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Thames Water
Rivers Division

KENNET VALLEY STUDY
READING - THEALE

Final Report
June 1987

SIR ALEXANDER GIBB & PARTNERS
in association with
INSTITUTE OF HYDROLOGY

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22nd June 1987

Thames Water,
Rivers Division,
Nugent House,
Vastern Road,
Reading,
Berks.

For the attention of Mr. G.P.G. Johnson

Dear Sirs,

KENNET VALLEY STUDY - READING - THEALE
FINAL REPORT

We have pleasure in enclosing six copies of the Final Report.

The methodology developed for the study represents an unusual approach to flood studies which has been tailored to the available records of hydrometric measurements and historic floods. It has enabled an evaluation to be made of the sensitivity of flooding to changes in flood plain storage without recourse to mathematical modelling. The techniques developed for computing flood plain storage and modelling the flood routing may well be applicable to other catchments where similar evaluations are required, particularly if more hydrometric data is available. The computerised calculation of storage volumes within the Kennet Valley may also be of use in evaluating the net changes resulting from development proposals.

We shall be pleased to assist with any further investigations that you require. If there is any matter that requires clarification in this present report please do not hesitate to contact us.

Yours faithfully,
for SIR ALEXANDER GIBB & PARTNERS

KENNET VALLEY STUDY

FINAL REPORT

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EXECUTIVE SUMMARY

1. OBJECTIVE

The study was commissioned to evaluate the sensitivity of flooding to changes in flood plain storage capacity within the Kennet Valley between Theale and Reading without recourse to mathematical modelling. The Brief required flood envelopes to be produced for a range of return periods and for consideration to be given to future policy with regard to management of the flood plain in the light of known and anticipated developments.

2. DATA

The topography of the flood plain was surveyed in February 1987 using parallel cross sections at 250m intervals, approximately perpendicular to the Rivers Kennet and Foudry Brook.

Records of flood levels within Reading are available as far back as 1894 but the only flood event for which a comprehensive data base is available is that of 1971. This event was photographed from the air by helicopter and surveyed on the ground. The flood level records show that the downstream portion of the Kennet can be influenced by levels in the River Thames.

The principal gauging station in the study area is that on the Kennet at Theale, but at high flows gauging is affected by flows crossing the adjoining flood plain and entering gravel pits upstream. There is no gauging station on the Foudry Brook. Flow records through Reading itself are not generally available because there is no fixed rating curve due to the influence of the River Thames.

3. HYDROLOGY

Although the Kennet Valley is predominantly a chalk catchment (75%), the flood response at Theale reflects primarily the non chalk component, the majority of which lies within the catchment of the Enborne. Because of this, a special unit hydrograph analysis of the Theale record was carried out to derive inflow flood estimates, and reconciled with results obtained using a statistical approach. Flood estimates for the Foudry, which is ungauged, were based on catchment and climatic characteristics alone.

Flood estimates to County Weir, which need to take account of the Kennet and the Foudry, were derived by applying a single design storm to the entire catchment and routing the inflows through a simple model to take account of flood plain storage. The model was calibrated from the 1971 flood event, and a frequency curve for peak outflows at County Weir derived. The modelling also yielded estimates of the quantity of flood water going into storage for a range of return periods.

The 1971 flood is assessed to have been a 50 year event at Theale but more like a 35 year event at County Weir and in terms of flood plain inundation. On the basis of a single gauging at Reading, the 1947 flood is estimated to have been a 50 year event. The volumes stored in the study flood plain area for different return periods are estimated to be:

Return Period	Volume
2.33 year	2.0 Mm^3
10 year	3.7 Mm^3
50 year	5.2 Mm^3
100 year	5.9 Mm^3

Attenuation of flood peaks between Theale and Reading is about 24% for events of return periods between 25 and 100 years.

4. FLOOD ENVELOPES

The volume of water entering storage in the 1971 event was estimated from the topographic survey and the record of flood levels. This was used to calibrate the flood routing model and to derive a storage frequency curve. The storage-elevation curve for flood surfaces parallel to the 1971 surface was estimated and used to locate the flood envelopes.

The conclusions are that a 1 in 100 year flood would attain levels about 0.1 - 0.15m higher than in 1971 whilst a 1 in 10 year flood would be 0.15 - 0.2m lower. This does not apply to the downstream reach below Fobney where the influence of the River Thames can be the predominant factor in determining flood levels. The flood envelopes are generally very close to one another for return periods exceeding 10 years and it is the depth rather than the extent of the flooding that varies because of the confined nature of the topography.

5. DEVELOPMENT IN THE FLOOD PLAIN

Historical changes within the flood plain have been reviewed. There have been two major types of development, the first being large scale extraction of gravels along the Valley and the creation of gravel lakes, and the second infilling, principally within the Foudry flood plain.

Gravel extraction began in the 1940's and until recently most excavations were returned to lakes. Of 620 ha for which permission for gravel extraction has been granted, some 250 ha have been restored to water. This is estimated to have added to the storage capacity by about 0.5 - 1.0 Mm^3. Recent applications for extraction have tended to show restoration to agriculture, with doming or ridge and furrow, for which the impact on flooding is difficult to evaluate. Nevertheless the creation of gravel lakes is planned to continue between Theale and Tyle Mill.

Infilling has occurred principally as a result of waste tipping and mainly within the Foudry flood plain. This is estimated to have removed nearly 1 Mm^3 of storage volume relative to 1971 flood levels, and significantly more relative to 1947 levels. The proposed Reading Business Park would remove the majority of the remainder of the storage within the Foudry flood plain which forms an integral part of the Kennet flood plain.

It is concluded that there has been a net loss in storage within the Kennet Valley in recent years, with the additional volumes created by gravel extraction failing to compensate for the loss in storage due to infilling.

6. FUTURE POLICY TOWARDS FLOOD PLAIN MANAGEMENT

In order to be able to develop an effective management policy for the flood plain it is necessary to be able to evaluate on the one hand substantial reductions in storage such as has occurred in the Foudry flood plain and on the other hand proposed localised changes where the net change might be small.

The study has demonstrated the importance of flood plain storage within the Kennet system in attenuating flood peaks through Reading and enabled estimates of the increased flow due to loss of storage to be made. The study has not been able to evaluate with any accuracy the rise in water level that would result from proposed changes, whether they are substantial or localised. The present criterion of maintaining storage on a level for level basis is judged to be prudent on the grounds that it prevents substitution of storage at a high level for that at a lower level, which might reduce the attenuation of peak flows, and guards against a cumulative loss of storage. The finding that the areal extent of flooding does not vary substantially with the return period of the flood limits the scope for zoning types of development within the flood plain and effectively confirms the boundary of the 1971 flood as the area within which housing or office development should not be permitted.

Further refinement with regard to flood plain management could be obtained by developing a mathematical model of the river system. However, this would require a substantial investment in time and money which needs to be weighed against the anticipated benefits.

7. FLOOD ALLEVIATION

An opportunity for providing some flood attenuation by routing the flood peak through four existing gravel lakes close to Theale has been identified. Preliminary studies suggest that this could reduce a 1 in 50 year flood at Theale to below a 1 in 10 year flood at Reading although this degree of reduction might not apply for more extreme events. Further studies are required to evaluate this opportunity in detail.

8. FURTHER STUDIES

It is recommended that the following studies should be undertaken:

- hydraulic study of the Holy Brook to evaluate the scope for improving channel capacity or varying the division of flows between the Kennet and Holy Brook

- study of the consequences of increased water levels in Reading and the interaction with the Thames in order to better evaluate the benefits of proceeding to mathematical modelling

- hydrometric monitoring of the Foudry and Kennet.

Other studies that warrant consideration are a more detailed survey to determine flood envelopes more precisely along the housing developments from Southcote to Beansheaf and a more detailed study of the possibility of providing flood alleviation.

KENNET VALLEY STUDY

FINAL REPORT

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES OF THE STUDY.

The Terms of Reference for the study, as set out in letter C81/6/RBW/JAQ dated 19th November, 1986 from Thames Water, are as follows:

To determine the extent of the existing flood plain under a range of conditions up to the June, 1971 flood.

