourt.

The Seacourt also acts as a discharge source for a distance of 1 km upstream from the southern boundary of the area. Evidence here is less conclusive but the pattern of groundwater contours seems to be controlled by the stream.

In between these two stretches the central section of the Seacourt does not control the trough which lies offset by 200-300 m to the east.

This happens because the Seacourt sits on a thick blanket of alluvium which isolates the stream from the gravel, thus considerably reducing the potential for groundwater discharge. It follows that in this region other discharge processes operate to maintain the trough. The most likely processes in operation are a combination of evapotranspiration from the water table and some limited groundwater flow into ditches. It seems that together these concentrate discharge in an area that is offset from the Seacourt channel.

* The Kingsbridge brook - Wolvercote Millstream groundwater trough

A steep groundwater trough is developed along the Kingsbridge brook southward from the point where it passes beneath the Thames to its outlet into the Wolvercote millstream at Wolvercote Mill. Along this section the intensity of the trough is increased by the presence of a flooded gravel pit to the east and a groundwater mound to the west. The combined effect is to compress the trough into a narrow steep corridor. South of Wolvercote Mill the feature is maintained along the course of the Wolvercote Millstream, although in a much subdued form since from this point the restricting influence of the adjacent gravel pit and groundwater mound is lessened. This section of the millstream is probably the ancient natural channel of the King sbridge brook. Figure shows it to be m lower than the man-made stretch from Wolvercote Mill upstream to the Thames. This lower elevation explains why it acts as a groundwater discharge source while the man-made section does not.

To the north of the Thames the trough widens into an elongated groundwater basin centred upon Oxey Mead. Here two major systems of drains meet and feed into the Kingsbridge brook. One branch drains the Worton Rectory Farm area to the west, while a second leads in from Yarnton to the north. Both br anches generate groundwater depressions radiating from Oxey Mead but the most intense is that developed by the northern drain leading from Yarnton. Similarly the Kingsbridge brook creates a groundwater low along its length upstream from Oxey Mead extending to a point north of the A34.

The groundwater basin and trough developed along the Kingsbridge brook and associated drains testify to the importance of this system as an important discharge source, even in the driest of summers. It also shows the natural section of Wolvercote Millstream, south of Wolvercote Mill, to be a significant source of groundwater discharge.

* The Portmeadow groundwater trough

A third groundwater trough is situated over the central and eastern part of Portmeadow. This feature is subdued and characterised by shallow gradients but nevertheless forms an important element of the groundwater flow pattern. Its presence is probably due to a combination of factors:-

1. Discharge into the ditch skirting the eastern margin of the meadow.
2. Evaporation from the areas of shallow water table over the eastern and central parts of the meadow.
3. Flow from 2nd terrace deposits to the east helping to intensify the feature.

* The Thames recharge mound

From a point upstream of Hagley pool to 1 km below Godstow Lock, seepage from the Thames has given rise to a prominent groundwater mound beneath the river. Development of the mound is most intense between Hagley Pool and King's Lock and is evidence of high rates of recharge along this stretch. Elsewhere it is more subdued, particularly below Godstow Lock from where it becomes progressively less prominent.

To the east of King's Lock water levels below Pixey Mead are maintained at a high elevation for several hundred metres from the river. This groundwater 'bulge' is difficult to explain but it may be related to rapid variations in transmissivity caused by the presence of the buried Thames channel beneath the mead. It is the eastward spread of the mound at this point that partly accounts for the intense nature of the adjacent Kingsbridge brook trough.

Downstream from Godstow Lock the Thames becomes isolated from the aquifer and within 1 km significant recharge has ceased. Groundwater contours in this region simply pass beneath the river without deviation. Reasons for the reduction of recharge along this section are discussed in Section .

Comparison of minimum and maximum water table conditions
(JULY 1984 and JANUARY 1985).

Water table conditions for January 1985 are typical of those for a period of above average winter rainfalls with elevations being at or close to the maximum for the region. Description of this water table is best approached by offering a comparison with that for the minimum condition of July 1984 and highlighting their differences. The differences of water table configuration and elevation between these two extreme situations provides an insight into the process of recharge and discharge that operate at various times of the year. In this section we compare these two extreme water tables first in terms of groundwater contour patterns and secondly in terms of absolute elevation.

1. Differences in groundwater contour pattern:

In broad terms the overall contour pattern for minimum and maximum conditions is similar. But there are a number of areas in which there are small but significant changes:-

(a) The Worton Rectory Farm region.

The most significant difference in pattern occurs in the region to the north of the Thames between the Evenlode confluence and King's Lock. The area covers much of Worton Rectory Farm and extends to the northern margin between Yarnton and Cassington. Here the pattern of summer and winter contours are positioned at 90° to each other. (Figures 13, 14).

In summer there is a very pronounced and intense groundwater mound developed beneath the Thames with steep gradients on both northern and southern banks. To the north of the mound the contours sweep around to form a gentle trough. This trough extends eastward to run into the groundwater 'basin' centred about Oxey Mead. But in winter the situation is totally different. At this time the recharge mound is much less intense and steep gradients are present only on the south side of the river. On the northern bank contours are aligned at right angles to the river and cross to the northern margin in a northerly and north easterly orientation. There is no trace of the summer trough. The filling of the trough and the pushing of contours to a northerly orientation is caused by inflow of groundwater into the floodplain from the Cassington region. Flow is from gravels of the 2nd terrace and is at a maximum during winter months when recharge from rainfall is greatest. During the summer this input slowly declines and the trough re-appears in response to ditch and evapotranspiration discharge. Ditch discharge also operates in the winter but its impact seems to be masked by the groundwater impact from the Cassington gravels.

(b) The Seacourt groundwater trough

The summer pattern of contours along the Seacourt shows the stream channel to control discharge along its northern and southern sections, but not throughout the central stretch where the groundwater 'valley' is offset to the east. In winter however this low point migrates westward to a position where it appears to be controlled by the position of the stream channel along its entire length. This suggests that different processes of discharge operate in winter and summer. In summer discharge into the Seacourt along the central section is insignificant. Instead most seems to take place by evapotranspiration from areas of shallow groundwater situated away from the stream channel. Along the northern and southern sections discharge takes place into the Seacourt throughout the year and the groundwater trough is here always controlled by the position of the stream channel.

(c) The Portmeadow trough

A groundwater trough exists beneath Portmeadow throughout winter and summer. But in winter it is a slightly more intense feature with its northern end displaced further to the east (Figure 13, 14).

A likely cause for this displacement is increased recharge over the central parts of Portmeadow through the unconfined gravels. Discharge taking place into the main ditch along the eastern side of the meadow appears to exert the main control over the lowest line of the trough itself. In summer with less recharge taking place over the meadow and less discharge taking place into the ditch the feature becomes much more subdued, but still centred along the eastern ditch. Some ditch discharge evidently still takes place at this time of year.

2. Difference in water levels (Jan 1985-July 1984)

Water level charges between the extreme for July 1984 and January 1985 range from a surprising - 0.2 m at UFS 13 near Hagley Pool to + 1.18 m at WR 2 on Worton Rectory Farm. An even greater change of + 1.39 is recorded for site UFS 26A but this is situated in 2nd terrace gravels on the University Field station.

Broadly the region can be divided into three zones; two in which water level change exceeds + 0.6 m and another where the change is less than + 0.6 m (Fig. 15).

The areas where water level changes exceed + 0.6 m are:

* Portmeadow and Wolvercote common, including a 100-300 m wide strip of land to the west of the Thames and the region between Portmeadow and the railway.

* The area covered by Worton Rectory Farm including a 200 m wide strip of land lying between Yarnton Mead and the A40.

Common to both these regions are characteristics which help explain their relatively large water level changes. Firstly both include large areas of thin alluvial cover which in places on Portmeadow and Wolvercote

Common are completely absent. Here underlying gravel crops out as shown in the geological map (Fig.). Although in the Worten Rectory area gravel is not actually exposed there are large areas, where the alluvium is only a few centimetres thick (Fig. 10). Because of the thin alluvial cover unconfined conditions are widespread throughout both regions particularly in the summer. Even in the winter, despite the fact that water levels lie within the alluvial/soil overburden, conditions cannot be considered fully confined.

Togetherr these two factors help promote direct recharge from rainfall in the winter. It is this direct input which causes water levels to rise significantly in the winter and lead to the large changes of water level. It is significant for example that the largest water level change in the Portmeadow area occurs in Borehole PTM 13 which is located directly on gravel outcrop. On Worton Rectory Farm the largest water level changes are recorded in the areas flanking the 2nd terrace gravels of Cassington to the north west. Leakage of water from these gravels help to boost winter water levels in this section of the floodplain. Flow from the 2nd terrace gravels during the summer is significantly reduced as rainfall recharge itself is reduced to zero. Similar leakage should take place from the fragment of 2nd terrace gravel preserved on the western margin in the vicinity of the University field station. However water levels in the floodplain flanking this deposit do not seem to be influenced to any significant degree. It is probable that the small area of the 2nd terrace gravel outcrop does not have sufficient storage to generate a flow capable of boosting winter water levels in the adjacent floodplain and accounts for the relatively small change recorded at this point. On the 2nd terrace itself water levels change by up to + 1.39 m (UFS 26A , this being due to the fact that recharge here is controlled entirely by rainfall.

The region where water level change is restricted to less than 0.6 m coincides remarkably closely with the old course of the river Thames, picked out on the top surface of the gravel (Figure 2). Here the alluvium is thick, in places exceeding 3 m, and results in the region being confined throughout the year. Hence direct recharge from winter rainfall does not take place and levels are not raised at this time of the year to the extent found in unconfined parts of the aquifer. Recharge which does take place is restricted to infiltration from the river Thames between Hagley pool and King's Lock. This source of recharge continues throughout the year but its magnitude tends to be controlled by the head of water in the river. Because river levels are maintained artificially at a near constant level the magnitude of recharge tends to controlled in the same way. As a result groundwater level changes caused by variations in river recharge are not as large as they would be under natural conditions. In the Hagley pool area for example at borehole UFS 13 control of river flow results in summer levels being 0.2 m higher than winter levels.

Apart from the Hagley pool region there are two other small areas where water level changes are minimal. These both lie along the Seacourt stream; the first is in the vicinity of Wytham Mill and the second lies to the west of Church Farm House. Why these should be regions of very little water level change is not clear. But one possibility is that rapid discharge into the Seacourt during the winter months tends to subdue water level fluctuations in the vicinity. Water level contours for January show discharge to bne taking place along the whole length of the Seacourt and tends to support this model. In the same way water level changes seem to be smaller along the lower reaches of Kingsbridge brook, where again rapid discharge into the stream may help regulate water level changes.

To summarise, in the region of smaller water level change (ie less than + 0.6 m) 3 factors seem to contribute toward subduing the scale of seasonal fluctuation.

(a) A thick cover of alluvium prevents or significantly reduces winter rainfall prevents or significantly reduces winter rainfall recharge.

(b) Where recharge does take place, by infiltration from the Thames, it tends to be carefully regulated by artifically maintained river levels.

(c) Rapid discharge into the Kingsbridge brook and parts of the Seacourt stream during winter may help to subdue seasonal fluctuations.

In those regions where water level changes exceed + 0.6 two factors operate to accenuate seasonal fluctuations:

(a) Large parts of these regions have a thin alluvial cover and readily accept winter rainfall recharge.

(b) Leakage from adjacent 2nd terrace gravel deposits, especially in the Cassington area contribute large flows in the winter but relatively little in the summer.

3. The Oxford water table

Water table maps for March, June and July 1985 include water level elevations for the 2nd terrace gravel deposits underlying Oxford.

Broadly the pattern is one of a north-south elongated recharge mound extending along the length of the 2nd terrace deposit. Highest levels are concentrated in the region to the east of Summertown where elevations in excess of 61 m are recorded. From here the ridge of the mound declines southward to elevations of 57.6 m in the vicinity of the City Centre. Water levels are higher in the north mainly because the base of the aquifer lies at a higher elevation and partly because rainfall recharged is increased. The increase is probably related to the less intensely urbanised nature of the northern region in comparison to the built up areas of the City centre to the south. Rainfall recharge is almost certainly supplemented by leakage from water mains which are known to lose up to 15% of the water they carry. A detailed study of recharge to this area is the subject of a project at present being carried out by a student as part of his university degree. Hopefully the results of this work will be available in the new year.

As far as the floodplain is concerned the presence of the recharge mound beneath Oxford is important because it provides the source of a groundwater input over the southern part of the eastern boundary. Groundwater levels on the 2nd terrace are between 1 and 3 m higher than those of the adjacent floodplain. Flow off the terrace must infiltrate into the floodplain by a process of leakage at the contact between the two areas. This is shown diagrammatically in Figure 16.

Flow appears to be maintained throughout the year and probably reflects the important contribution to recharge made by leaking water pipes. The fluctuation that does take place, (+ 0.1 to 0.7 m from February 1985 to July 1985), is attributable to changes in rainfall recharge.

RECHARGE AND DISCHARGE PROCESSES

Introduction

The recharge and discharge processes operating in the study area are as follows:-

Recharge processes

1. Rainfall
2. Infiltration from the Thames
3. Flow into the area through the aquifer
4. Flow into the area across boundaries

Discharge processes

1. Discharge into ditches and natural water courses
2. Evapotranspiration losses from the water table
3. Flow out of the area through the aquifer.

No other processes have to date been identified with certainty although it is possible that more might be revealed through further investigation. One of the major problems of our study is the quantification of these processes. Although some, such as ditch discharge can be measured directly most of these processes cannot be fully quantified by field investigation alone. Even where local estimates of river recharge or discharge for example can be obtained extrapolation across large aceas is still required. Realistically all we can hope to achieve is:-

* A series of localized measurements
* A good understanding of how the process operates and the various controls upon them
* Recognition of how the various processes are spatially distributed. In the study area this has been well defined and is summarised in Figure 19.

Armed with this knowledge it is possible through the use of numerical groundwater flow models to fully quantify recharge and discharge, through simulation of measured water tables. In this way calculated values take on the same degree of reliability as all other hydrogeological data used by the model.

We now review the mechanisms of recharge and discharge and examine the evidence for their identification.

RECHARGE

1. Rainfall Recharge

Rainfall usually contributes significantly to recharge only in the winter months. For the year used for the calibration of our time varying numerical model the estimates of rainfall recharge are given in Table 6. This is based on data provided by the Meteorological Office for the Oxford region. Table 6 gives the initial estimates of rainfall recharge used in our time varying model. This assumes that evaporation takes place at the potential rate and that there is no surface runoff. As such the figure will tend to be conservative.

Recharge from rainfall is restricted to those regions which are unconfined. Areas of unconfined and confined aquifer are identified using the water table map for July 1984. The low water table conditions of this period help to highlight those sections of the aquifer which are most confined and hence least likely to receive rainfall recharge (Figure 17). In these locations recharge from rainfall is assumed to be zero throughout the year.

The January 1985 water table was not used to define confined and unconfined conditions simply because almost the entire region would fall into the confined category (Fig. 18). But this is misleading since at this time of year the 'confining' layer is often only a few centimetres of soil with water levels at or very near the surface. Such a thin layer is insufficient to prevent percolation of rainfall.

Relationships between groundwater level and rainfall are best shown by comparison of borehole hydrographs and daily rainfall figures. Hydrographs for two boreholes WR29 and WR18 are available for the period February 1985 to date, but unfortunately we do not yet have daily rainfall figures for much of this time. Our records at the moment end in April 1985 while we await updated information. Hence it is not yet possible to provide any long term correlation with rainfall at these two sites. However with updated rainfall data such a correlation will be feasible,

2. River Recharge

Within the study area the only watercourse recognisably contributing to groundwater recharge is the river Thames. Here significant recharge is restricted to the section of the Thames between Hagley Pool and Godstow lock beneath which a significant mound has developed. Below Godstow lock the mound becomes progressively subdued. Restriction of recharge to the section of river upstream from Godstow lock is likely to be related to the contrasting nature of the river bed above and below this point. Where recharge is active the river bed is characterised by a large number of scour hollows distributed along its length. This is illustrated by the long profile of the Thames river bed taken in 1980 (Fig. 20). Scour hollows between 1 to 2 m deep are scattered at regular intervals throughout the section from the Evenlode confluence to Godstow lock. The deepest seem to be concentrated between Hagley Pool and Godstow coinciding with the most intense development of the recharge mound.