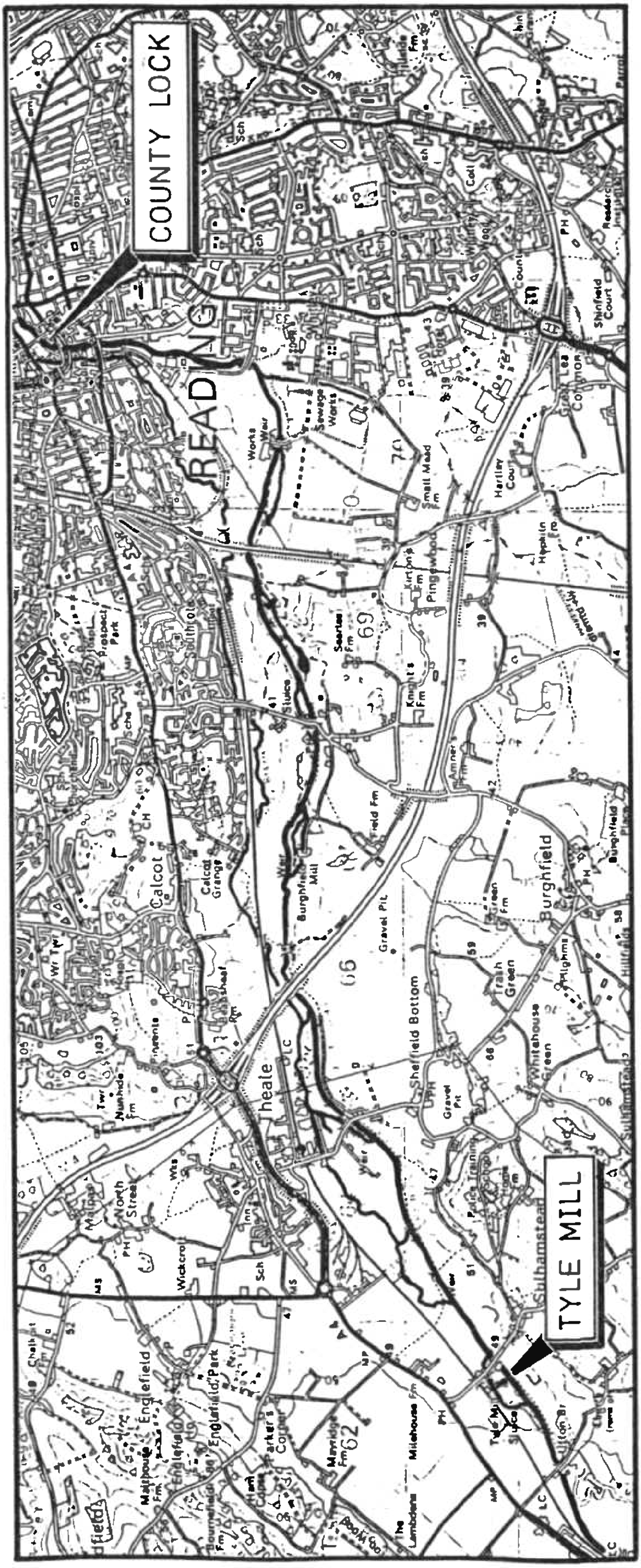
To produce flood envelopes for rarer events up to the 1947 flood and determine the level of risk.

To assess the effects of changes in the flood plain on flood risks locally and downstream.

To consider the recommendations on the policy with regard to the future establishment and management of the flood plain in light of known and anticipated developments including mainly gravel extraction and reinstatement proposals.

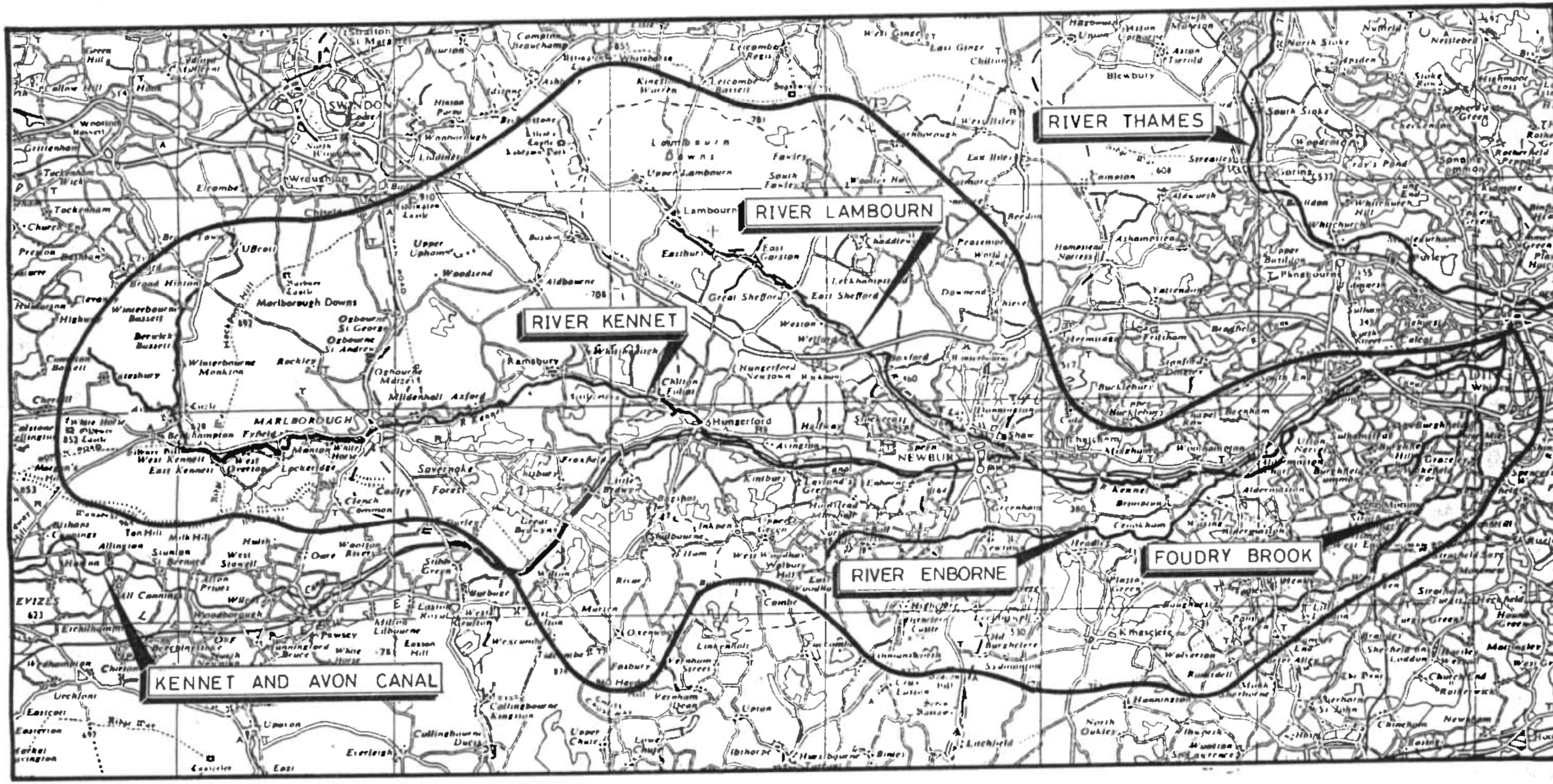
To provide information to permit some assessment to be made on the need and implications of extending the study to mathematical modelling.

The study area extends from Tyle Mill Bridge, approximately 2 km upstream of Theale, to County Lock (near the inner distribution ring road in Reading) and is marked on Figure 1.1. The location of the study area within the catchment area of the River Kennet is shown on Figure 1.2.



STUDY AREA

FIGURE 1·1



CATCHMENT AREA.

FIGURE 1·2

1.2 METHODOLOGY

The methodology was developed bearing in mind the objective that the study should evaluate the sensitivity of flooding to changes in flood plain storage capacity without recourse to mathematical modelling. Should such modelling prove necessary, then the value of the present study would reside in providing the necessary data base for it to be carried out. The methodology employed covers three principal topics namely hydrology, flood plain storage and the extent and influence of development in the flood plain.

1.2.1 Hydrology

The first objective of the hydrological analysis was to estimate design flood hydrographs of different return periods.

It was also the intention at the outset of the study to develop a simplified model that could be used to provide quantitative information on the effects of changes in flood plain storage on the alteration or shape of floods of different return periods. It was hoped that it would be possible to calibrate a simplified flood routing model by using :

(i) gauged inflows at Theale for the 1971 flood
(ii) estimated outflows at County Lock for the 1971 flood
(iii) flood plain storage derived from topographical survey and recorded 1971 flood levels

The inflow and outflow hydrographs would enable an estimate of flood volume going into storage to be made which could be compared with (iii) above. Unfortunately, this did not prove possible as there is no unique stage discharge relationship at County Lock or Blake's Lock due to the influence of the Thames so that it was not possible to reconstitute an outflow hydrograph.

A revised approach has been developed using a 'lag and route' modelling method to simulate the volume of the flood going into storage.

1.2.2 Flood Plain Storage

An important factor in estimating the sensitivity of flooding to changes in flood plain storage capacity is some knowledge of the global storage capacity available under a range of floods of different return periods. A survey contract was let to provide the basic topographic information necessary to undertake this task. The record of the flood water surface profile for the 1971 flood has been used to estimate the volume that went into storage for this important event. The sensitivity of storage to parallel water surfaces above and below the 1971 profile has also been tested.

1.2.3 Extent and influence of development in the flood plain

The study area has undergone a transformation over the last forty years as a result of large scale gravel extraction activities and the increasing demand for land arising from expansion of Reading and Theale. These changes have been documented to provide an historical perspective and plans for future development have been assessed.