In sharp contrast the stretch of river marked by the absence of a recharge mound, between Godstow and Medley weir, has a remarkably smooth profile. Here there are no scour hollows nor indeed are there any features worthy of note. A constant elevation, varying by little more than 0.5 m is maintained throughout the section.

We suggest that the presence of scour hollows to the north of Godstow indicates the river is actively eroding its bed at these points keeping it clear of silt and mud. Since all the hollows cut deeply into the gravel aquifer they all offer suitable locations for recharge. Downstream where the river profile is smooth the dominant river process is likely to be depositional tending to seal the bed with silt and mud. Under these conditions the potential for recharge is greatly reduced.

As mentioned earlier this section of the Thames is man made. Hence it is possible that during its construction efforts were made to artificially seal the bed in the manner of a canal. If os it helps to explain why recharge is considerably reduced.

The difference in river bed profile could also have resulted through recent dredging operations. However, the Thames water authority have confirmed that no dredging of this section of river has taken place since the 1930's. Clearly therefore dredging is not a relevant factor.

Apart from the presence of the groundwater mound, direct evidence for river recharge is provided by the hydrograph of borehole WR29. This is located approximately 10 m from the north bank of the Thames at its confluence with the Evenlode. Here the river appears to be in direct connection with the aquifer. Groundwater and river levels show close correlation as illustrated in Figure 21. For the period of record from February to October 1985 there is a linear relationship and a correlation coefficient of 0.983. Similarly a good correlation exists for water levels taken at UFS 20 during 1980-1981 and the Thames river stage between King's lock and Godstow lock for the same period. Here groundwater levels have been correlated with river levels interpolated between readings taken at the two locks. Despite the drawbacks involved the correlation coefficient of 0.917 is still very good (Fig.22). Once again this is direct evidence for river recharge in the section of river above Godstow lock.

Along the section of river where little recharge is taking place we have no boreholes close to the river for which simultaneous river stage and grounwater levels are available. Hence we are not able to show how river-groundwater relationships differ in this zone. Boreholes PTM4, PTM have long term records collecte during 1980-81 but river stage readings for the same period are not yet available.

To obtain these levels we require the lock readings taken at Osney for the 1980-81 period in order to extrapolate river levels between here and Godstow lock. When enquiries were made to Thames Water earlier this year the Osney levels were not accessible but we were promised they would become available at a later date. When this is obtained, correlation between interpolated river levels and the hydrographs from PTM4, PTM10 and PTM12 should be undertaken.

These correlations will help prove where river recharge is taking place but they cannot be used to quantify the amount. To quantify recharge requires accurate gauging of river flow over given stretches to enable calculation of losses taking place. Because the magnitude of groundwater flow is so small in comparison to surface flows, however, this is not possible in the study area. The magnitude of such losses usually fell well within the errors of existing methods of flow gauging. As a result whereas we are able to pinpoint the location of river recharge we have to rely on numerical modelling to provide a quantification.

3. Recharge across the boundaries

Significant recharge takes place across the boundaries of 4 locations (Fig. 11).

1. The western boundary drawn across the floodplain at the Thames-Evenlode confluence.
2. The northern boundary drawn across the floodplain between Yarnton and Kidlington.
3. The southern section of the eastern boundary.
4. The 0.5 km stretch of boundary to the south of Cassington.

Flow across the first two boundaries simply represents water moving through the aquifer into the study area. This recharge is quantified by application of Darcy's Law. Thus:

$$Q = T.I.W.$$

where Q = Flow in m^3/day
T = Transmissivity in m^2/d
W = Width of aquifer in m
I = Hydraulic gradient

Using this simple equation the water table maps for each of our monitoring periods can be used to quantify this input. For example flows across the northern and western boundaries during July 1984 were 252 m^3/day and 124 m^3/day respectively.

Input across the second two boundaries is flow not through the aquifer, but leakage from adjacent 2nd terrace gravels situated at a much higher level. The southern section of the eastern boundary of the study area receives water from the recharge mound developed beneath Oxford. This mound, maintained by a combination of rainfall and leaking water pipes, provides a steady westward recharge throughout the year. Water passes between the two sets of gravels by leakage through a thin cover of soil and slumped gravel as shown in Figure 16. Head differences of 1 to 3 m between the Oxford and floodplain water tables provide the driving force for the transfer of water. The July 1984 water table indicates an input of 848 m^3/day across this boundary, which represents 20% of total recharge into the area. It is hoped that modelling of the Oxford water table at present being undertaken by a university student will help verify the total recharge being input across this boundary. Clearly the westward output of an Oxford water table model should equate with the westward input required by the model of the floodplain area.

Finally a similar mechanism is operating along the boundary to the south of Cassington. Once again transfer of water is taking place by leakage from 2nd terrace gravels. But in contrast to the Oxford situation the input across this boundary seems to become greatly reduced and even cease during the summer months. During the winter the 2nd terrace deposits in the Cassington region are recharged by rainfall which feeds the southward leakage of water. As this recharge source diminishes during the summer, storage with the gravels becomes rapidly exhausted and is unable to maintain flow during the dryest months. Such a situation does not arise within the Oxford region because here summer recharge is sustained by leaking water pipes and flow into the floodplain area continues throughout the driest period.

DISCHARGE

1. Discharge into ditches, streams and rivers

During the winter months over 90% of groundwater within the area is discharged into surface water channels. In summer this figure is reduced as other processes such as evapotranspiration from the water table become more important. Three major systems of surface water channels account for most of the discharge:-

(a) The Kingsbridge brook and associated ditches

Here we include the 'natural' section of the Wolvercote Millstream channel, downstream from Wolvercote Mill, the system of ditches that drain into the Kingsbridge brook as well as the Kingsbridge brook itself. This system of channels accounts for most groundwater discharge in the region. In July 1984 modelling studies suggest that 47% of total discharge is accounted for by this system (1970 m^3/day).

To compare model discharges with actual discharges a series of flow measurements have been made throughout 1985 at 4 points on the Kingsbridge brook system. These positions coincide with our recorded locations which are shown on Figure 19. The most important is to the north of the A34 by the Gravel pit at the lower end of the drainage system. During 1985 from February to June flows recorded at this point range from 47,600 m^3/day to 6800 m^3/day. Highest flows were recorded in June following a period of very heavy rainfall and clearly includes a substantial surface runoff component. A low flow of 6800 m^3/day was recorded in March. These high figures reflect the abnormally wet period experienced during the first half of 1985. Model predicted flows at this point for the exceptionally dry July 1984 condition, was 1970 m^3/day. Thus the lowest recorded 1985 flow is three times higher than that for 1984. It is particularly important to ensure that further flow measurements are made now (October 1985) to record the low flow conditions following the extremely dry September. By doing this we will be able to build up a range of flows for the Kingsbridge brook system covering an extreme of conditions. Model predicted discharge should then be required to fall within this envelope of values.

Correlation between groundwater and dtich levels have been possible at the site of WR18. Here the borehole hydrograph for WR18 can be correlated with levels in a major ditch feeding the Kingsbridge brook. Borehole and ditch are approximately 20 m apart. A plot of groundwater depth against ditch stage (Figure 23) shows a 1:1 relationship for most conditions of low flow. Where the ditch stage is lower than 1.05 m below datum the correlation is exact. A stage of 1.2 m below datum translates to a flow of 6000 m^3/d so 1.05 m represents a significantly higher figure. Where ditch levels are over this point the 1:1 relationship breaks down as surface water runoff forms an increasingly important component. Similar plots should be carried out for the other three surface recorder sites with the nearest available borehole site. Groundwater level data here will be restricted to the bi-monthly monitoring reading, but there should be sufficient to allow correlation.

For the two other major ditch and stream systems in the Seacourt and Portmeadow regions we have no flow data. Model results for the July 1984 condition suggests that the Seacourt region accounts for 40% of discharge from the area although part of this is probably accounted for by evapotranspiration. In contrast the Portmeadow ditch carries less than 10% of total discharge. For quantification of flow in these systems we rely totally on model calculations. But we are able to identify where ditcvh discharge is taking place at different times of the year by recording which ditches continue to flow. To date only two complete ditch surveys have been carried out for 1985. These have been for June and September and are shown in Figures 24 and 25. It is important that a third survey is done now (October 1985) since present conditions are representative of a very dry period.

Such surveys make it possible to pinpoint locations where ditch and stream discharge may be taking place. Obviously where ditches are dry they cannot be operating as a discharge process. The picture that emerges from the two completed surveys is very useful and surprising. In the north all major branches of the Kingsbridge brook system continue flowing into September, although several of the secondary ditches have become dry. By September the natural course of the brook north of the A34 is dry and flow only increases significantly when joined by secondary ditches running in from Yarnton. It can reasonably be assumed that ditch discharge remains a significant process in this system at least until September. A further survey will show whether this continues on into the present dry period.

Along the course of the Seacourt the situation is very different. Here few ditches were flowing even during the extremely wet period in June. On Figures 24 and 25 the large ditch connecting the Thames and Seacourt should be discounted since it simply transfers surface water from one river to the other. Those ditches carrying groundwater are restricted to a few small channels near the Seacourt and one large ditch flowing south from Medley Manor Farm. Because of poor borehole coverage locally the impact of this dtich on the water table is difficult to assess. Logically it should create a sgroundwater 'valley' but without more groundwater monitoring points the problem must remain unsolved.

Given the poorly developed ditch system we must conclude that the groundwater trough developed in this region is due to two processes:-

(a) Discharge into the Seacourt channel itself, plus the few flowing ditches in its vicinity.

(b) Evapotranspiration from shallow water tools.

Discharge into the Seacourt during winter and summer conditions has been discussed in Section and need not be respected, while evapotranspiration is discussed in the following section.

The third and final ditch system is that situated on Portmeadow; it is also the least important in terms of volume of groundwater discharged. Our model for the June 1984 condition required a discharge of no more than 380 m^3/d from this system. The June and September surveys demonstrate that one large ditch extending along the eastern margin of the meadow carries all discharge from the meadow. A secondary ditch running in from Wolvercote did not flow even in the very wet June period, and other small ditches had only a limited discharge. It follows that all groundwater discharge is concentrated along the main eastern ditch.

2. Discharge by Evapotranspiration

This process involves the removal of groundwater from the water table by upward movement through the unsaturated zone and discharge to the atmosphere via vegetation. To understand and ultimately quantify this phenomena therefore requires a study of water movement within the unsaturated zone. Essentially such a study revolves around the measurement of soil moisture profiles under a wide range of conditions. With this basic data calculations of water balances within the unsaturated zone are possible. We have recognized that during periods of stress evapotranspiration of groundwater from storage can be a significant discharge process, especially where water tables are shallow. The problem we face is to identify those areas where this type of discharge is able to take place and to quantify the process.

First attempts to measure the soil moisture profile were made between August and November 1984, on Yarnton Mead. This period coincided with the final few weeks of a particularly dry summer, which came to an end with the onset of wet conditions in mid-September. A report of the observations made at this time is given in Appendix II. Briefly the data indicated that throughout the summer months, the shallow water table at the site (PX11) keeps the soil profile very moist and supplies water to the vegetation.

The report concluded that the maintenance of an upward flux (flow) was only possible if the water table remained within the fine grained alluvium overlying the gravels. Because of the low unsaturated hydraulic conductivity of the gravels such an upward flux could not be sustained if water levels were allowed to fall below the alluvial cover. Thus from these initial measurements we were able to confirm that evapotranspiration operates as a discharge process and that the role of the overlying alluvium is vital in this operation.

Based on the experience of the 1984 work a soil moisture monitoring programme was set up for 1985. Four stations, each including a tensiometer and neutron probe, were installed at locations of contrasting hydrogeology. Sites were established next to existing boreholes. These were at WR15, PX11, WR8 and UFS27. At PX11 the water table lies above the base of the alluvium throughout the year whereas at UFS27 it lies below the base at all times. Water levels at WR15 and WR8 fluctuate over the bnoundary and thus represent a third contrasting situation.

The aim of these sites is to use the meteorological data to calculate estimates of daily potential evaporation. These data will be compared with the soil moisture content changes caused by evapotranspiration at the field site. Tensiometer data indicate when the soil water flux is upward ie. induced by evapotranspiration. If as data recorded at Yarnton in 1984 indicate, the daily potential evapotranspiration demand cannot be met by soil moisture content changes during periods when tensions indicate an upward flux, then it can be assumed that plants obtained some moisture from groundwater.

The model recently obtained from Holland can be used to help quantify the amount of water lost from the water table under a range of conditions. At the same time the model is to be used to predict how soil moisture profiles will respond to falling water tables under both confined and unconfined situations. Various predictions can be made simulating ever decreasing water levels from confined through to an unconfined state. In this way the state of the unsaturated zone can be predicted for any given rise or fall of water table.

On a regional scale we have attempted in a very broad sense to define those regions where evaporation from the water table is most likely to take place. It is considered probable that most groundwater loss by this sprocess takes place where groundwater levels are shallow and are located within the alluvium in the summer months. By remaining within the alluvium a sufficient unsaturated hydraulic conductivity is maintained to support a continued upward flux throughout the zone. Where water levels fall within the gravel hydraulic conductivity falls to virtually zero and no or very little upward flux can continue.

Areas of shallow water level (ie. less than 1.2 m below ground level) for the driest condition (July 1984) have been defined in all regions to the south of grid line 09. To the north levels have yet to be calculated.

When complete this map should be overlain upon that showing unconfined/unconfined conditions for July 1984. In this way areas of greatest discharge potential by this process can be defined.

* Value at end of month.
** Assuming No run-off.

	1984						1985							
	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	TOTAL	JUL
RAINFALL MM.	13.6	32.7	91.1	54.4	104.6	44.5	44.4	34.7	36.7	32.7	80.5	122.5	689.4	45.8
POTENTIAL EVAP. MM.	112	91	57	35	18	8	11	13	31	56	78	80		94
ACTUAL EVAP. MM.	33	56	44	34	18	8	11	13	31	56	77	80		90
S.M.D.* MM.	122	125	82	70	0	0	1	0	0	24	17	10		44
RECHARGE** (USING P.E.) MM	0	0	0	0	83	36.5	33.4	21.7	5.7	0	0	~~0~~ [illegible]		0

NB For first run assume that rainfall recharge takes place only through the unconfined areas.

ICRI MODEL

Initial inputs into Flowcon.

For month 1 (JULY) I have ~~adapted~~ translated the results from the gollin model.

For Recharge from the river I have increased the value by 5% per month ~~to~~ up to and including month 7. From this point it is decreased by 5% per month to month 12.

~~For~~ For ~~Rech~~ Discharge from ditches / evapotranspiration I have increased values by 3% up to and including month 4. For months 5, 6, 7, 8, 9 when rainfall recharge is taking place I have assumed that approximately 50% of the rainfall recharge is discharged via ditches or evapotranspiration. The remainder is either passed through the aquifer or goes into storage.
~~From month 10 to 12~~
From months 10 to 12 discharge is decreased by 3% per month.

APPENDIX II

SOIL MOISTURE MEASUREMENTS AT YARNTON MEAD :
A brief report of results August to November 1984.

INSTRUMENTATION

A very basic set of equipment was installed on 28th Aug. This comprised a neutron probe access tube enabling measurements to 150cm depth and 6 tensiometers at depths of 10,20,40,60,80 and 100cm. The water table level has been recorded in the observation well [illegible] 25m from the plot. Measurements have been made at the site at approximately weekly intervals.

OBSERVATIONS

Only two sets of observations were made before the wet period in mid-September which brought the particularly dry summer to an end. These observations confirmed what was apparent when the equipment was installed, that the moisture content of the whole of the soil profile was high in spite of the preceding dry period. On both occasions [illegible] the moisture content exceeded 0.42 MVF (moisture volume fraction) [illegible] was 0.[illegible] MVF in the underlying sands. The water table was observed to be at 85cm, and the tensiometers recorded total potentials of greater than -500cm water head (ie. well within plant abstraction range) and indicated an upward potential gradient from the water table. Thus, there will have been an upward flux from the water table the rate of which will have depended on the conductivity of the soil.