The impact of future specific developments that might alter the characteristics of the storage elevation curve have been examined and future policies with respect to management of the flood plain advanced in the light of the flood envelopes for different return periods.

1.3 SCOPE OF THE REPORT

The structure of the report reflects the methodology outlined above. The information collected to form the data base for the study, such as surveys and flood records, is reviewed in Chapter 2, and the results of the hydrological analysis are presented in Chapter 3. Estimates of storage in the flood plain for the 1971 event are derived in Chapter 4, together with the variation in storage for higher and lower flood profiles, and an estimate of flood plain storage lost as a result of development. Flood envelopes for different return periods are developed from this information

Historical developments within the flood plain are reviewed in Chapter 5 and policies with regard to future development advanced in Chapter 6 in the light of the flood envelopes developed for different return periods. An assessment of the effect of local changes in flood plain storage characteristics is also given.

Whilst the study of flood alleviation measures does fall within the terms of reference, certain opportunities have been identified and these are reported on in Chapter 7. The conclusions of the study together with recommendations concerning the need for further studies are presented in Chapter 8.

CHAPTER 2

DATA BASE

The present chapter aims to summarise the information available for the study in terms of survey, mapping and aerial photography and flood records. A description of the study area and the results of the site reconnaissance undertaken are also given. The data base used for the hydrological analysis is given in Chapter 3. A list of the documentation and information used is given in Annexe A.

2.1 STUDY AREA

2.1.1 Topography

The study area extends some 11 km from Tyle Mill to County Lock and over this stretch the normal water level of the river Kennet falls from 47m to 37m A.O.D. The river meanders on a bed of alluvium underlain by valley gravels which overlie chalk, and the flood plain is generally slightly less than 1km wide although widening to 2 km close to the confluence with the Foudry Brook at the downstream end. The flood plain is negligible in extent at the entrance to Reading where the Kennet has cut steep-sided channels through the Reading Beds at Coley just upstream of County Lock.

The exploitation of gravel deposits has changed the appearance of the flood plain over large areas due to the creation of gravel pits.

2.2.2 Rivers and hydraulic structures

The structures in the study area are shown on Fig. 2.1.

The Kennet divides into two channels just upstream of the M4 motorway at the Arrow Head sluices. Less than two fifths of the flow enters the Holy Brook which runs parallel to the Kennet about half a kilometre to the north. A high proportion of the flow in the Holy Brook returns to the Kennet at Coley Weir, half a kilometre upstream of County Lock, with the remainder flowing through culverts under Reading and returning to the Kennet just upstream of Blake's Lock.

The Holy Brook was diverted in order to supply water to Reading Abbey from a point close to Southcote and now runs in an artificial channel alongside Coley and through the centre of Reading. This is recorded in the following extract from Kennet Country:

"According to a deposition of 1596 'the Hallowed Brook taketh hedde at the lower end of a mead called the Theale Mead and endeth at the West side of the Orte bridge and runneth into a great stream called Kennet'. It had been "diverted out of the said river to the weir not far from Southcote House at Hadsey ditch'"

The Kennet is joined by a tributary, the Foudry Brook, just downstream of Fobney. The Foudry flows northwards under the M4 and has an extensive flood plain about 1.5 km wide between the M4 and the confluence with the Kennet. The Reading Sewage Treatment Works discharges treated effluent into the Foudry Brook just upstream of the confluence.

One further stream bed that is worthy of mention is the Draper's Osier Bed Stream which is fed by a weir on the main Kennet at Sulhampstead and rejoins the river just downstream of Sheffield Mill.

The relatively steep gradient of the river was harnessed in the past to develop a series of mills at Tyle Mill, Sheffield Mill, Burghfield and Calcot. The construction of weirs at these locations to obtain the necessary head necessitated the provision of locks when the Kennet and Avon Canal was constructed in order to bypass them. There are as a result three channels at these sections namely, the main river course, the mill race and the bypass canal. There are also locks to bypass the weirs at Southcote and Fobney; a new labyrinth weir has recently been constructed at the latter location to maintain a more constant water level at the Fobney water supply intake.

The hydraulics of the river system between Tyle Mill and County Weir is therefore complex, with five sets of weirs and locks on the main Kennet, the division of flows between the Holy Brook and the Kennet, and the confluence with the Foudry Brook. This has been further complicated by the excavation of a number of large gravel pits close to the river which interact hydraulically with the river through the gravels, some of which are liable to flood.

2.1.3 Development

Extensive development has taken place in the flood plain over a long period of time including railways, roads, gravel extraction, waste filling and building all of which tend to restrict flow routes. Three railway embankments divide the flood plain into sections. The Reading to Newbury line runs within the flood plain on the northern side crossing the Holy Brook in four places, while the Reading to Basingstoke line runs north-south across the flood plain midway between Fobney and Southcote. The old Coley branch line also crosses the Holy Brook in the Fobney Meadows.

Four roads traverse the flood plain, namely a minor road between Sheffield Bottom and Theale, the M4 just downstream of Theale, the Burghfield Road linking Southcote to Burghfield and Rose Kiln Lane in the downstream reach linking Berkeley Avenue to the Basingstoke Road.

The gravels in the valley have been exploited since the 1940s, altering dramatically the landscape where the restoration has been to lakes; nearly 600ha of land has received planning permission for gravel extraction of which about two-thirds has been excavated and 250ha returned to water. In recent years the growth of Reading and Theale has also resulted in increasing pressure for development within the flood plain for water supply facilities, sewage works, waste disposal, housing and industrial development.

2.2 SURVEY

2.2.1 Study Survey

A survey of the flood plain within the study area was undertaken in February 1987 in accordance with a drawing prepared by Gibb that is reproduced as Fig. 2.2. The extent of this survey was fixed largely by the limits of the 1971 flood. Cross sections were taken at 250m intervals with spot heights every 100m or less where necessary adequately to describe the topography. The specification for the survey was prepared by THAMES in order to conform with their standard procedures.

The objective of the survey was to enable the volume of storage within the flood plain to be assessed. It is unlikely to be detailed enough for a mathematical hydraulic modelling exercise, but it was judged that the additional expenditure in time and money that would be required for this could not be justified. Detailed surveys of individual areas of land have, however, been carried out by gravel companies and developers in the course of the preparation of their planning proposals.

The results of the survey were plotted by THAMES on 1/2500 maps and cross sections provided using computerised methods.

2.2.2 Survey of the river channel

A survey of the river channels of the Kennet, Holy Brook, and Foudry Brook was undertaken in 1975 by Rofe Kennard and Lapworth (RKL) and the results are recorded on the following drawings:

Kennet	967/103/A/1/1 - 29
	967/103/A/1/1 - 36
Holy Brook	967/111/0/1/1 - 31
Foudry Brook	967/106/0/1/1 - 2

The drawings include:

plans of the area at 1/2500 scale
longitudinal sections at 1/10 000 scale
cross sections at 100m intervals along the rivers at 1/100 scale; the datum for these sections is the water level in the river which was recorded on that particular day.
details of the structures (bridges, weirs, locks, etc) along the rivers.

A note was found on these drawings to the effect that anomalies had been noted and that they should be used with caution. The levels of the river banks were therefore checked against the results of the recent survey. An exact comparison is impossible because the survey cross sections are not coincident and the levels on the RKL survey had to be scaled from the recorded water surface; the levels are nevertheless generally in agreement to $\pm$ 0.2m.

A recent survey of the river channel between Blake's Lock and the Reading Sewage treatment works was undertaken for the laying of the new sewage main in the river channel between these points.

2.3 MAPPING AND AERIAL PHOTOGRAPHY

Ordnance Survey maps of the entire area are available at scales of 1/10 000 and 1/2500 and the part of the area nearest Reading is available at 1/1250. The 1/10 000 maps have contours at 5m intervals but there are no contours on the 1/2500 series. Both series are substantially out of date because of the changes wrought by the gravel workings over the last few years.

Aerial photographs at a scale of 1/10 000 are flown every five years by Berkshire County Council. The most recent series was flown in November 1986 and colour copies have been obtained by THAMES. A copy of the 1981 series is also available and photocopies of the 1947 and 1971 series have also been obtained in order to identify the changes that have taken place within the flood plain.

2.4 FLOOD RECORDS

2.4.1 Flood Levels

THAMES possess records of flood levels downstream of Burghfield bridge as far back as 1894. These are reproduced in Table 2.1.

TABLE 2.1

FLOOD LEVELS (metres A.O.D.)