An estimate of the quantities of water involved can be made using the probe data. The soil moisture content reduction above the water table between the 29th Aug and 6th Sept was 4.0mm; in the same period at Wallingford there was 4.5mm of rainfall and the potential evaporation loss was 19.2mm. Thus over the 8 day period an estimated 10.7mm of water was supplied to the vegetation (assuming it was transpiring at the potential rate) ie of the order of 1.3mm per day of water will have been supplied from the ground water. (Note that earlier in the summer daily potential evaporation rates of up to 4mm per day will have been usual.)

Since mid-September the observations have indicated that the profile responds rapidly to rainfall. On one occasion the tensiometers have indicated the presence of a perched water table. Generally the whole profile wets up and the groundwater table level rises. The water table subsequently falls again presumably as a consequence of drainage and some evaporative losses. Since the end of August the water table has risen from 85cm to about 70cm.

The data indicate that throughout the summer months each year the the shallow water table at the site keeps the soil profile very moist and supplies water to the vegetation. It seems probable that if the water table were lowered much below the junction of the underlying sands with the silty-clay, the water regime of the soil would be considerably changed. Because of the probably low unsaturated hydraulic conductivity of the sands, the upward flux from the water table would almost cease, and thus the soil, and plants would have to rely on rainfall for their water supply.

CMHB Nov. 1984.

Figures.

- ✓* Map of the 39 region and the Worton Project region with the locations of the Meads indicated. Fig 1
- ✓* Physical setting. Showing regions of high ground surrounding the region Fig 2.
- ✓* ~~F~~ Historical changes of watercourses in the study area Fig ~~3~~ 5
- ✓* w/levels in the Seacourt / Thames / Wolvercote Mill stream / Kingsbridge Brook Fig ~~4~~.3
- ✓* Surface water catchments and drainage ditches. Fig ~~5~~.4
- * Base of Aquifer Figure 6.
- ✓* X section Figure 7
- * Gravel thickness Fig 8
- ✓* Top surface of gravel Fig 9
- * Alluvial thickness Fig 10. * ✓
- * Aquifer boundaries. Fig 11 * ✓
- (*) Observation network density. Figure 12. *
- * Figure 5A Godstow / Kings Lock levels. *
- ✓* Figure 5B. } 1981 } Water level measurements.
- * Figure 5C } 1984
- ✓* Figure 13. JUN 1984 water table * ✓
- ✓* Figure 14 JAN 1985 water table * ✓ ?
- * Figure 15 ~~Difference~~ Change in g/w levels between JUL 1984 / JAN 1985.
- ✓* Figure 16 Leakage from Oxford Road — X section.
- (*) Figure 17 confined / unconfined aquifer July '84 ?
- (*) Figure 18 confined / unconfined aquifer Jan '85 ?

✓ Fig 19 – distribution of recharge/discharge ✓

✓ Fig 20 – Therms profiles. ✓ ?

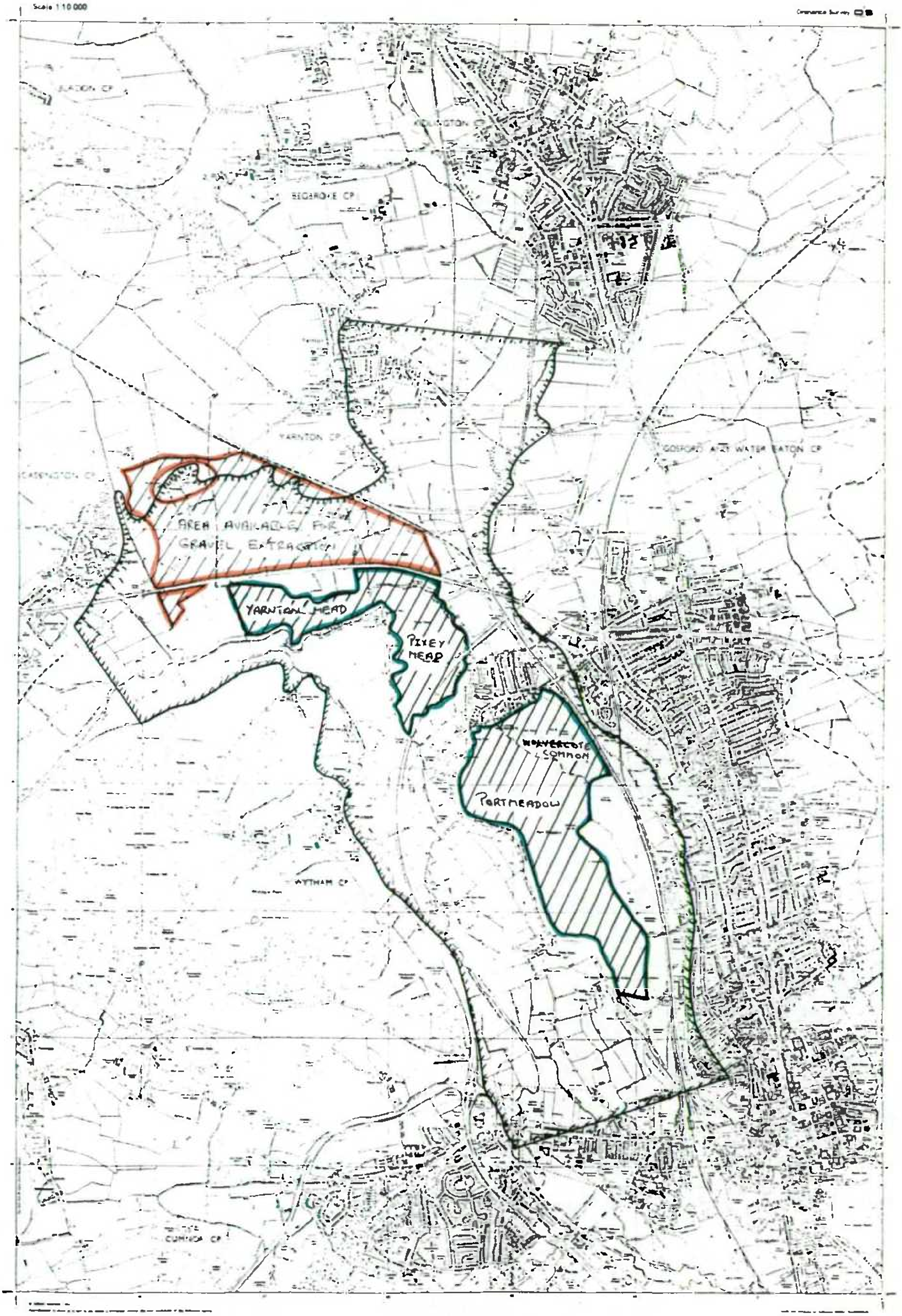
✓ Fig 21 – Correlation of WR28 and Therms. ✓ ?