	Distances km	1943 Summer	1894 Nov.	1910 Dec.	1925 Jan.	1929 Dec.	1940 Feb.	1946 Dec.	1947 Mar.	1971 June
KENNET		(Normal Water Levels for Reference)								
Kennet Mouth	0	35.11	37.00	36.52	36.47	36.49	36.48	36.48	36.94	
Blakes Lock TW	0.77	35.11	37.22	36.60	36.7	36.61	36.62	36.51	37.03	36.22
HW		36.21			36.8	36.64	36.64	36.56	37.01	36.42
County Lock TW	2.00	36.24	38.45		37.7	37.35	37.0	37.30	38.1	37.19
HW		36.52			37.9	37.42	37.12	37.44	38.2	37.70
Fobney Lock TW	4.6				38.45	38.24	38.3			38.82
HW						39.37	39.4			39.73
Southcote Lock TW	6.0				39.72	39.61	39.7			40.62
HW					40.97	40.98	40.98			41.31
Burghfield Bridge	7.3					41.24	41.23	41.16	41.39	41.51
Holy Brook										
Chestnut Walk (Blakes Lock)						36.64	36.64	36.56	37.00	
Castle Street - Almshouses								38.12	38.44	
Rifle Range Cottages								38.57	38.80	
Burghfield Road Bridge TW							40.83	40.07	40.57	
HW							40.87	40.29	40.57	

Note: Levels prior to 1971 have been converted from feet Liverpool datum to metres A.O.D. (Newlyn).

The records show the three worst floods over the last century to have been those of 1894, 1947 and 1971. The 1894 flood would appear to have been the highest but unfortunately there is very little information available for it. A comparison between the 1971 and 1947 floods shows the 1947 flood to have been more severe close to the confluence with the Thames but the 1971 flood to have reached higher levels at Burghfield Bridge. The reason for this is that the 1947 flood included rapid snow-melt which affected both the Thames and the Kennet whereas the 1971 flood resulted from very heavy rainfall centred over the Kennet catchment.

A longitudinal section of the River Kennet and the 1971 flood levels recorded along the river are given in Figure 2.1 together with the river bank levels.

2.4.2 Extent of the flooding

The 1971 flood is well documented as the extent of the flood was surveyed from a helicopter approximately 10 hours after the flood peak was recorded at Theale as well as from the ground. A report on the flood is given in Annexe B and the area flooded is shown on Figure 2.3. This also shows flood levels recorded over the flooded area; these were predominantly at head and tail of control structures.

2.5 SITE RECONNAISSANCE

A reconnaissance of the whole length and breadth of the study area was made to visit the hydraulic structures, walk the river banks, study the topography of the flood plain and examine flow routes. This enabled the flow routes observed during the 1971 event to be confirmed and these are summarised below for the three lengths Tyle Mill to Burghfield, Burghfield to Fobney and Fobney to County Lock.

2.5.1 Tyle Mill to Burghfield

The flood plain extends for about half a kilometre on either side of the river as far as Theale, but from Theale to Burghfield is concentrated on the left bank. A series of gravel pits have been excavated along this stretch. A large drain 5 to 10m wide runs from Ford Bridge at Tyle Mill to join the right bank of the Kennet just upstream of Theale. This drain is partly fed by a small diversion weir off the Kennet and Avon canal at Tyle Mill and flows between the Woolwich Green East and West Lakes. There is hydraulic connection from the drain into the East Lake via a 300mm pipe, with a difference in level between the drain and the lake of 0.5m to 1.0m under normal conditions

A flow route observed during 1971 was across the Woolwich Green East and West Lakes over the Theale Road, and into Theale Lake. Since 1971, Hosehill Farm has been excavated and culverts now direct water from Woolwich Green East Lake into Hosehill Farm and from there into Theale Lake. A culvert under the M4 directs water from Theale Lake into Wellman's Farm lake, and an overflow weir allows water from the latter to spill back into the Kennet via the Clayhill Brook. The levels in the four lakes - Woolwich Green East, Hosehill Farm, Theale and Wellman's Farm - are therefore controlled by culverts or weirs.

It was noted that during the flood of the 27th March 1987, for which the peak flow at Theale was $24m^3/s$, the level in Theale Lake appeared to have risen by about 0.2m. This may have been due to the gate on the outlet culvert having been closed, as it was only partially open when observed on 29th March. The lake is held artifically high by a small cofferdam of sandbags that has been constructed in front of the intake.

2.5.2 Burghfield to Fobney

The Kennet divides into the Holy Brook and Kennet just upstream of Burghfield and from this point to Fobney the main flood plain comprises the area between the two rivers, which is about 0.5 km wide.

The excavation of the Searle's Farm Lake has substantially altered the area on the right bank between the Burghfield Road and the Basingstoke railway line which may well have also been liable to flooding. It was observed in 1971 that Searle's Farm Lake was flooded and an examination of flow routes into this lake has therefore been made. Two routes have been identified, one across the small gravel pit between the Kennet and Green Lane immediately downstream of Burghfield Bridge and the other from the Southcote weir pool. The former was the route observed and noted in 1971 whilst the latter can be deduced from the recorded flood level in the pool (40.62m) and the level of the right bank at that point (40.39m). This is a low point about 20m long in the bank that otherwise separates Searle's Farm lake from the Kennet at an elevation above 41.5m.

No outlet structures from Searle's Farm lake have been observed and it is thought that the level of lake is determined by the groundwater level and the influence of the Kennet via the very permeable gravels. The water level in the lake recorded during the survey was 39.34m as against 39.55m in the adjacent river.

2.5.3 Fobney to County Lock

Downstream of the Reading to Basingstoke railway line, the Holy Brook and the Kennet diverge to form a flood plain 1 km wide. The Foudry Brook joins the Kennet with a flood plain up to 1.5 km wide on its left bank, limited by the railway line.

Flooding on the Foudry Brook and the Kennet was separated during the 1971 event by a combination of waste landfill at the confluence of the rivers and a higher natural ground level towards the railway. The ground levels on the Foudry Brook plain are however below the flood water levels recorded on the Kennet, so that flooding on the Kennet influences the flooding on the Foudry.

2.5.4 Flooding at a flow of 28m^3/s

A minor flood occurred on the 5th April 1987, just prior to the completion of the draft final report, and was observed along the length of the study area. The flood peak of 28m^3/s was attained at 9.00 am at Theale gauging station and was photographed over the time period 9.30 am to 1.00 pm. A set of the photographs has been handed to THAMES.

Flooding between Tyle Mill and Reading was observed at the following points:

in the meadows immediately downstream of Tyle Mill

in the field between the canal and river upstream of Sulhampstead Lock, due to overtopping of the left bank of the canal

from the 'drain' that flows between Woolwich Green West and Woolwich Green East Lakes into Woolwich Green East, the footpath to Bottom Lane being impassable. Woolwich Green East Lake was within centimetres of overtopping into Hosehill Farm Lake

Southcote weir pool, towards Searle's Farm Lake; flow into the lake was on the point of occurring

from the Holy Brook into Southcote meadows; it was necessary to walk through 150mm depth of flowing water to get from the Holy Brook to Southcote Lock.

from the Holy Brook into the meadows immediately upstream of Rose Kiln Lane which were completely inundated.

It can be concluded that limited flooding of the Kennet flood plain upstream of Reading occurs several times every year.

CHAPTER 3

FLOOD HYDROLOGY

3.1 INTRODUCTION

3.1.1 Objective

The objective of this chapter of the Report is to assess the significance of the Kennet Valley flood plain in attenuating flood flows through Reading, and in limiting inundation of areas peripheral to the flood plain. Flood frequency estimation is an integral part of the study.

3.1.2 Approach

The problem calls first for an assessment of the physical characteristics and flood potential of the Kennet and Foudry catchments. Design flood hydrographs for a range of return periods are derived separately for the Kennet at Theale (Section 3.4) and the Foudry Brook at M4 culvert (Section 3.5). Later, in Section 3.6, inflow hydrographs to the flood plain are derived for the Kennet, Foudry and Local areas which, collectively, are consistent with an overall flood design to County Weir, Reading. The inflow hydrographs are subsequently combined and routed through a simple representation of the flood plain storage. In this way an estimate of the maximum inundation volume frequency is constructed. Finally, in Section 3.7, inferences are made from (and about) the severe flood which occurred in June 1971.

3.2 CATCHMENT CHARACTERISTICS

3.2.1 Catchments of interest

Flows in the Kennet are gauged at Theale, just upstream of the main Kennet flood plain area. (See Fig. 3.1.)

Flows in the Foudry Brook are ungauged but it is convenient to delineate a catchment boundary to the M4 motorway culvert. Remaining parts of the catchment to County Weir (Reading) comprise a minor tributary draining part of Burghfield Common, the Kennet and Foudry flood plains, and developed areas in Reading on the north and east fringes of the flood plain; these are collectively treated as the 'Local' catchment (ie. local to Reading).

Basic information about the three catchments is given in Table 3.1.

TABLE 3.1 BASIC CATCHMENT INFORMATION

Catchment	NGR	Area km^2	Chalk portion km^2	Non-Chalk portion km^2	Urban area km^2
Kennet at Theale	SU649708	1048	828	220	13.0
Foudry at M4	SU701694	68	23	45	5.3
Local	SU714730	38	14	24	9.5
Total to County Weir	SU714730	1154	865	289	27.8

The catchment areas were computed from boundaries digitized at 1:50,000 scale. (Note that the value for the Kennet at Theale differs somewhat from the 1033 km^2 normally quoted for this gauging station.) While the Foudry and Local catchments are small in comparison to the Kennet, they are seen to be rather more important when only non-chalk portions are considered. Allowing for the disparate response of chalk and non-chalk portions is fundamental to an assessment of the flood potential of the Kennet.