✓ Fig 22 – Correlation of UF120 and Therms. ✓

✓ Fig 23 – WR18 - Ditch correlation. ✓ X

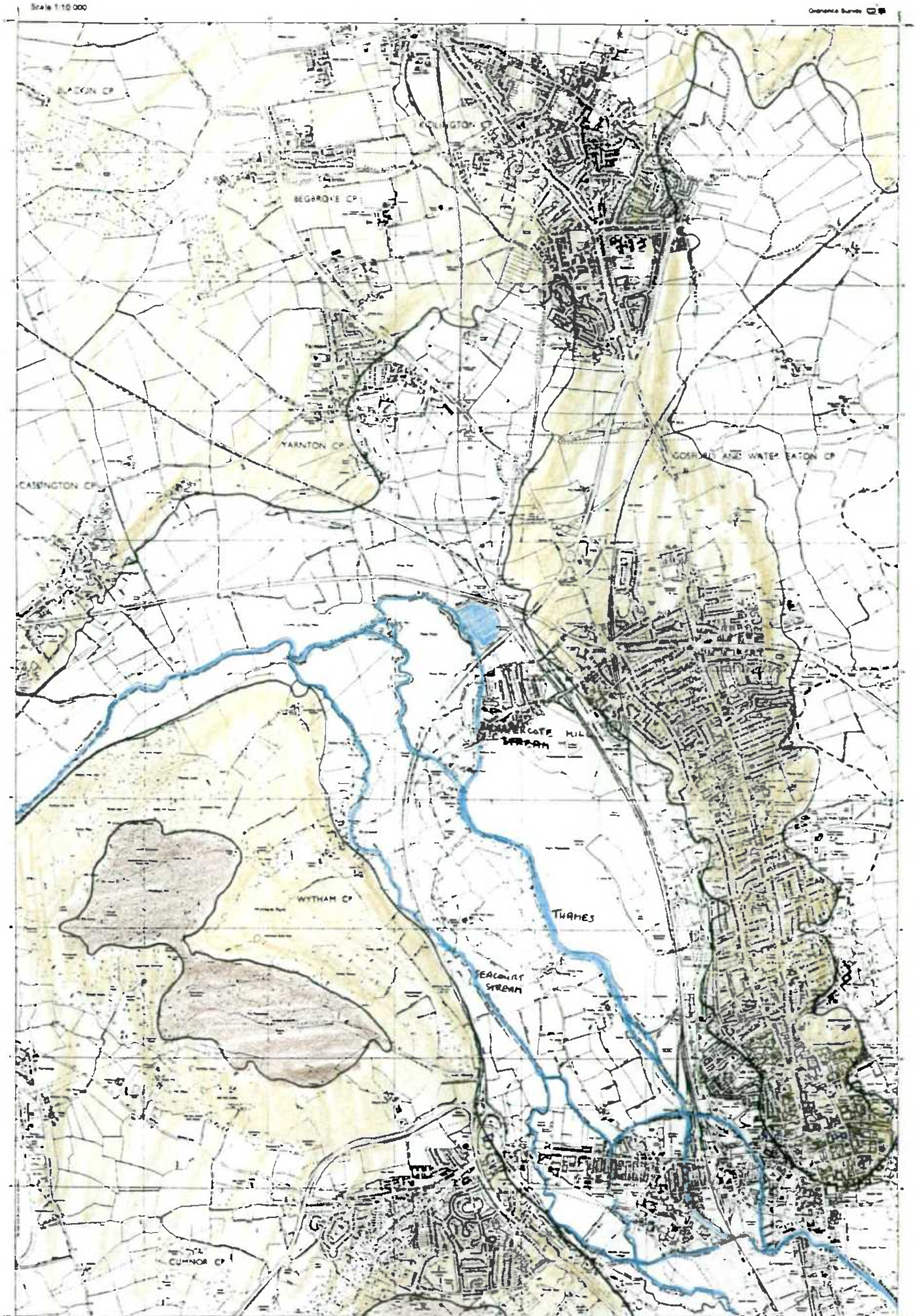
✓ Fig 24 – Ditch survey June '85

✓ Fig 25 – Ditch survey Sept '85



AREA OF RESEARCH STUDY

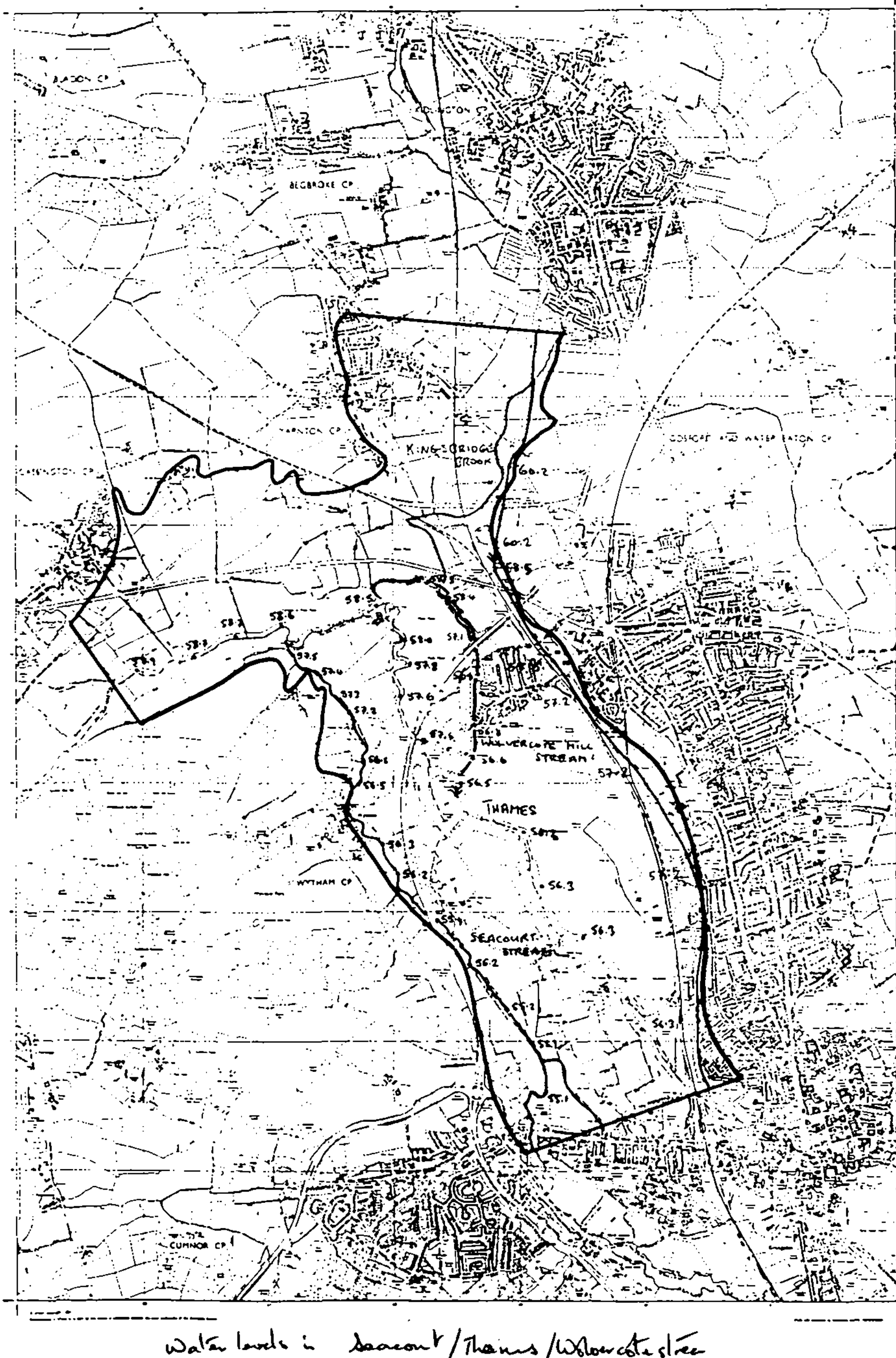
Fig 1



Physical setting

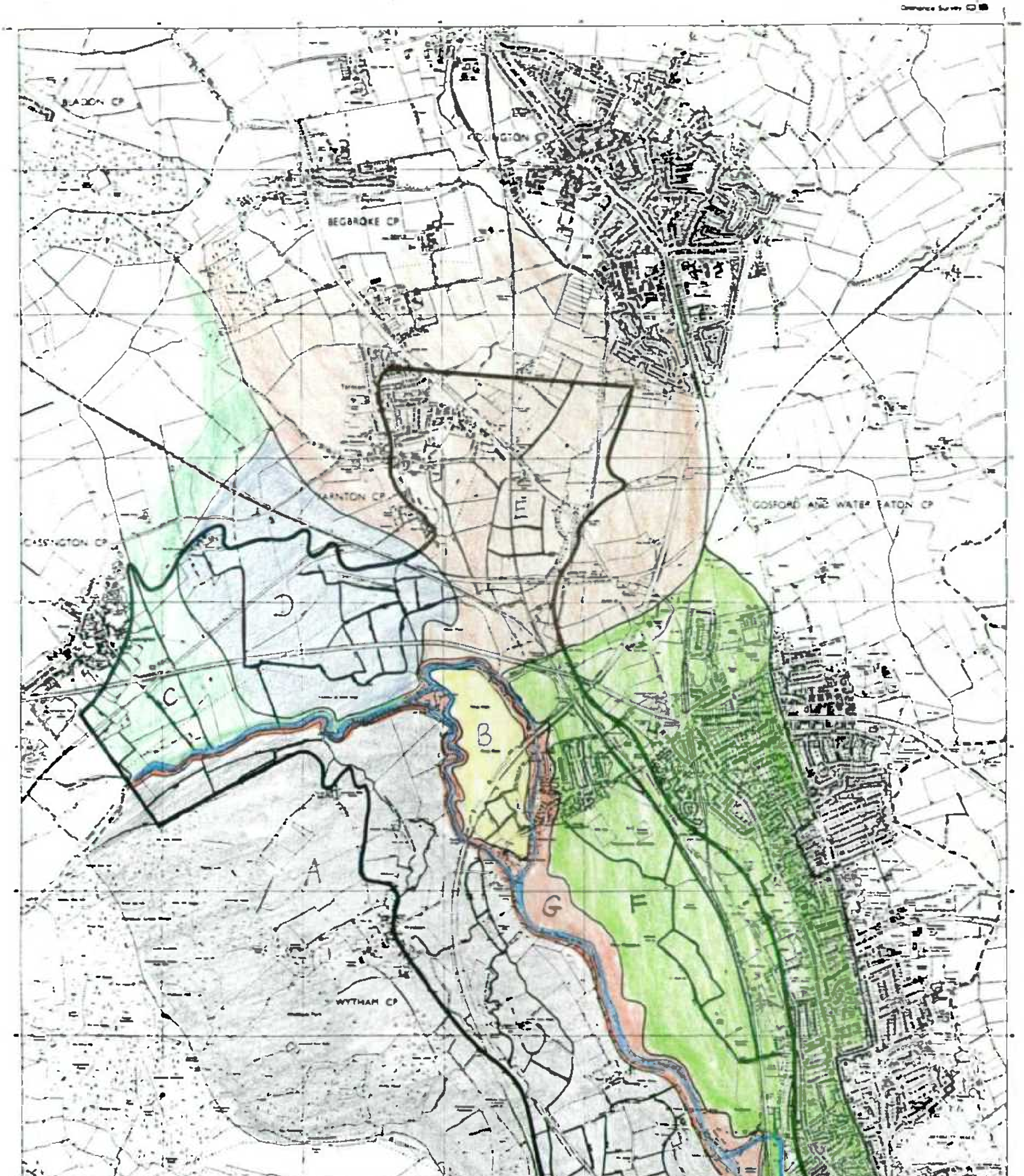
- < 60 m OD
- 60 - 120 m OD
- > 120 m OD

Fig 2



Water levels in Seacourt / Thames / Wolvercote stream
Kingsbridge brook / Canal Dec - Jan 1979

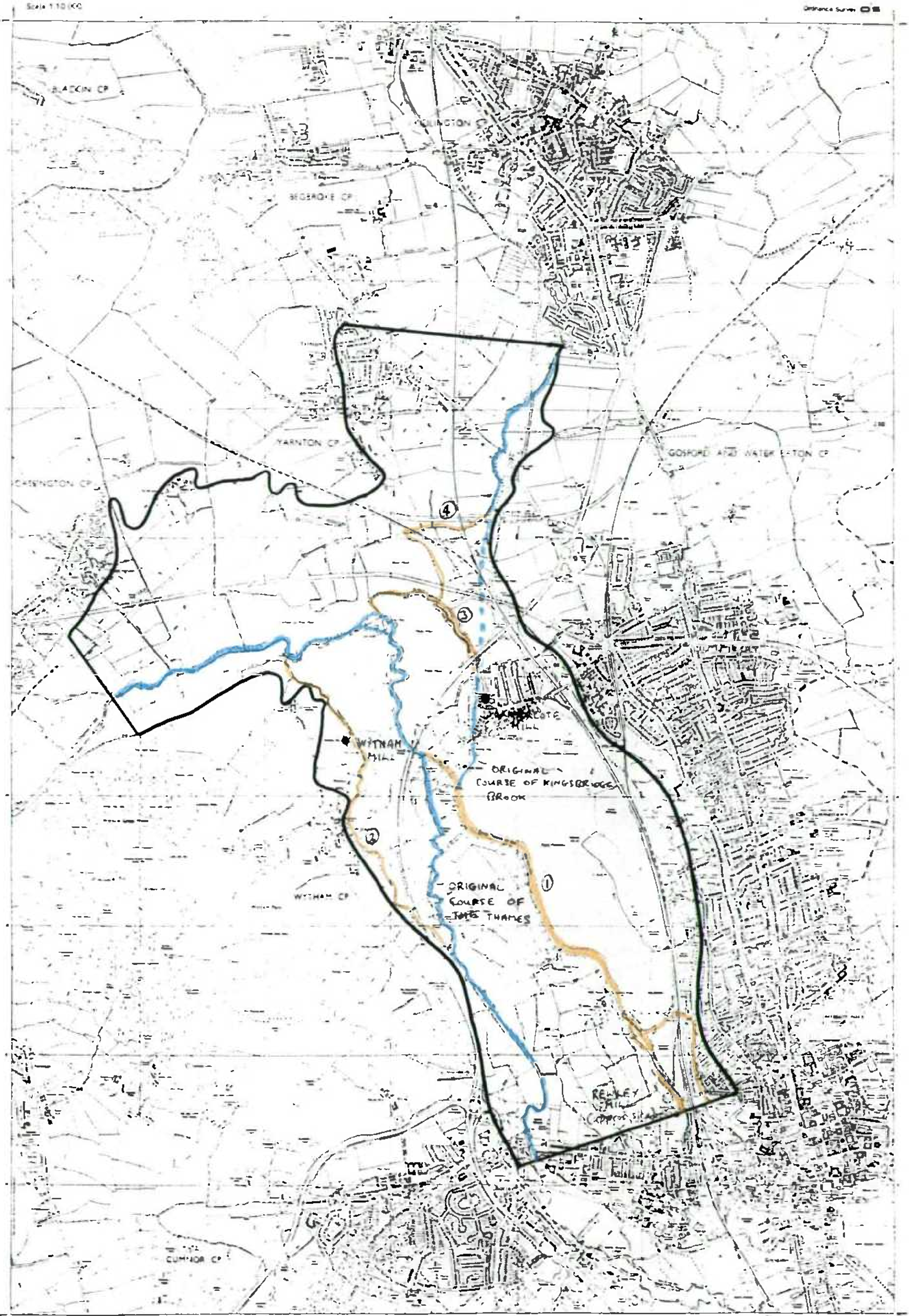
Fig 3



Catchments and Drainage Ditch Network

A - SEACOURT
B - PIXEY MEAD
C - CASSINGTON
D - KINGSBRIDGE WEST
E - KINGSBRIDGE EAST
F - WEST OXFORD
G - THAMES

Fig 4



Historical development of water courses

Fig 5

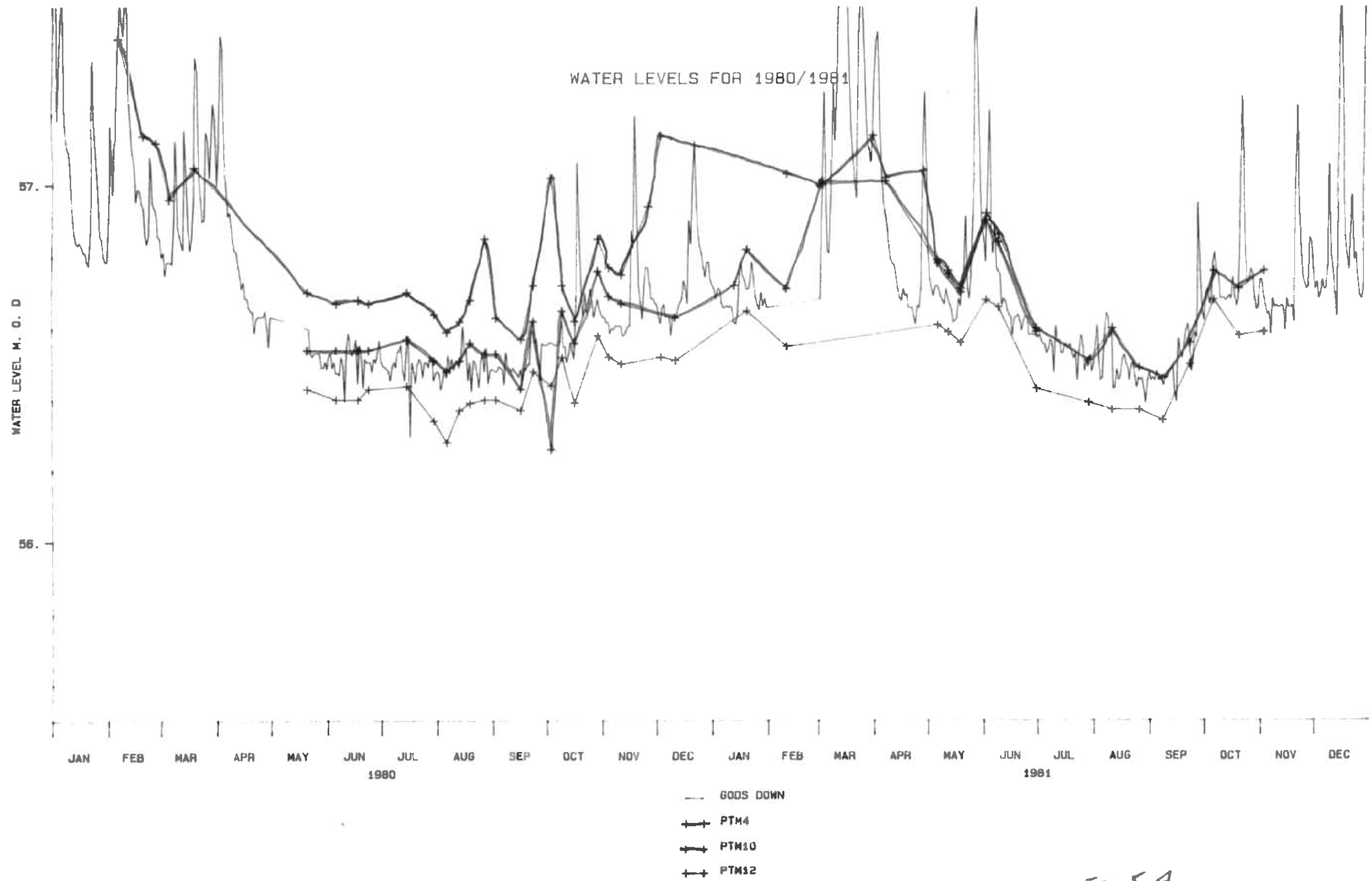
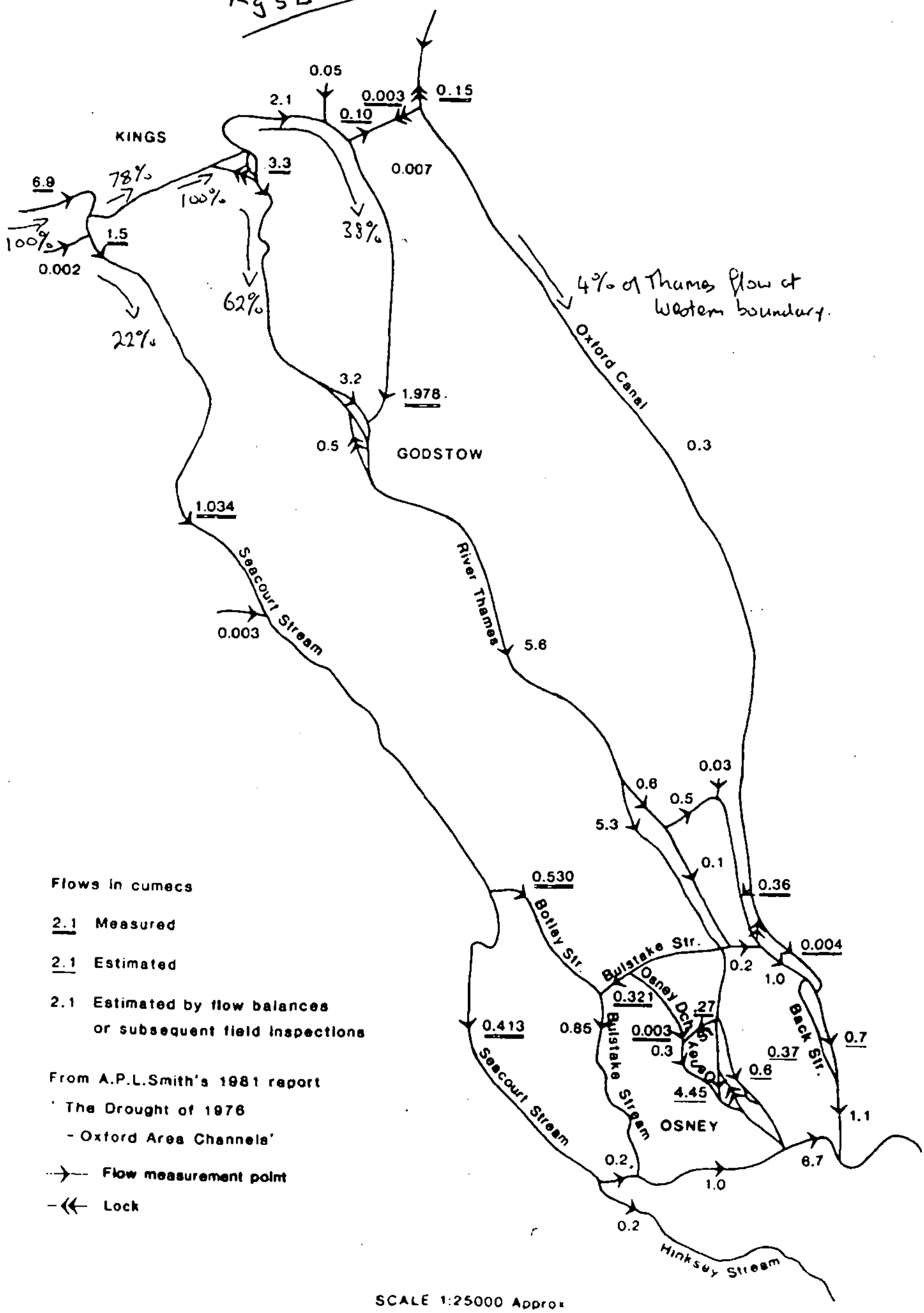

WATER LEVELS FOR 1980/1981
WATER LEVEL M. O. D
57.
56.
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1980
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1981
GODS DOWN
PTM4
PTM10
PTM12

Fig 5A

~~Fig 1~~ The Thames in Oxford

~~Fig 5B~~ 16/9/81

Fig 5B



Flows in cumecs

2.1 Measured

2.1 Estimated

2.1 Estimated by flow balances or subsequent field inspections

From A.P.L.Smith's 1981 report 'The Drought of 1976 - Oxford Area Channels'