3.2.2 Soils

The non-chalk portions were delineated by reference to the 1:250,000 soil map of South East England and are indicated in Fig 3.2. The relevant soils comprise: tertiary clays in the Wickham 4 and 5 associations; alluvial soils in the Frome, Fladbury 3, Thames and Newchurch associations and river terrace soils (affected by groundwater) in the Hucklebrook and Hamble 1 associations; and Eocene/Jurassic loam and clays in the Burlesdon association. Assignment to the Winter Rainfall Acceptance Potential classes of FSR methodology is a matter of judgement. By reference to the recently published companion text "Soils and their Use in South East England", and the older but more detailed "Soils in Berkshire", the tertiary clays were assigned to WRAP class 4 and the remaining non-chalk soils to WRAP class 3.

3.2.3 Urbanization

The principal urban areas within the catchment to County Weir are shown in Fig 3.3. Comparison with Fig 3.2 indicates that all these areas are in the non-chalk portion of the catchment and this is generally also true of the lesser urban settlements within the catchment. The effects of urbanization on flood runoff are principally to increase runoff volumes (through greater imperviousness and shorter residence times) and to accelerate the response (through more direct drainage paths). The location of urban development within a catchment can sometimes be important. In the case of the Kennet, some of the development close to Reading may have the effect of accelerating runoff from the Local subcatchment ahead of the mainly rural response seen at Theale. On the other hand, special features of the catchment such as the M4, Greenham Common, Aldermaston and Burghfield - to which published maps do not always do justice - are partly sited on chalk areas. The net effect on flood runoff of such development may be rather more significant (since the change from naturally permeable to generally impervious is more drastic) and act to increase flood flows at Reading.

Within the remit of the study it was practical to take account of urbanization only in broad terms, using the standard Floods Studies Report (FSR) catchment characteristic URBAN. This is the proportion of the catchment shown pink on 1:50,000 maps.

3.2.4 Other characteristics

Other standard characteristics required in the FSR rainfall-runoff method of flood estimation are relatively well defined from maps and require no specific comment. These are given in Tables 3.2 and 3.3, with Table 3.4 clarifying the nomenclature. Note that - for reasons that will become clear later - the characteristics for the Theale catchment pertain only to the 220 km^2 non-chalk portion.

TABLE 3.2 FSR CATCHMENT CHARACTERISTICS

Catchment	AREA km^2	MSL km	S1085 m/km	SOIL1	SOIL3	SOIL4	URBAN
Non-chalk to Theale	220	35.5	2.23	0.000	0.400	0.600	0.06
Foudry to M4	68	20.4	2.27	0.340	0.235	0.425	0.08
Local (to Reading)	38	11.7	3.99	0.370	0.525	0.105	0.25

TABLE 3.3 FSR CLIMATE CHARACTERISTICS

Catchment	SAAR mm	M5-2day mm	Jenkinson 'r'
Non-chalk to Theale	775	53.5	0.360
Foudry to M4	685	48.0	0.400
Local (to Reading)	645	46.5	0.405

TABLE 3.4 NOMENCLATURE

Name	Unit	Meaning
AREA	km^2	Catchment area
MSL	km	Mainstream length
S1085	m/km	Stream slope
SOILi	-	Fraction of catchment in WRAP class i
WRAP		Winter Rainfall Acceptance Potential
URBAN	-	Fraction of catchment urbanized
SAAR	mm	Average annual rainfall
M5-2day	mm	2-day rainfall depth of 5-year return period
r	-	Ratio of M5-1hour/M5-2day rainfall
CWI	mm	Catchment wetness index
PR	%	Percentage runoff
SPR	%	Standard percentage runoff
Tp	h	Time to peak of unit hydrograph
D	h	Design storm duration
RLAG	h	Reservoir lag time
BFI		Baseflow index
ADF	cumecs	Average daily flow
AARO	mm	Average annual runoff

3.2.5 Average and low flow characteristics

The mixed nature of the Kennet catchment response is confirmed by reference to average and low flow characteristics for gauging stations in the area. Figure 3.4 shows subcatchment boundaries for two stations on the Kennet and three stations on major tributaries. Flow characteristics were also examined for the neighbouring Pang at Pangbourne and Loddon at Sheepbridge catchments.

TABLE 3.5 AVERAGE AND LOW FLOW CHARACTERISTICS

Gauging station			AREA	BFI	ADF	AARO	SAAR
No	River	Site	km^2		cumecs	mm	mm
39/16	Kennet	Theale	1048	0.886	9.66	291	790
39/19	Lambourn	Shaw	236	0.967	1.72	231	770
39/22	Loddon	Sheepbridge	165	0.781	2.15	411	740
39/25	Enborne	Brimpton	150	0.553	1.26	265	835
39/27	Pang	Pangbourne	171	0.874	0.64	118	710
39/28	Dun	Hungerford	102	0.956	0.75	234	815
39/43	Kennet	Knighton	303	0.957	0.86	90	815

Table 3.5 gives average daily flow (ADF) and baseflow index (BFI) values calculated from 18 to 24 years of record. For each station, the ADF shown is the arithmetic mean, while the BFI is the median of yearly values. It is seen that the response characteristics of the Dun and Upper Kennet are indistinguishable in terms of BFI; a value of 0.955 represents a response heavily dominated by baseflow. That of the Lambourn is even more heavily dependent on springflow from the chalk. In contrast, baseflow represents a much smaller component of the Enborne response. The intermediate value of BFI for the Kennet at Theale reflects the mix of chalk and non-chalk areas and is comparable to that of the Pang.

While the BFI values largely confirm the difference inferred from soils, it is interesting to note that the ADF's are less consistent. In particular, the equivalent average annual runoff (AARO) of the Enborne would appear to be unreasonably low given the moderate SAAR and fast response of this catchment.

3.2.6 Comparison of Theale and Brimpton flood response

Inspection of limnigraphs and Average Daily Flow (ADF) hydrographs for the Kennet at Theale and the Enborne at Brimpton reveals a strong correspondence in flood response. While the baseflow component of the Kennet is very much greater (reflecting the large chalk portion of that catchment), the response to heavy rainfall is remarkably similar in shape. (See Fig. 3.5). This confirms that the clayey Enborne catchment is both the most significant Kennet tributary (with regard to flood generation) and is typical of the remaining non-chalk portions of the Theale catchment. It is concluded that the chalk portions of the Theale catchment are of little consequence to normal flooding of the Kennet, other than in providing concurrent baseflow. (It is possible that the chalk portion would be significant in abnormal conditions of snowmelt and frozen ground, such as are held to have occurred in the March 1947 flood, see Section 3.8).

At the outset of the study it was intended to exploit an existing standard unit hydrograph analysis for the Enborne at Brimpton. (See Appendix 2 of IH Report No 94). However, a recent rating revision for this station supplied by Thames Water radically reduces gauged flows in excess of 12 cumecs and has a profound effect on the analyses. For reasons given in Appendix C.1 to this chapter, we have placed no reliance on the Brimpton flows in this study.

Realization that the flood response at Theale reflects only the 220 km^2 non-chalk component of the catchment led to the decision to carry out a special unit hydrograph analysis of the Theale record.

3.3 UNIT HYDROGRAPH ANALYSIS FOR KENNET AT THEALE

3.3.1 Selection of data

Ten events were selected from the 1961 - 1986 Theale record: the six having the highest peak flows and four others that offered reasonably clear-cut events for analysis. (See Table 3.6.)

TABLE 3.6 EVENTS SELECTED

Event No	Date	Peak flow cumecs	Antecedent flow cumecs	CWI mm	Observed PR %
1	10/3/69	45.2	15.1		
2	17/3/71	33.6	14.8	130	42.9
3	8/6/71	71.0	8.6	75	41.7
4	3/3/72	34.4	12.5	127	43.6
5	1/12/72	47.4	5.8	93	44.0
6	8/2/74	44.8	13.2	130	68.4
7	10/11/74	43.1	7.4	127	43.1
8	14/1/75	47.8	12.6	127	52.3
9	12/12/79	34.1	5.7	125	34.2
10	26/12/79	38.7	6.1	123	34.2

Flow data at 3-hourly intervals were supplied by Thames Water for all but Event 1. (Data for this event were subsequently reconstructed by Thames Water but arrived after the study had been concluded.) The flow data were taken largely at face value but appeared to be of good quality given the inherent difficulty of gauging the Kennet at this section. (It is a shallow graded river with alternative courses that may be relevant in flood events, viz. the adjacent flood plain, the parallel Kennet & Avon Canal, and possible bypassing through Theale town to the north, and through Woolwich Green, Hose Hill and Theale lakes to the south).

An economy made in the analysis was to use only daily raingauge data, apportioning the daily total evenly over eight 3-hour periods. This is less restrictive than at first appears. The derivation of percentage runoff figures is largely insensitive to the rainfall data interval. It is much more important that the raingauges be spatially representative. Thus rainfall on the 220 km^2 non-chalk catchment to Theale was taken as the average of gauges sited at Inkpen, Wolverton Common, West Thatcham and Englefield. Nor is the derivation of an average unit hydrograph from nine events acutely sensitive to the rainfall data interval. In contrast, the use of 3-hourly flow data was essential to an adequate definition of both percentage runoffs and unit hydrographs.

3.3.2 Analysis

The unit hydrograph analysis assumed a percentage separation of rainfall losses, a 60-hour time base for the 3-hour unit hydrograph, and a straight line separation of baseflow. Unit hydrographs were derived for each event using the restricted least-squares method (Reed (1976), Boorman and Reed (1981)). A shape factor analysis indicated that the unit hydrograph derived for Event 7 was typical and this was taken as the average unit hydrograph for the catchment. (See Fig. 3.6.)

The percentage runoff figures ranged from 34.2 to 68.4% but averaged about 40%. These are discussed further in Section 3.4.2.

3.4 FLOOD ESTIMATES FOR KENNET AT THEALE

3.4.1 Statistical method

There are 22 recorded annual maxima from Theale dating from 1961 to 1982. The 1971 flood (71 cumecs) is 47% bigger than the next largest flood and 1.9 times the mean annual flood of 37.7 cumecs, computed as the arithmetic mean of the series. Figure 3.7 shows the annual maxima, plotted using the Gringorten plotting position formula, together with a number of fitted frequency curves.

The EV1 (Gumbel) and GEV curves are fitted by the method of probability weighted moments (PWM: see Hosking et al, 1985) to the 22 annual maxima from Theale. It can be seen that neither fit the higher floods very closely - and appear to underestimate the magnitude of rare floods, although the fits for middle range floods (less than 10 year return period) appear satisfactory.

The other three curves on Fig. 3.7 are regional growth curves rescaled by the site mean annual flood (37.7 cumecs). The FSR curve is that for Region 6 as published in the Flood Studies Report and revised in Supplementary Report 14, and clearly does not fit the recorded data very well. Thames Water have developed a regional curve for use on Thames tributaries using data from the Wey and Mole catchments (Thames Water, 1982), and this is also shown on Fig. 3.7. It appears to fit the data for Theale slightly better than the FSR curve. The third curve is the regional growth curve for chalk catchments presented in Supplementary Report 4. Although flood behaviour at Theale is strongly influenced by the non-chalk areas, data from Theale were among those used to construct the chalk curve.

All three regional curves, however, overestimate the magnitude of floods with return periods between 5 and 20 years.

3.4.2 Rainfall - runoff method

Application of the FSR rainfall-runoff method - as revised in FSSR 16 - to estimate flood frequency at Theale was necessarily unorthodox. The procedure adopted was to consider rapid response only from the 220 km^2 non-chalk portion of the catchment but to make a baseflow allowance for the whole catchment. From the unit hydrograph analysis of Section 3.3 it was concluded that a standard FSR triangular unit hydrograph fitted well provided that a time to peak of 24 hours was adopted. (See Fig. 3.6)

Following the methodology of FSSR 12 (as modified by FSSR 16) the 'observed' percentage runoff values of Section 3.3.2 were standardized to take account of the antecedent and storm characteristics of the events.

TABLE 3.7 DERIVATION OF STANDARD PERCENTAGE RUNOFF (SPR) VALUES

Event No	Observed PR %	Storm Depth, P mm	CWI mm	Deduced SPR %
2	42.9	34	130	41.6
3	41.7	178	75	40.0
4	43.6	51	127	40.7
5	44.0	114	93	42.8
6	68.4	74	130	61.8
7	44.2	130	127	33.2
8	52.3	109	127	43.1
9	34.2	54	125	31.3
10	34.2	44	123	33.5

The only serious anomaly in Table 3.7 is the rather high standard percentage runoff (SPR) derived for Event 6. Reference to ADF hydrograph plots for tributary stations indicated that the contribution from the Upper Kennet (gauged at Knighton) was unusually high in this event. From the scant climatological information to hand it would appear that precipitation immediately prior to the event fell as snow and that the response to rainfall on 8-10 February 1974 was accentuated by some snowmelt, possibly from a wider area than just the non-chalk portions. Further investigation of local weather station data would be required to substantiate this.

The median value of standard percentage runoff (SPR) from Table 3.6 is 41.6%. This agrees well with the 43% value estimated from soils (see Table 3.2) and the latter value was retained.

A remaining difficulty concerns the allowance for baseflow. Application of the FSSR 16 procedure yields an allowance of 21 cumecs for the 1048 km^2 catchment to Theale. Use of this value gives flood estimates consistently higher than those by the statistical method. Reference to a flow duration plot of the Theale ADF data confirmed that 21 cumecs is an excessively rare flow to be considered as an antecedent condition to a flood event. Using instead a baseflow allowance equal to the long-term ADF (9.66 cumecs), reasonable agreement was obtained between the statistical and rainfall-runoff methods at low return period. (See Fig. 3.8)

Appendix C.2 summarizes the calculations for the 50-year design flood at Theale using the rainfall-runoff method. The flood frequency curve is shown in Fig. 3.8 and sample design hydrographs in Fig. 3.9. Investigation of the significance of the flood plain storage in attenuating floods between Theale and Reading requires hydrographs rather than peak flow estimates alone. Having reconciled the estimates from the rainfall runoff method with what the statistical analysis reliably demonstrates at low return period, this can proceed in Section 3.6.

3.5 FLOOD ESTIMATES FOR FOUDRY AT M4

The Foudry Brook is ungauged and there is no suitable analogue catchment other than the Enborne at Brimpton, analysis of which has been discounted in this study. (See Appendix C.1). The flood estimates are therefore based on catchment and climate characteristics alone.

Flood estimates for the Foudry at M4 were available from an earlier study (Reed, 1984). These were modified slightly to take account of the more detailed interpretation of soils now possible through 1:250,000 soil maps. The resultant flood frequency curve is shown in Fig. 3.10 and typical design hydrographs in Fig. 3.11. Appendix C.3 summarizes the calculations for the 50-year event.

3.6 FLOOD ESTIMATES TO COUNTY WEIR, READING

3.6.1 Method

When making flood estimates for sites just downstream of a confluence it is tempting simply to add together flood estimates for the two tributaries. Such a method is in general erroneous. In the case of two such differing tributaries as the Foudry and the Kennet it would probably lead to serious overestimation of design floods at Reading. This is because the Foudry is sensitive to appreciably shorter duration storms than the Kennet. From Appendices C.2 and C.3 it is seen that the design storm durations are 19 and 45 hours respectively. To obtain consistent estimates it is necessary to impose a single design storm on the entire catchment to Reading (neglecting, however, the chalk portion of the Theale catchment). Additionally, it is appropriate to extend the design storm duration for the 'reservoir lag' effect that the flood plain storage imposes on flood runoff from the Kennet and Foudry. Finally, it is reasonable to make some allowance for the relative timing of runoff from the Kennet, Foudry and Local subcatchments.

3.6.2 Flood peak travel times: storage lags

The availability of water level observations at Blake's Lock - some 1.5 km downstream of County Weir - is of some assistance in judging characteristic response times of the Kennet to Reading. Although the relationship between level and flow at Blake's Lock is a highly complex one (depending as it does on operational settings of paddles and gates), it is reasonable to assume that the time of maximum headwater level gives a general indication of the time of peak flow. Blake's Lock water level data (in the form of 'tackle sheets') were inspected for those events selected for unit hydrograph analysis.

Head and tail water levels are read at 3-hour intervals between 09.00 and 21.00 but not otherwise. From the events examined it was possible to estimate Blake's Lock peak times reliably for only three events: June 1971 (event 3), February 1974 (event 6) and a lesser event in December 1985.

These yielded peak-to-peak travel times (from Theale to Blake's Lock) of 15, 15 and 9 hours respectively. On the basis of these estimates it is suggested that a typical flood peak travel time for in-bank events is between 3 and 6 hours from Theale to County Weir, with flood plain storage delaying major flood peaks by up to 12 hours more. Water level data at finer time resolution would be needed to confirm this.

3.6.3 Consistent inflow hydrographs

The main prerequisite to constructing consistent inflow hydrographs to the Kennet/Foudry flood plain is selection of an appropriate design storm duration, D. Because not all of the design flood will be subject to flood plain storage action, it is not immediately clear what 'reservoir lag' (RLAG) value should be used in the equation:

$$D = (1 + SAAR/1000) (Tp + RLAG)$$

nor what unit hydrograph time to peak (Tp) value. This difficulty was resolved by considering a range of design storm durations, namely 45, 69, and 93 hours. It was found that the resultant flood estimates were relatively insensitive to this choice and that the results for a 93-hour storm should be adopted. (The longer storm duration yields a design criterion that is slightly more relevant to the assessment of flood plain inundation volumes, whereas a shorter duration would be slightly more testing in terms of design flows at County Weir. The preference for adopting the longer duration took into account the long-term history of Kennet flooding - see Section 3.8).