→ Flow measurement point

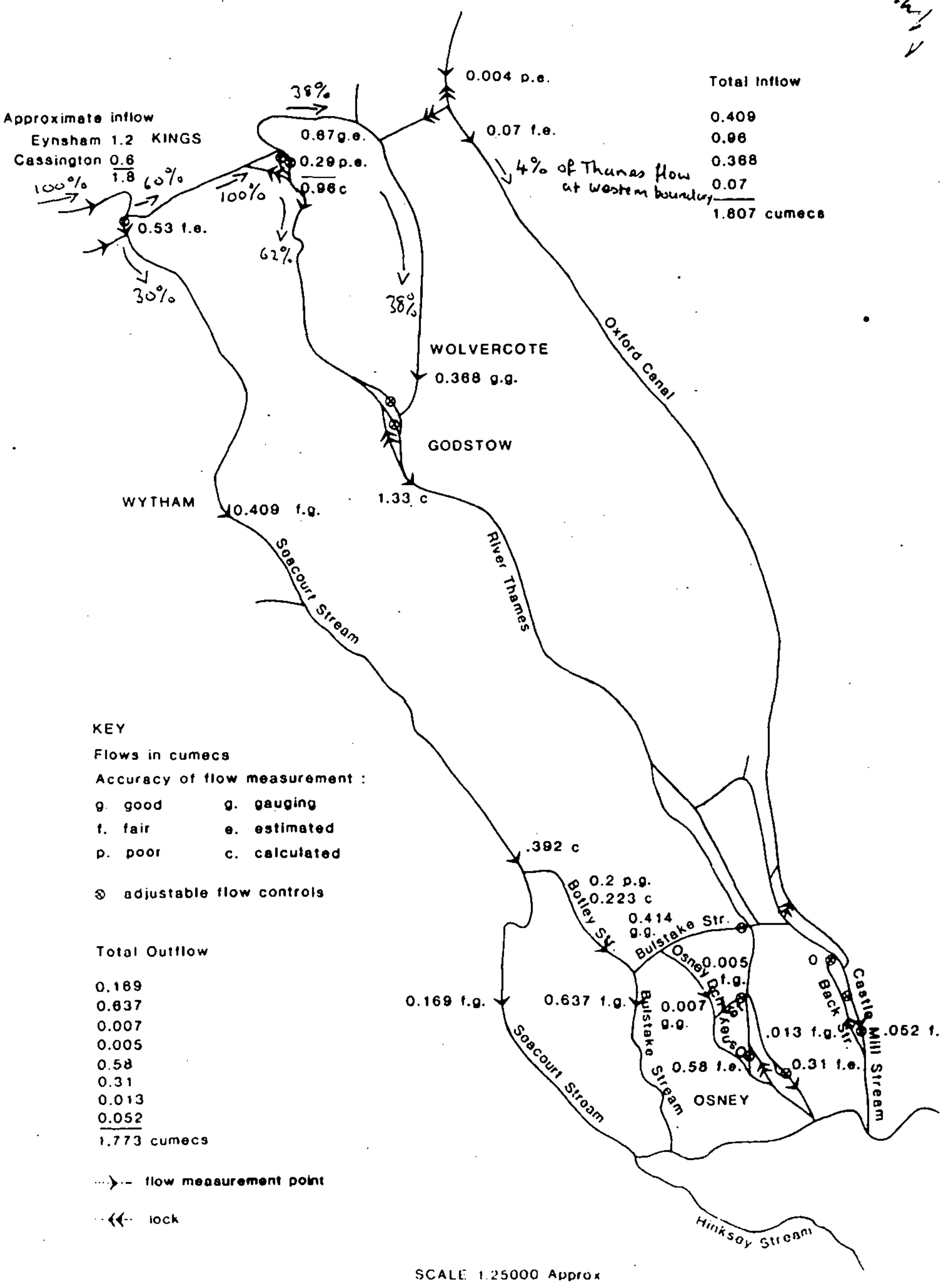
-≪- Lock

SCALE 1:25000 Approx

Seacourt Stream

Fig. 5C The Thames in Oxford

29/8/84



Base of aquifer

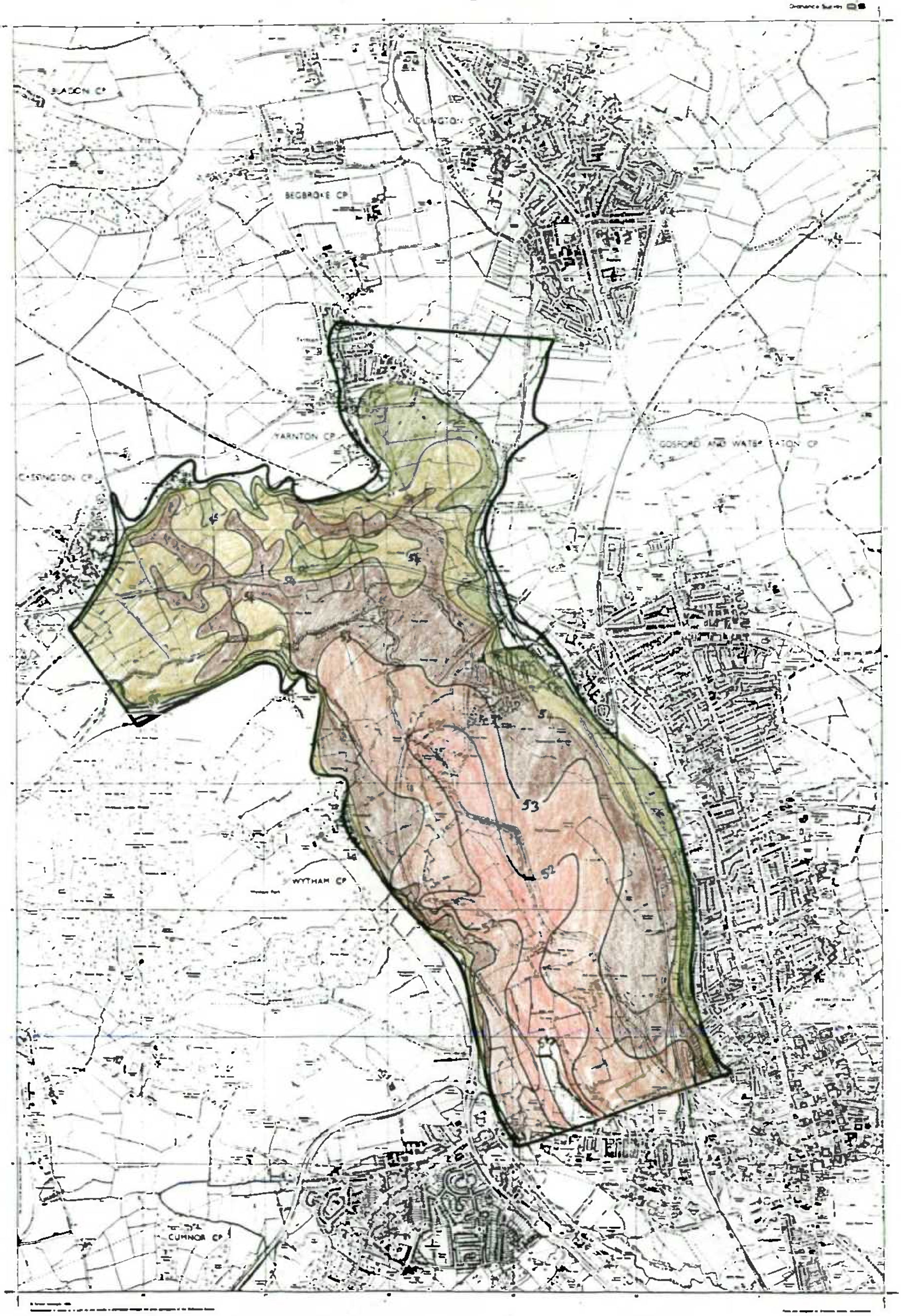


Fig 6 (6)

FLOOD PLAIN CROSS SECTION

Figure 7

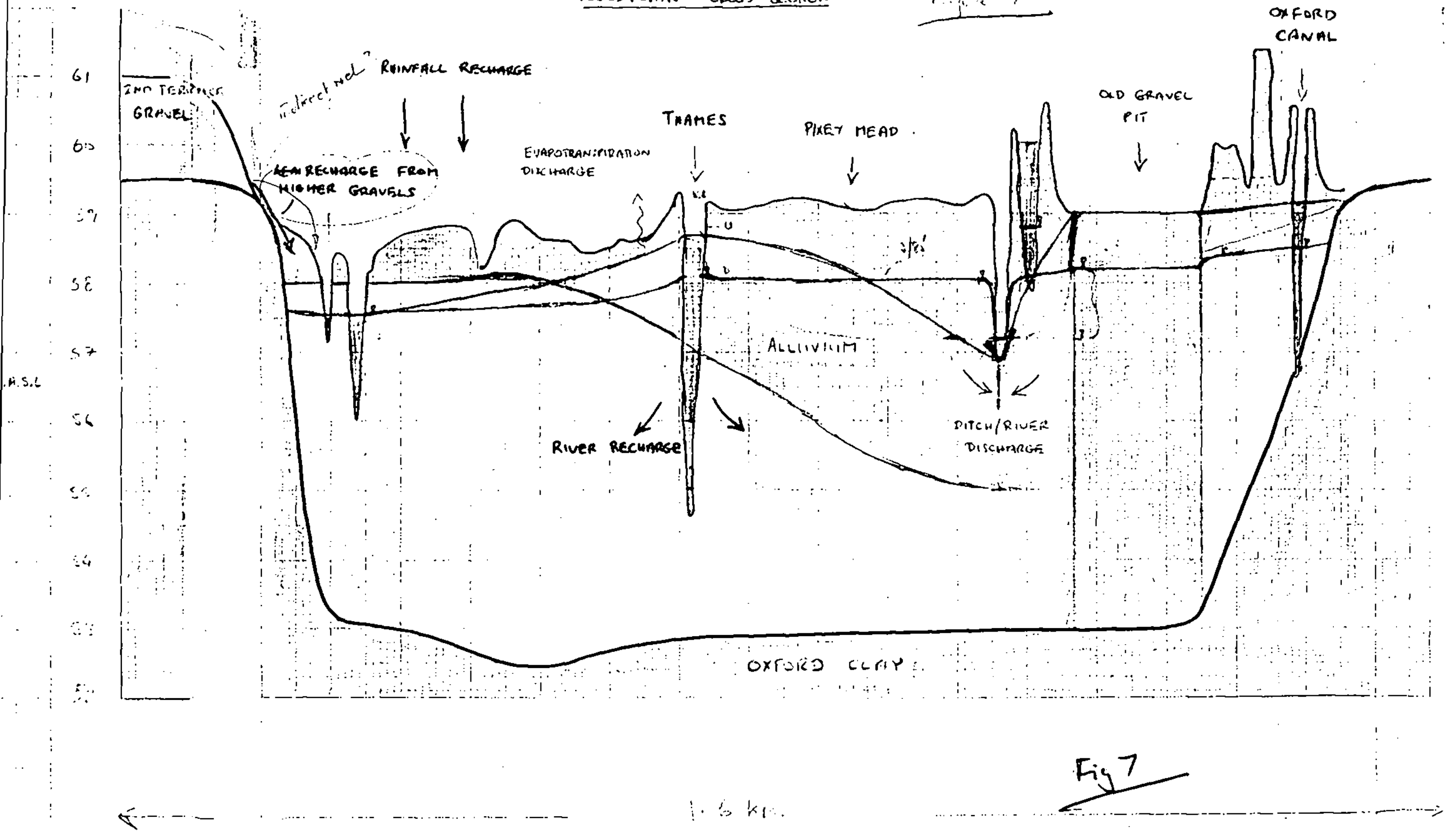


Fig 7

Thickness of gravel(m)

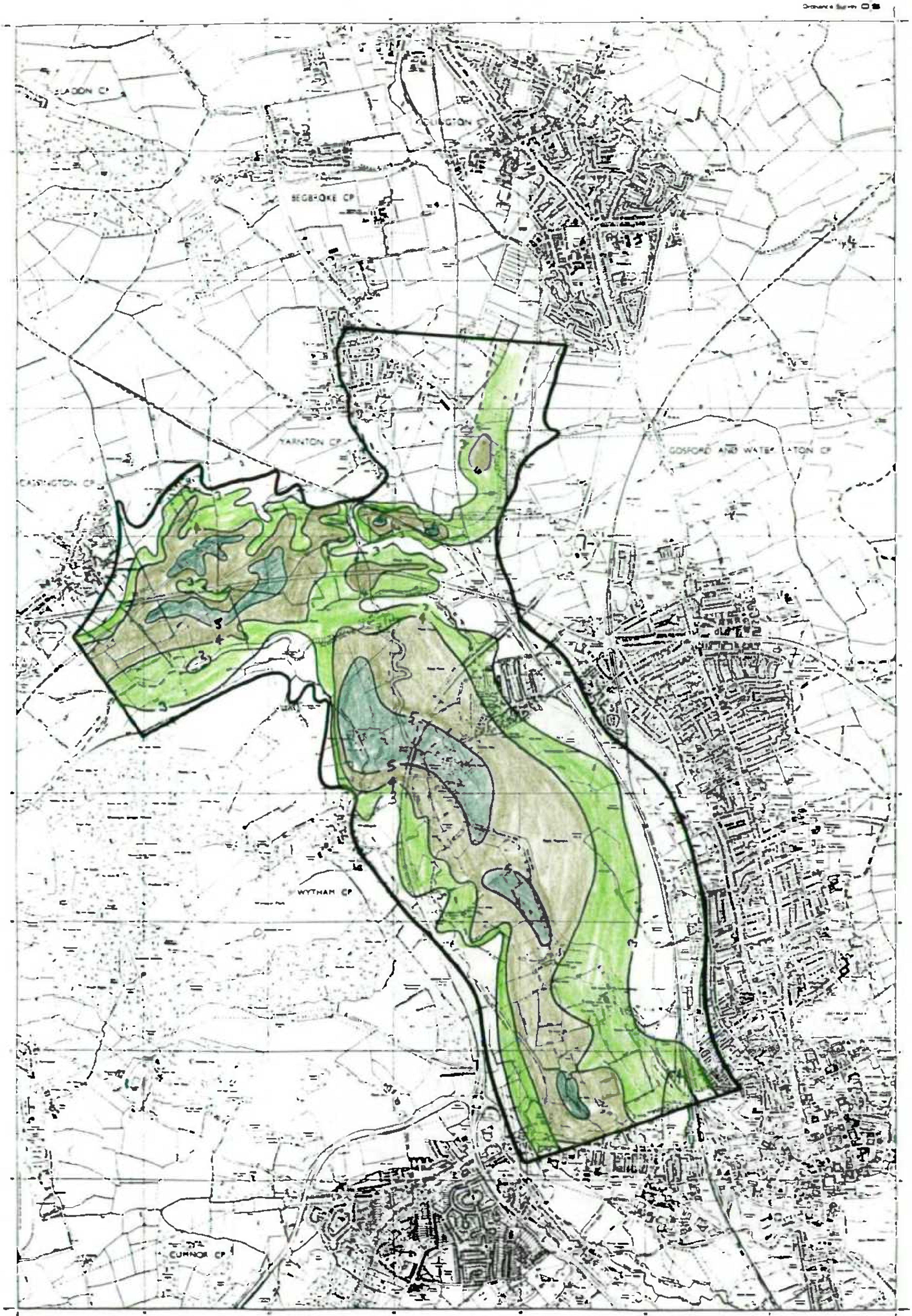


Fig 8

Top of aquifer(upper surface of gravel)

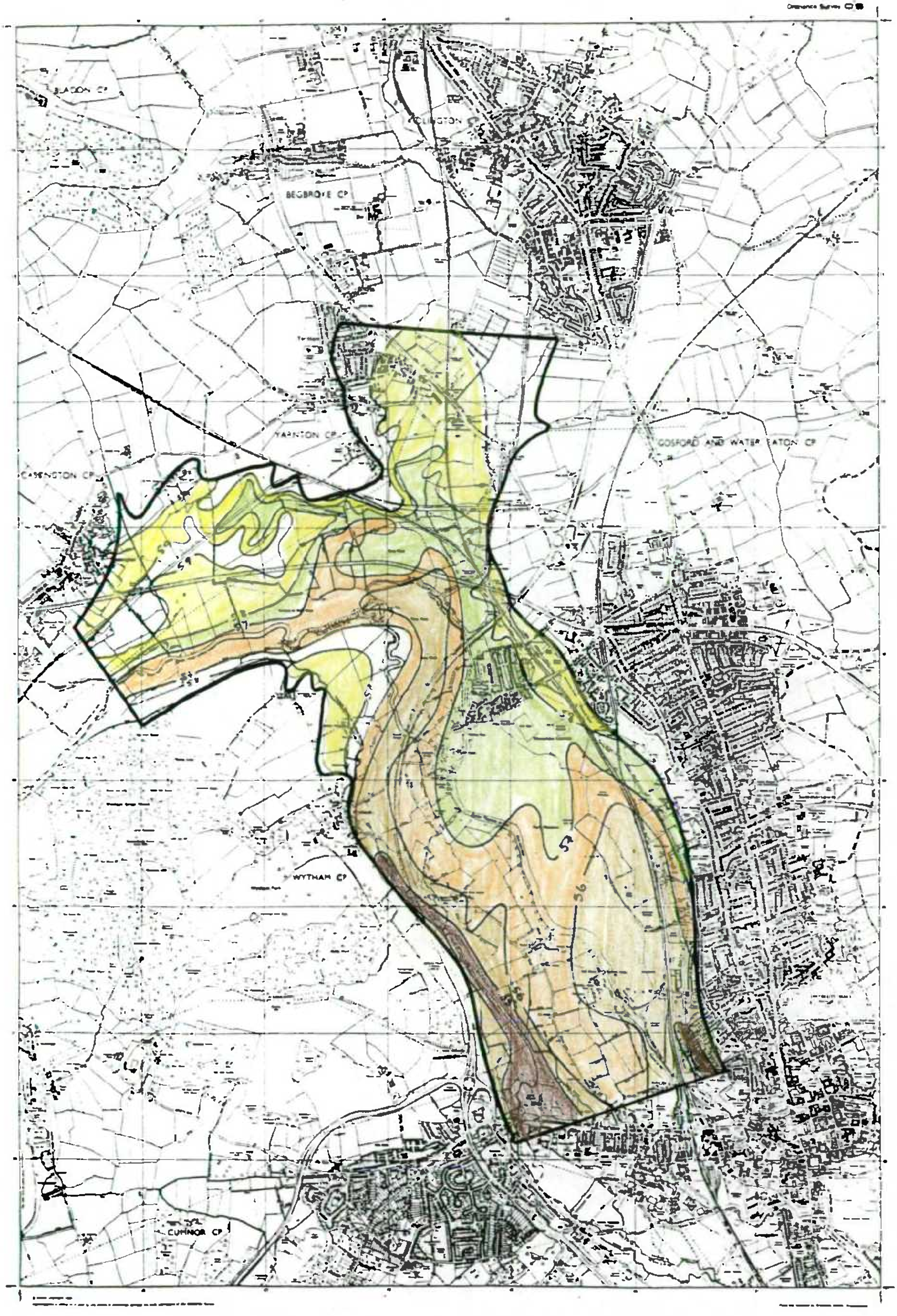
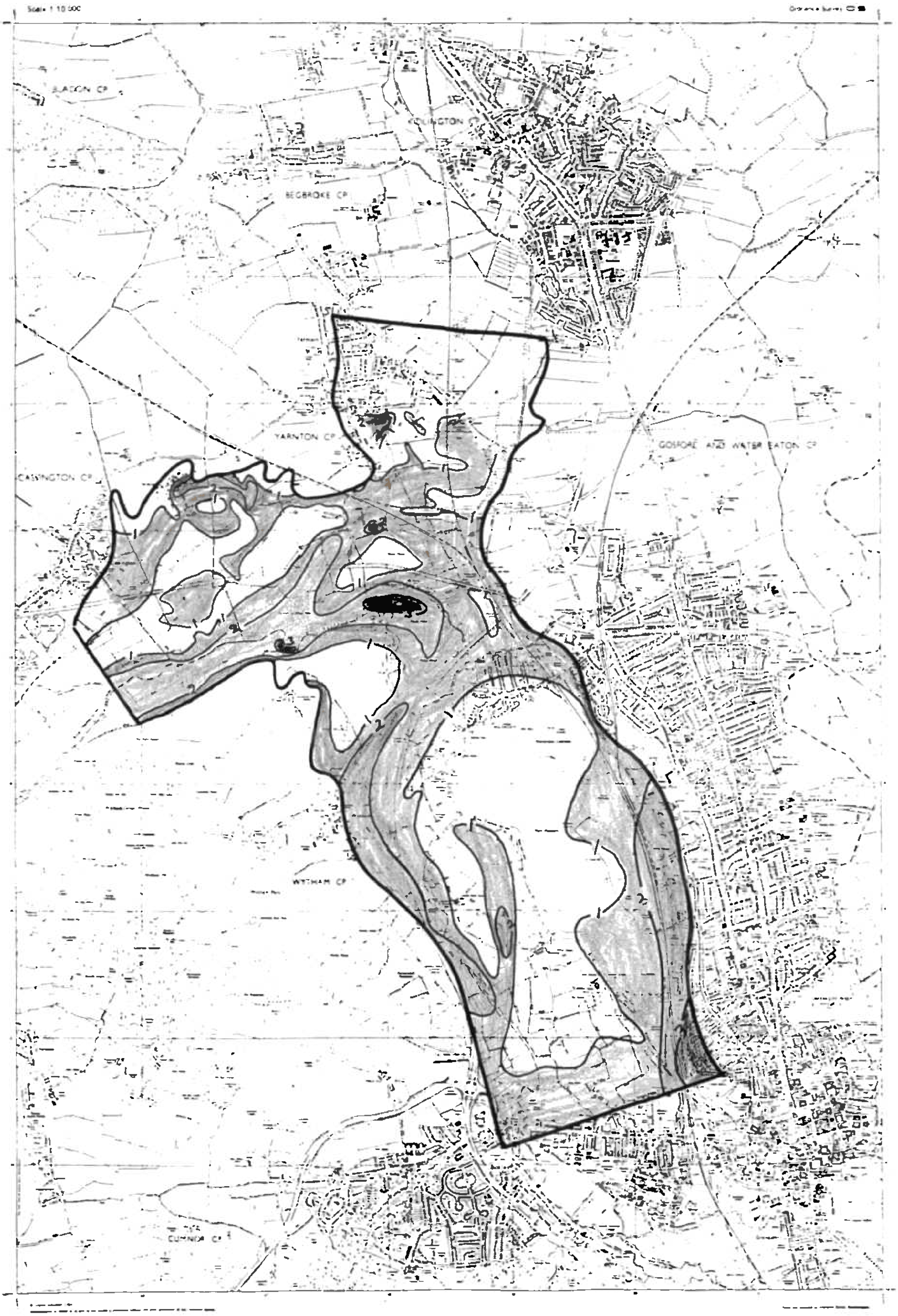


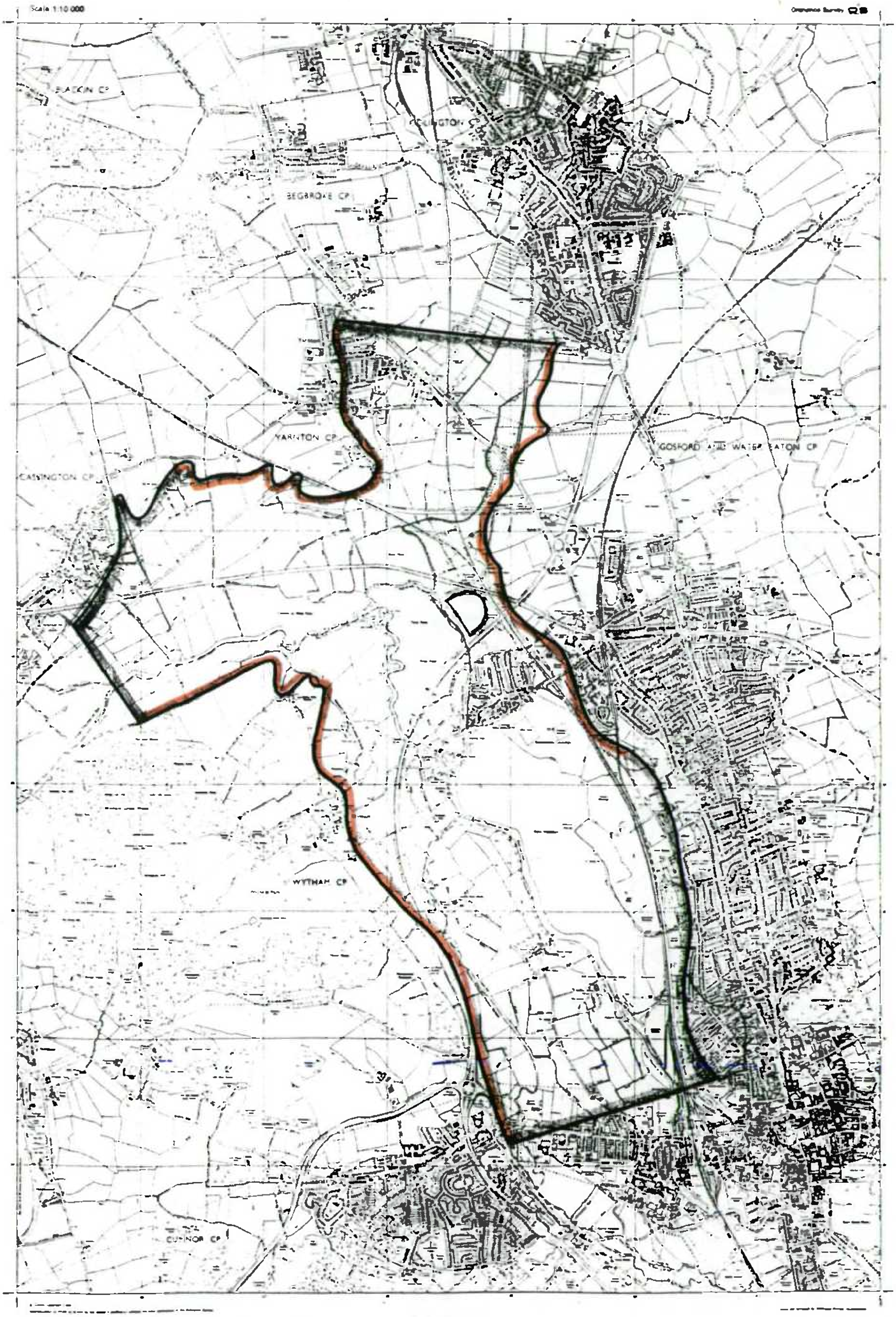
Fig 9

(9)



Alluvial Thickness

Fig 10



NO FLOW BOUNDARIES
FLOW BOUNDARIES

Fig 11

Minimum water levels : July 1984

Fig 13

Maximum water levels : January 1985

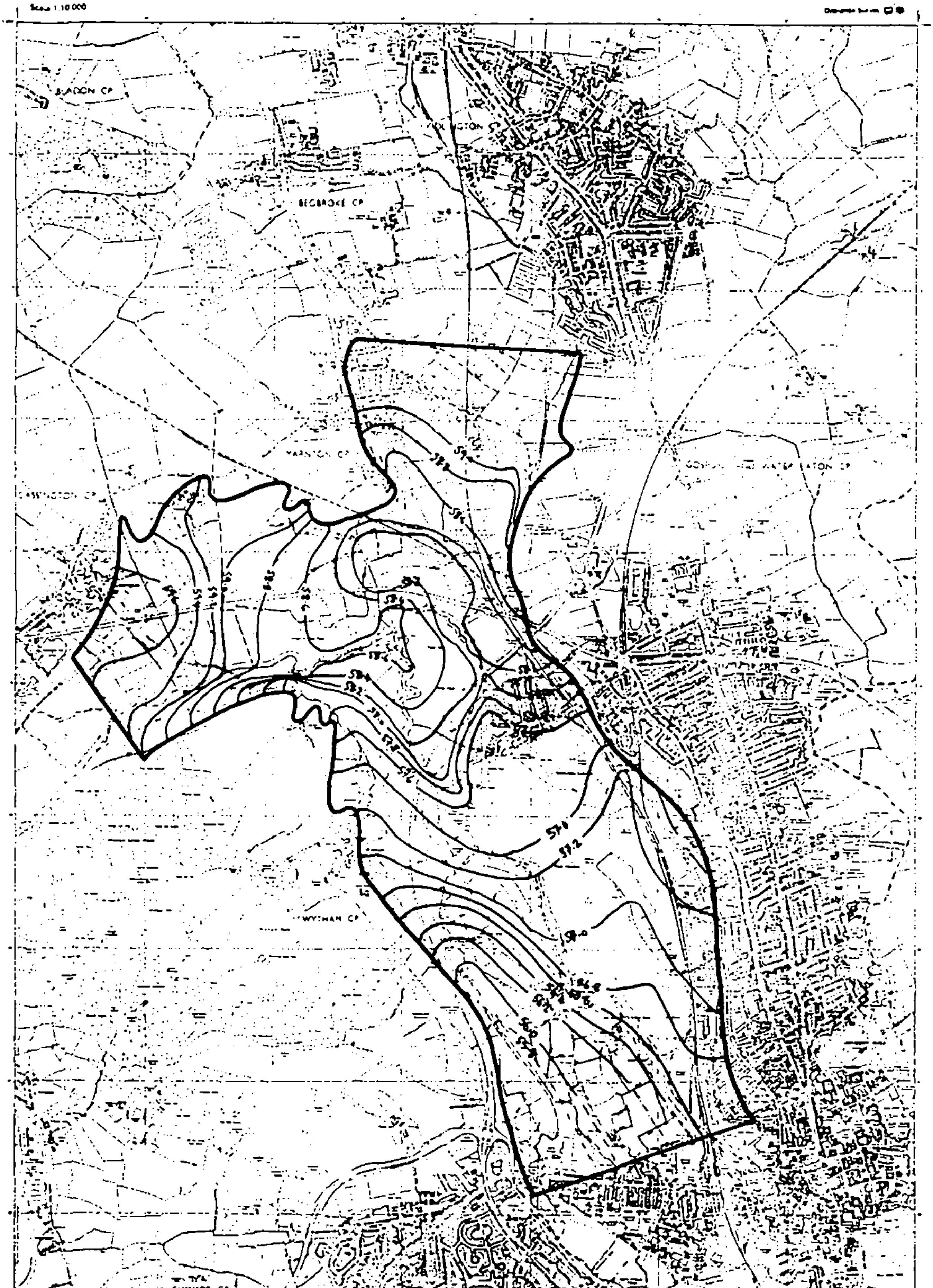


Fig 14

Water level change : July 1984 to January 1985

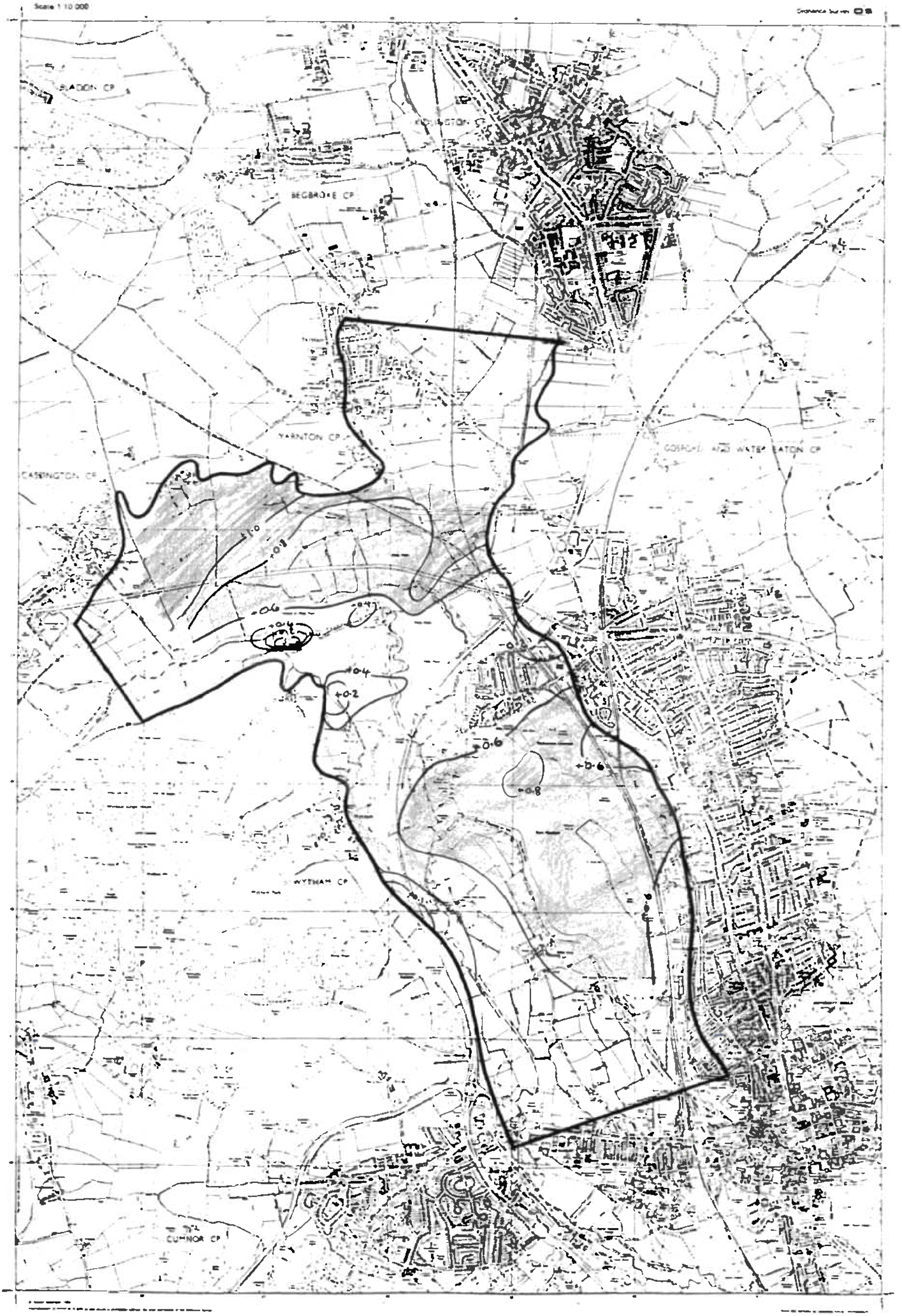


Fig 15 (15)