The design storm depth was adjusted by an areal reduction factor for a 500 km^2 area, reflecting the physical area spanned by the Local, Foudry and Theale (non-chalk) subcatchments. The depth was distributed into a hyetograph using the customary bell-shaped "75% winter profile". (This is an uncomfortable assumption for such a long duration event. However,the alternative of distributing the depth according to some locally observed storm profile could be unduly subjective.)

Finally, the design hyetograph was factored by a subcatchment percentage runoff and convolved with the subcatchment unit hydrograph to construct the inflow hydrograph to the flood plain from each of the Theale, Foudry and Local subcatchments in turn. In accumulating the combined inflow hydrograph to the flood plain, account was taken of typical subcatchment response timings by deferring the Theale hydrograph by 9 hours. Comparison of the Theale and Brimpton limnigraphs with rainfall data suggests that perhaps 6 hours of the 9-hour Theale 'pure time delay' occurs upstream of Theale. (See also Section 3.6.2). The synthesis of the composite inflow hydrograph for the 50-year event is given in Appendix C.4 and the flood frequency curve for the combined inflow is included in Fig. 3.12.

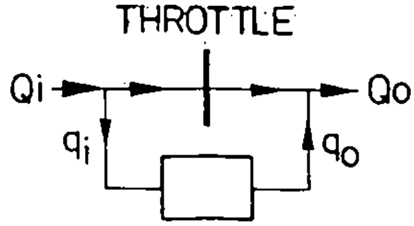
3.6.4 Flood plain routing

The study brief specified that a simplified flood routing model would be calibrated for the Theale/Reading reach by combination of:

(i) gauged inflows at Theale, estimated contributions of the Foudry and other ungauged inflows
(ii) estimated outflows at County Weir
and (iii) flood plain storage information.

Adoption of a relatively simple approach was consistent with the requirement to route hypothetical design floods (as opposed to intensively gauged real ones). As the study proceeded, it became clear that outflows at Reading (item ii) could not be estimated reliably from the information available. It was therefore necessary to assume a somewhat simpler flood routing model than initially intended.

The model structure is illustrated below:



LINEAR RESERVOIR

Here Qi represents the composite inflow to the Kennet/Foudry flood plain area, and Qo is the outflow at County Weir, Reading. Inflows less than a threshold (or "throttle") discharge, QT, pass through the model unattenuated. Flows in excess of QT are diverted into a linear reservoir which represents the storage action of the flood plain.

Equations defining the inflow, qi, and outflow, qo, of the linear reservoir are:

$$qi = \max(0, Qi - qT)$$

and

$$K \, dqo/dt + qo = qi$$

where K is the mean residence time, and t is time, both in hours. Prior to routing a flood event, qi and qo are initialized at zero.

The model has two parameters: the mean residence time (K) and the threshold discharge (QT). These were calibrated by trial-and-error simulation of the June 1971 event. (See also Section 3.7.) This was made possible by two pieces of information about the June 1971 flood: an estimate of the <u>maximum</u> inundation storage (obtained by survey - see Section 4.2). The calibration yielded parameter values of K = 32 hours and Q = 14 cumecs.

It should be appreciated that the routing model is an empirical device and that conceptual interpretation of its parameters may be misleading. In reality, part of the flood plain will act as "flowing" storage and part will provide "dead" storage. The model provides storage of the former type only. Empirical calibration of the model parameters (as opposed to subjective assignments) will partly compensate for this and other simplifications.

The routing of the composite inflow hydrograph for the 50-year event is detailed in Appendix C.4. The peak composite inflow of 77.4 cumecs is attenuated to a peak County Weir outflow (21 hours later) of 59.1 cumecs. The simulated peak flood plain inundation storage is 5.2×10^6 m^3.

3.6.5 Flood frequency estimates for County Weir

From analyses for further return periods (see Appendix C.6) it was possible to arrive at frequency curve estimates for peak outflows at County Weir (see Fig. 3.12)

Comparison of the "combined inflow" and "County Weir" flood frequency curves confirms that the flood plain storage has a significant attenuating effect on flood frequency at Reading. For events of return period between 25 and 100 years, the attenuation is about 23.5%.

3.6.6 Maximum flood plain inundation volume

The above flood plain modelling also yielded estimates of the maximum flood plain inundation volume (or "storage") for each design event. The relevant frequency curve is given as Fig. 3.13.

3.7 ANALYSIS OF JUNE 1971 EVENT

3.7.1 Rainfall

The June 1971 event followed a dry period, with soil moisture deficits of about 50mm prevailing until the 8th. Moderate depths of rain on the 8th were followed by showers on the 9th. The main storm began at 09.00 on the 10th and lasted for 24 hours, neatly coinciding with rainfall measurement "days". Thus daily totals for the 10th (see Fig. 3.15) give a good impression of the spatial characteristics of the storm.

3.7.2 Flows at Theale

Following the approach of FSSR 12, the unit hydrograph model was used to simulate the Theale hydrograph for the June 1971 event. Comparison with the "observed" flows (see Fig. 3.14) is more re-assuring than at first appears. The early part of the hydrograph is modelled well. The "shoulder" at 35 cumecs on the rising limb is not simulated. This appears to be consistent with substantial quantities overflowing into gravel pits, the hydrograph at Theale rising again only when the available storage has been utilized. Note that the observed flows plotted in Fig. 3.14 are the 3-hourly data supplied by Thames Water. The peak estimate of 71 cumecs (2500 cusecs) quoted for this event is a little higher.

3.7.3 Flows at County Weir

In a similar fashion the responses from the Foudry and Local subcatchments were also simulated for the June 1971 event. The combined inflow hydrograph was routed through the flood plain model and flows at County Weir thereby simulated (see tabulations in Appendix C.5.).

3.7.4 Maximum volume of inundation

The maximum volume of inundation for the June 1971 event was simulated to be 4.9Mm^3.

3.8 ANALYSIS OF MARCH 1947 EVENT

Reference is made in Section 3.9 to the problematic nature of the March 1947 event. The various factors giving rise to that flood are difficult to quantify in terms of the probability of their joint recurrence.

However, it is understood (Thames Water Planning Division reference flood card) that the peak flow through Reading on 14 March 1947 was estimated (presumably by current meter gauging) to be 2085 cesecs or 59 cumecs. Neglecting any changes that may have occurred in the behaviour of the flood plain (note, for example, Section 4.4), the return period of the March 1947 peak outflow is assessed from Fig. 3.12 to be about 50 years, i.e. more severe at Reading than the June 1971 event.

3.9 DISCUSSION

It is reassuring to note that the various estimates of the rarity of the June 1971 flood concur reasonably well. It is assessed to have been a 50-year event at Theale but more like a 35-year event in terms of flow at County Weir and in terms of flood plain inundation. While the magnitude of the design flows and inundation volumes are subject to uncertainty (particularly the latter), it can be asserted with slightly greater confidence that the volume of inundation in the June 1971 event represented about a 35-year event.

These qualifications arise because of the concern that the Kennet catchment may be prone to flooding by snowmelt and rain (as occurred in March 1947) as opposed to rainfall alone - as has been assumed above. There can be little doubt that snowmelt was a major contributing factor in the March 1947 flood. There is the suspicion that the chalk portions of the catchment generated some rapid response runoff, perhaps as a result of frozen ground. In the absence of a gauged flow record of sufficient length and quality on which to base flood estimates on the Kennet, it is advisable to turn to historical water level and rainfall records to check that the flood potential of this river has not been underestimated.

Historical water level records have been referred to in Section 2.4 of the report.

Figure 3.16 shows extreme 1, 2, 4 and 8-day rainfalls recorded in the Kennet catchment. (Generally these are catchment average rainfalls but note that for early events - excepting November 1894 - these are Reading rainfalls). That the November 1894 had exceptional 4 and 8-day rainfalls but less noteworthy 1 and 2-day rainfalls suggests that the Kennet to Reading is indeed sensitive to relatively long duration events. (See Section 3.6.3). It is confirmed from Fig. 3.16 that the March 1947 flood cannot be accounted for by rainfall alone.

Symons and Chatterton (1895) refer to Kennet floods prior to that of November 1894, including that of October 1891 (see Fig. 3.16). Of interest is the reference to the 1809 event, "which was produced by the sudden melting of deep snow".

Perhaps the inference to be drawn is that, while the flood estimates made in this report are reasonable and appropriate to meet the study objective, occasional very severe events arising partly from snowmelt can occur. Thus it is suggested that the flood and inundation volume frequency curves derived herein should not be applied beyond a return period of 100 years.

That the conditions giving rise to frozen ground, snow accumulation and subsequent rapid melt are likely to be spatially widespread is of some comfort - other catchments will be in trouble!