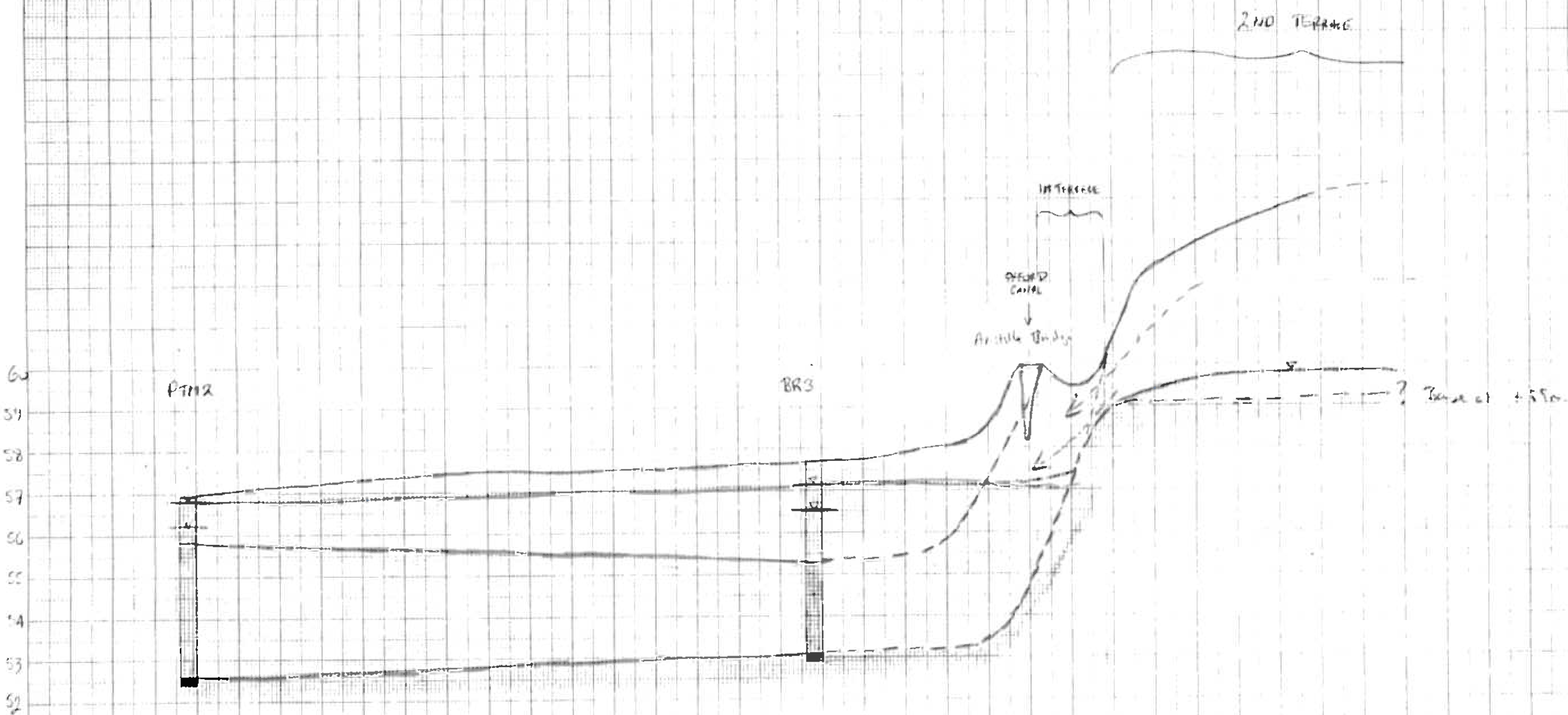
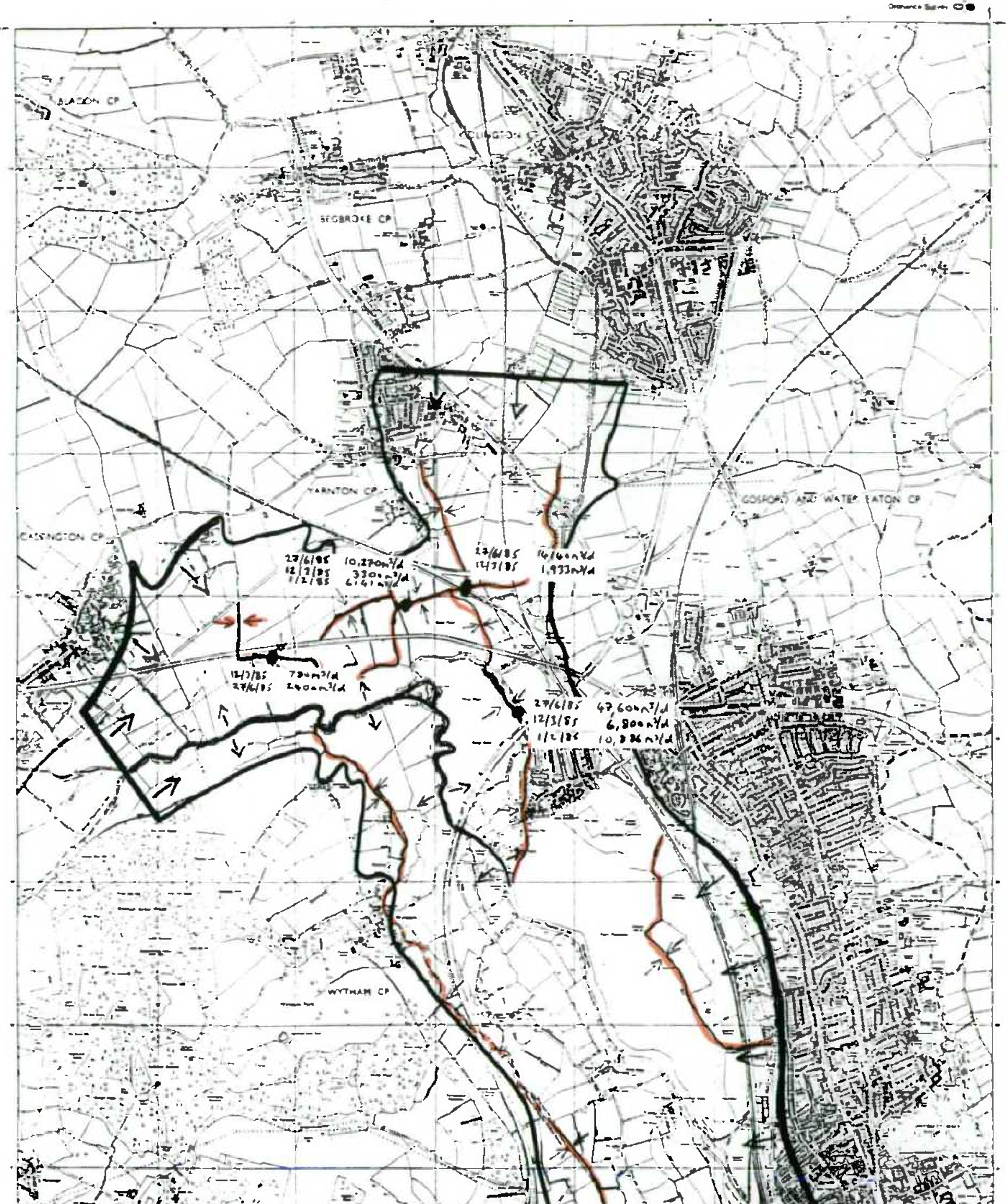


Figure 16

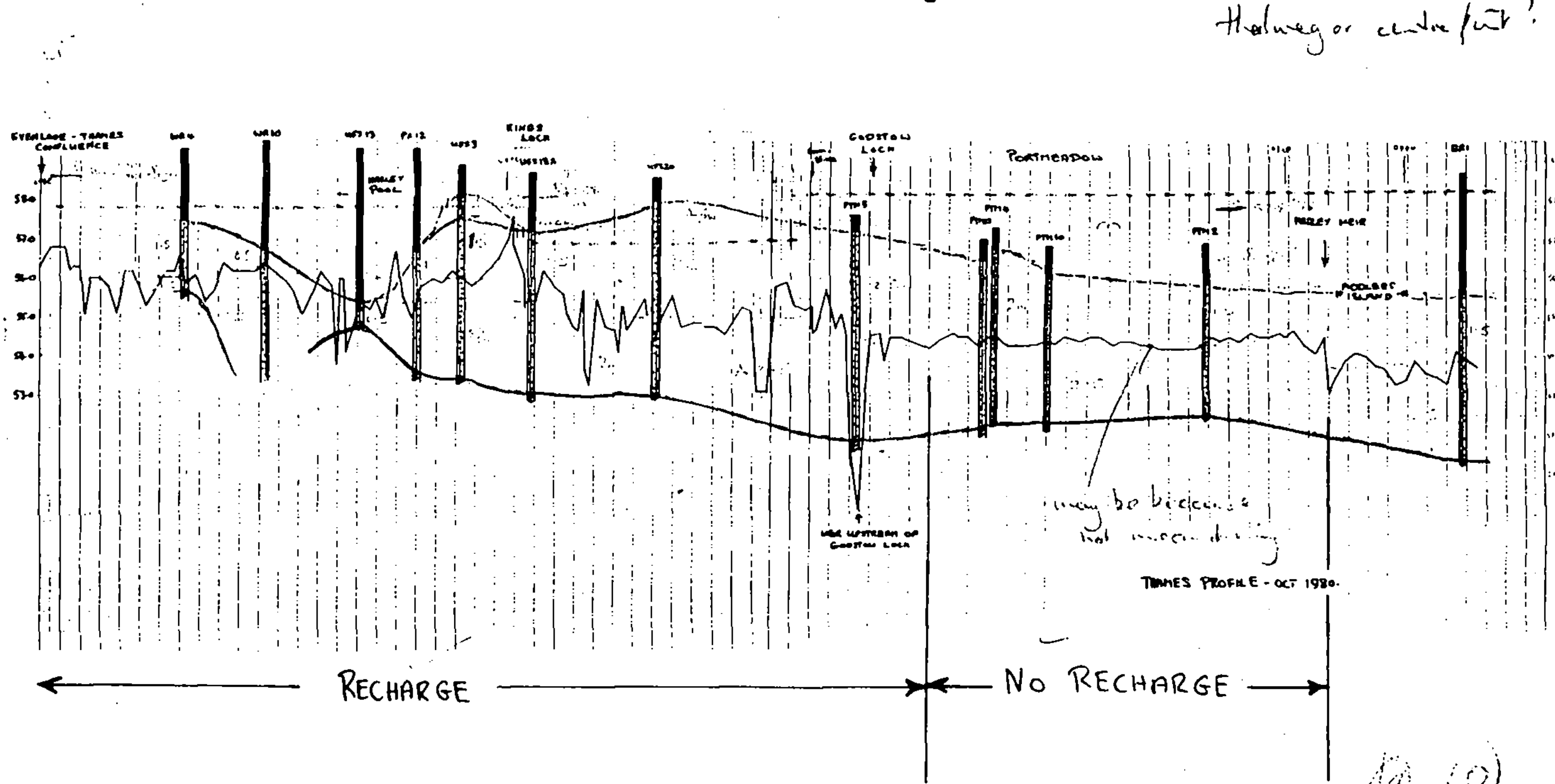
Fig 16

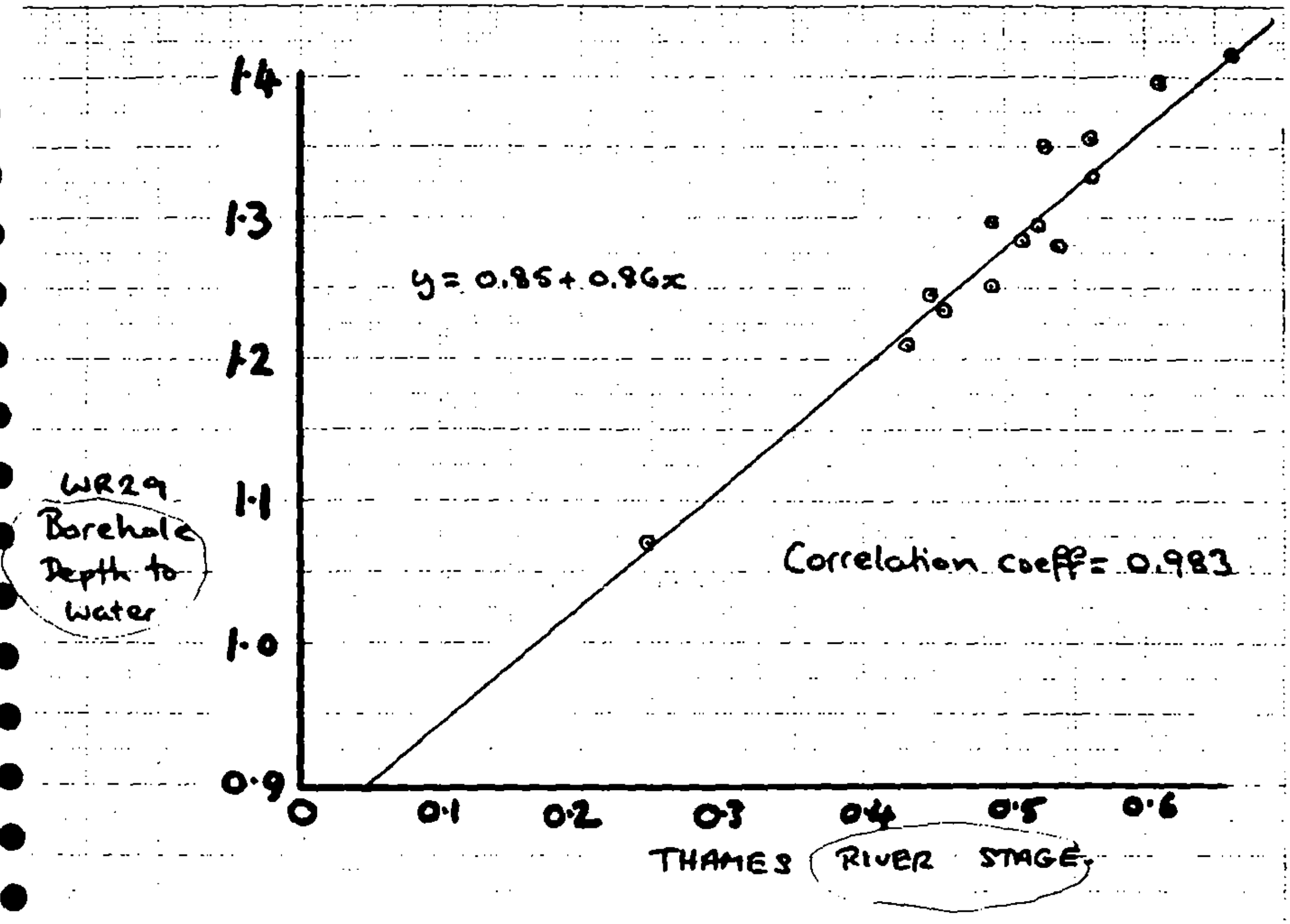


Distribution of Recharge / Discharge

Fig 19

River Thames bed profile

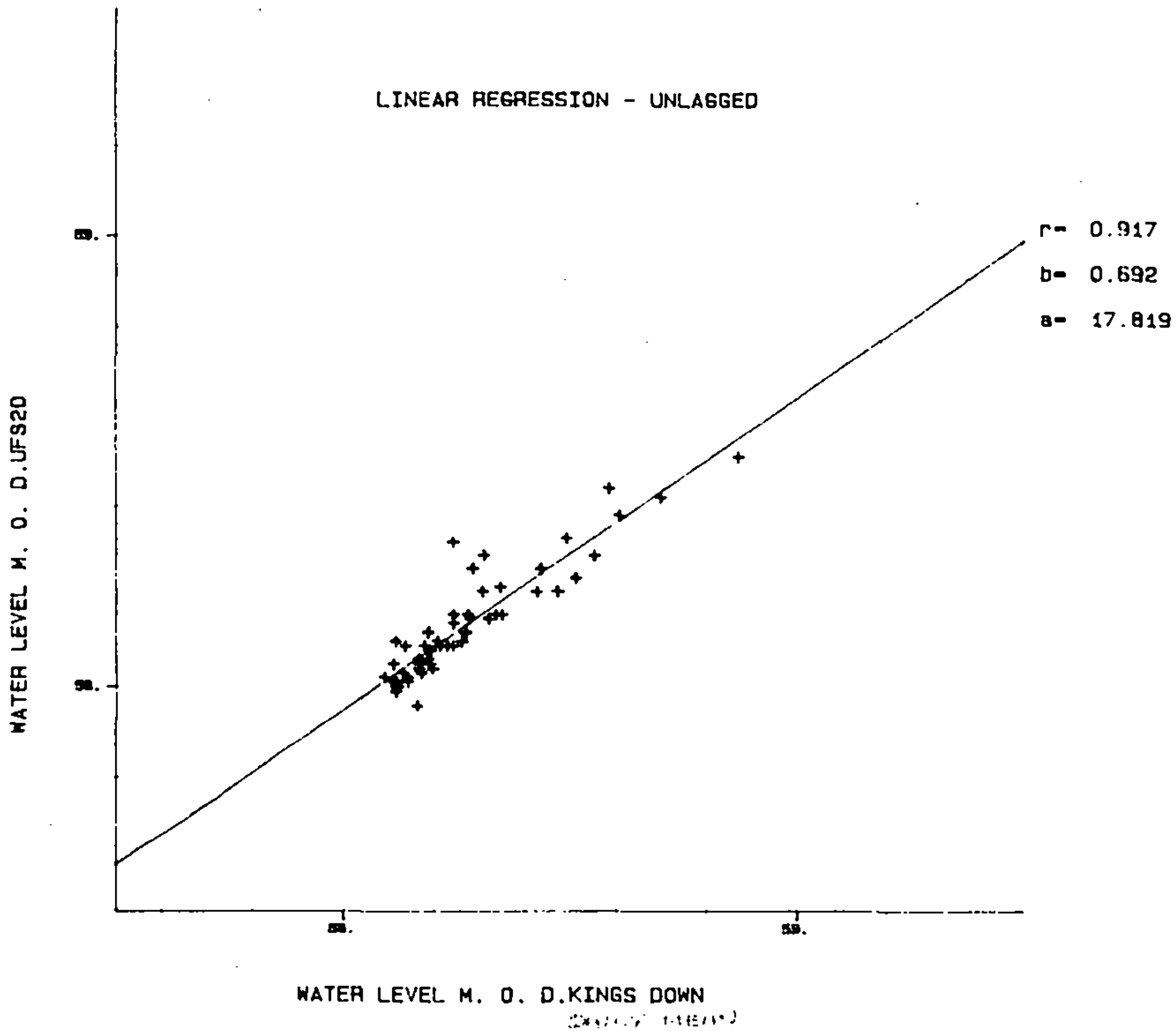




Relationship between aquifer and river Thames

21

Fig 21



LINEAR REGRESSION - UNLAGGED
r= 0.917
b= 0.692
a= 17.819
WATER LEVEL M. O. D.UFS20
WATER LEVEL M. O. D.KINGS DOWN

Fig 22

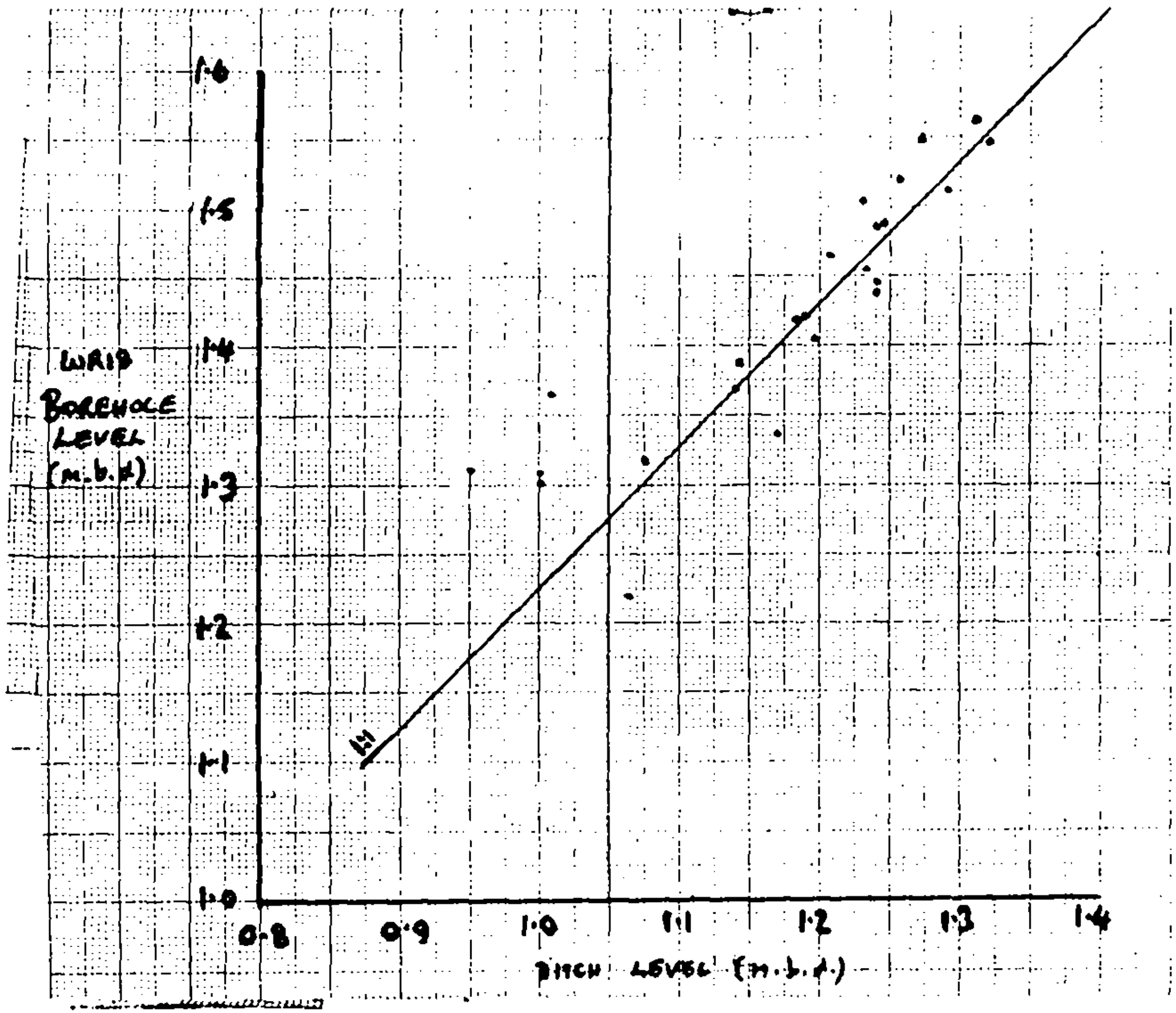


FIG 23 Correlation of WRIS B/h level with ditch level.

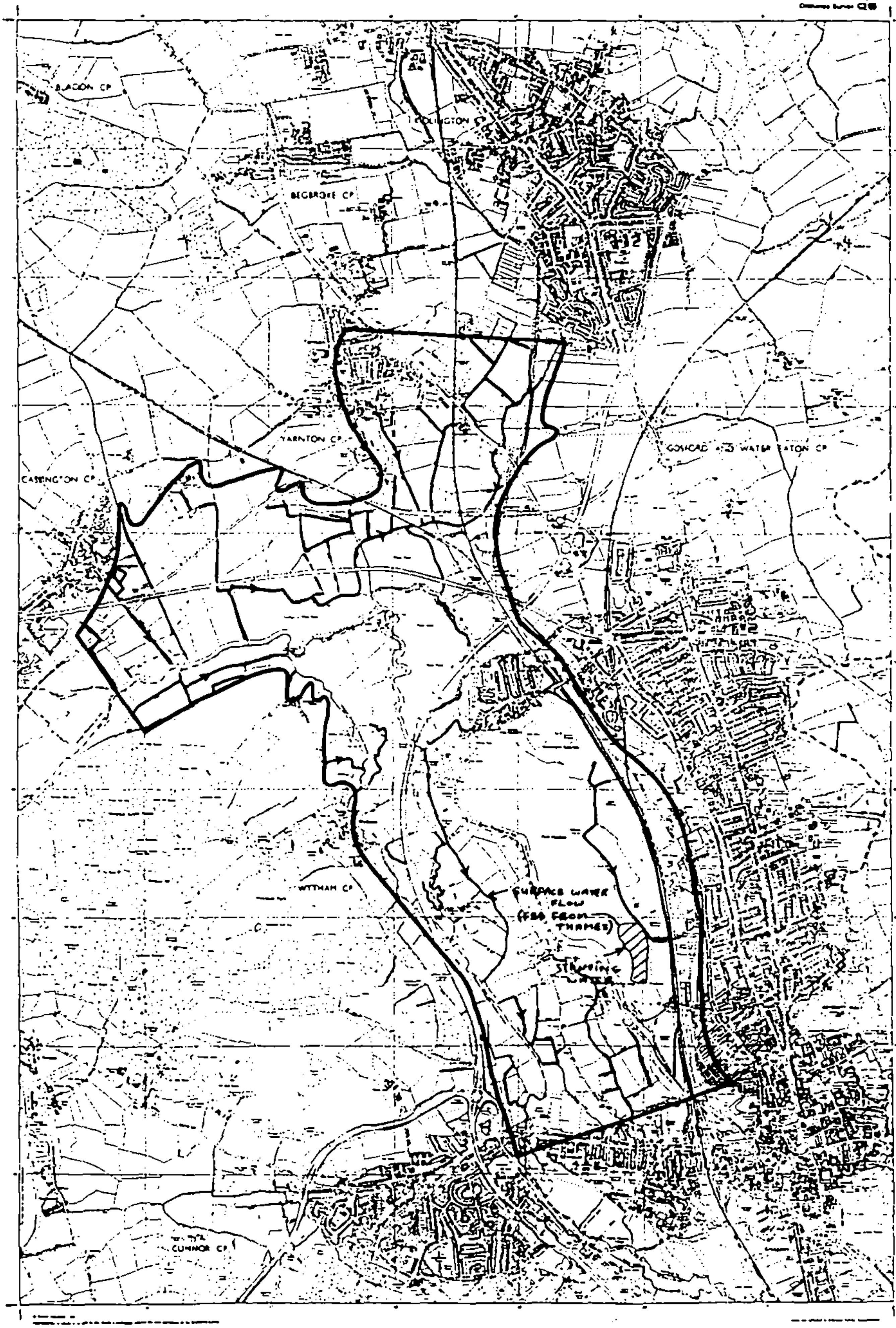
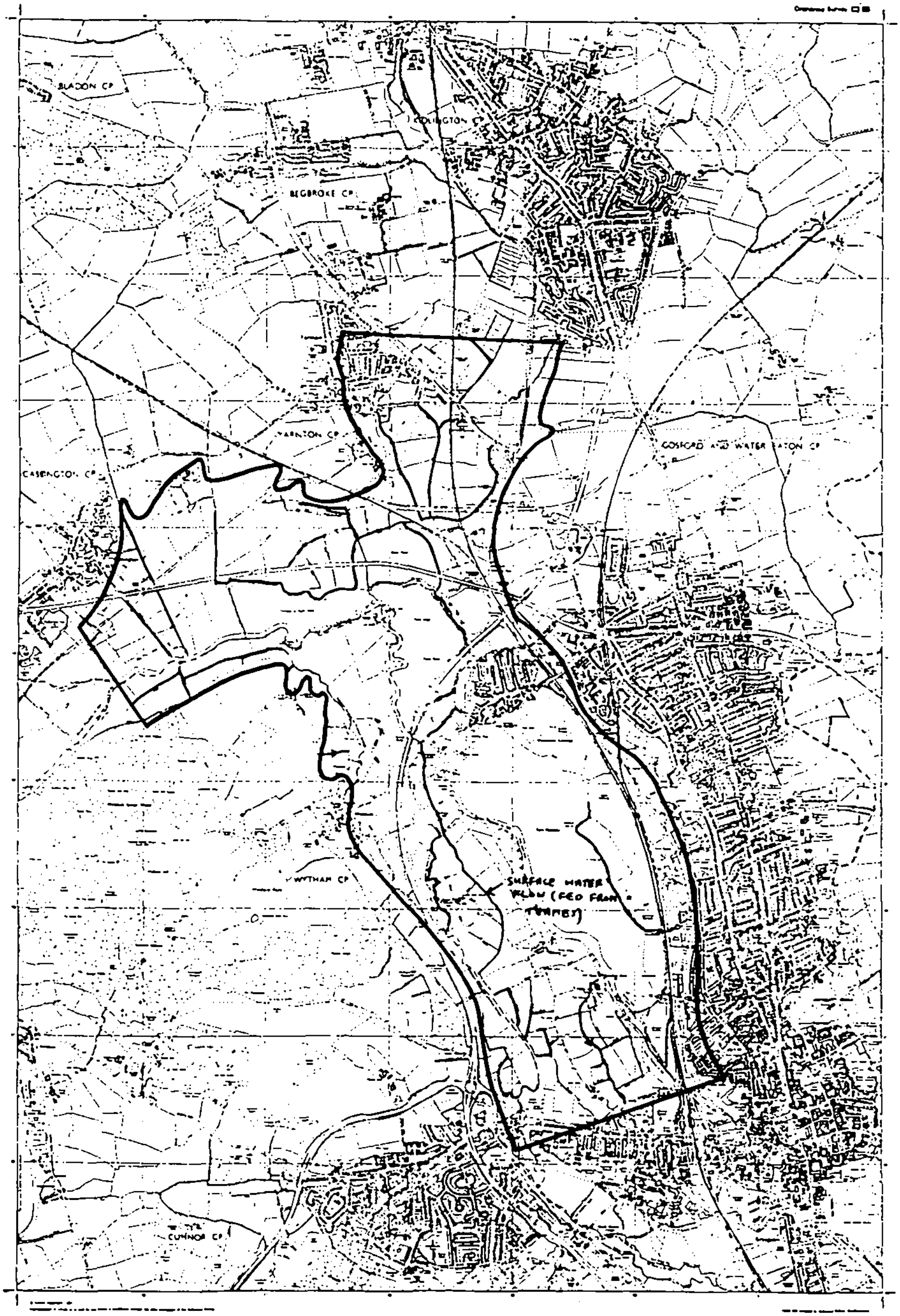


Fig 24

DITCH SURVEY
19–21st JUN. 1985



DITCH SURVEY
17th - 18th Sept 1985

Fig 25