3.10 CONCLUSION

Figure 3.13 is the most important product of the hydrological and flood routing analysis. From the figure it is possible to judge the significance of long-term loss (or gain) in the available flood plain storage upstream of Reading.

It is estimated elsewhere (in Section 4.4) that some $0.5 \times 10^6\ m^3$ of storage have been lost in the period 1971 -1986 through infilling. From Fig. 3.13 it can be seen that such a loss would in itself have a profound effect on the frequency with which a given inundation level is experienced. For example, the June 1971 inundation level would now accommodate only $4.4 \times 10^6\ m^3$, corresponding to about a 20-year event rather than the 35-year event inferred in Section 3.8. The effect on outflows at County Weir would be the same, the incidence of a given flood flow becoming almost twice as frequent (i.e. once in 20 years rather than once in 35 years).

Whereas Figs. 3.12 and 13 can be used to judge the strategic importance of maintaining adequate flood plain storage, it would be unwise to apply these results to minor short-term developments (where only small amounts of storage are concerned). Specific developments may have specific consequences for flood risk - born from the nature and location of the infilling and the compensatory works proposed. However, Fig. 3.13 provides a broad assessment of the significance of flood plain storage which is entirely appropriate to appraisal of the long-term management policy of the Kennet/Foudry flood plain.

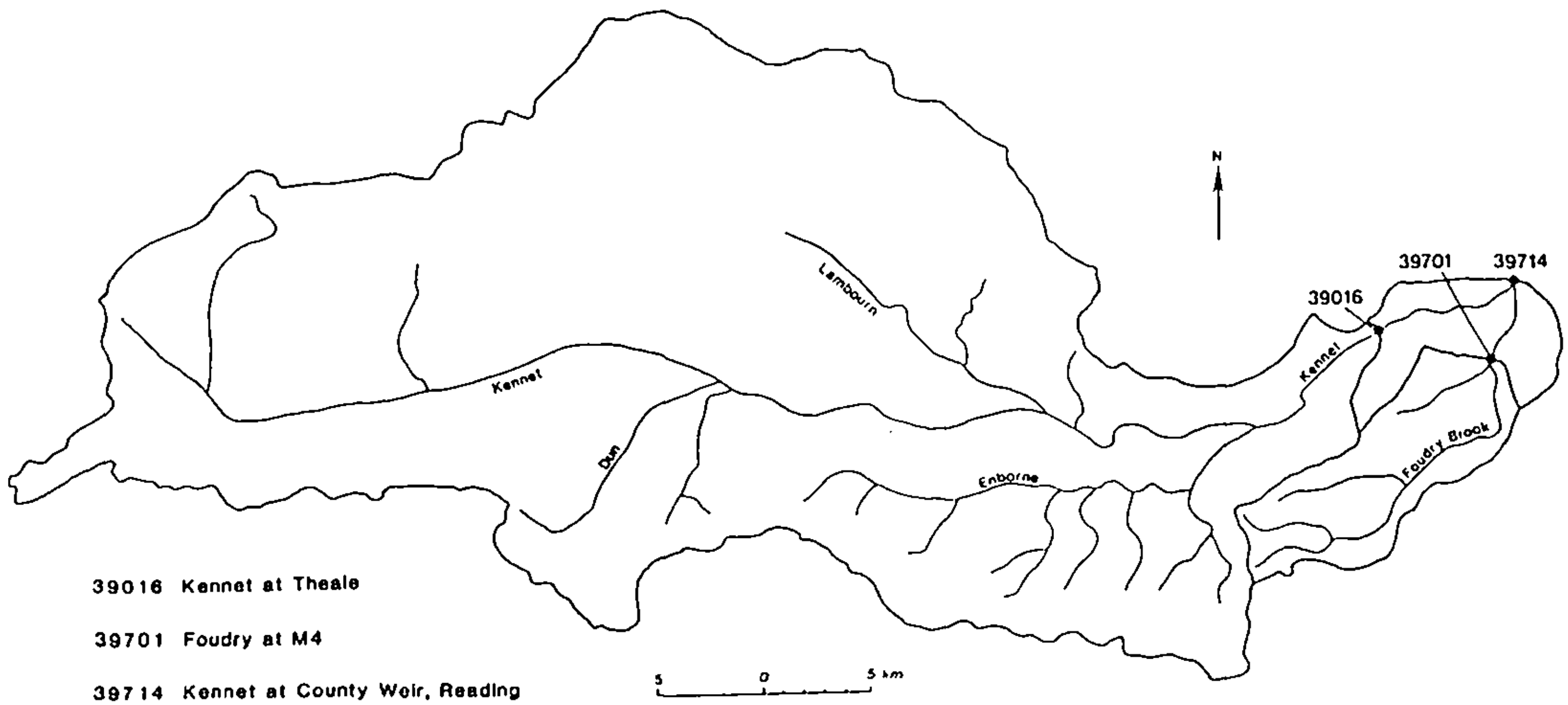


Fig. 3.1 Catchment Plan.

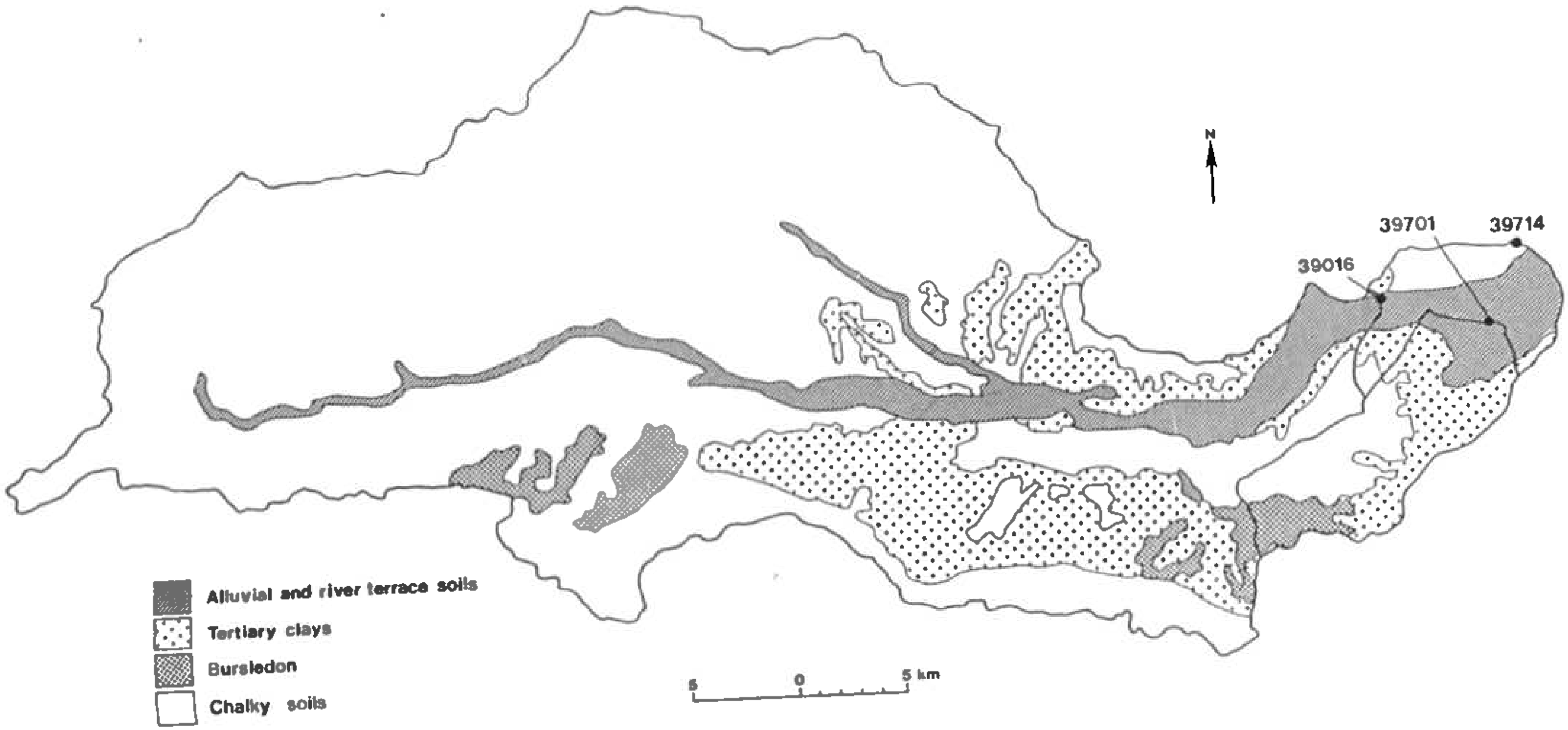

N
39016
39701
39714
Alluvial and river terrace soils
Tertiary clays
Bursledon
Chalky soils
5
0
5 km

Fig. 3.2 Soils

Figure 3.3 Principal Urban Areas

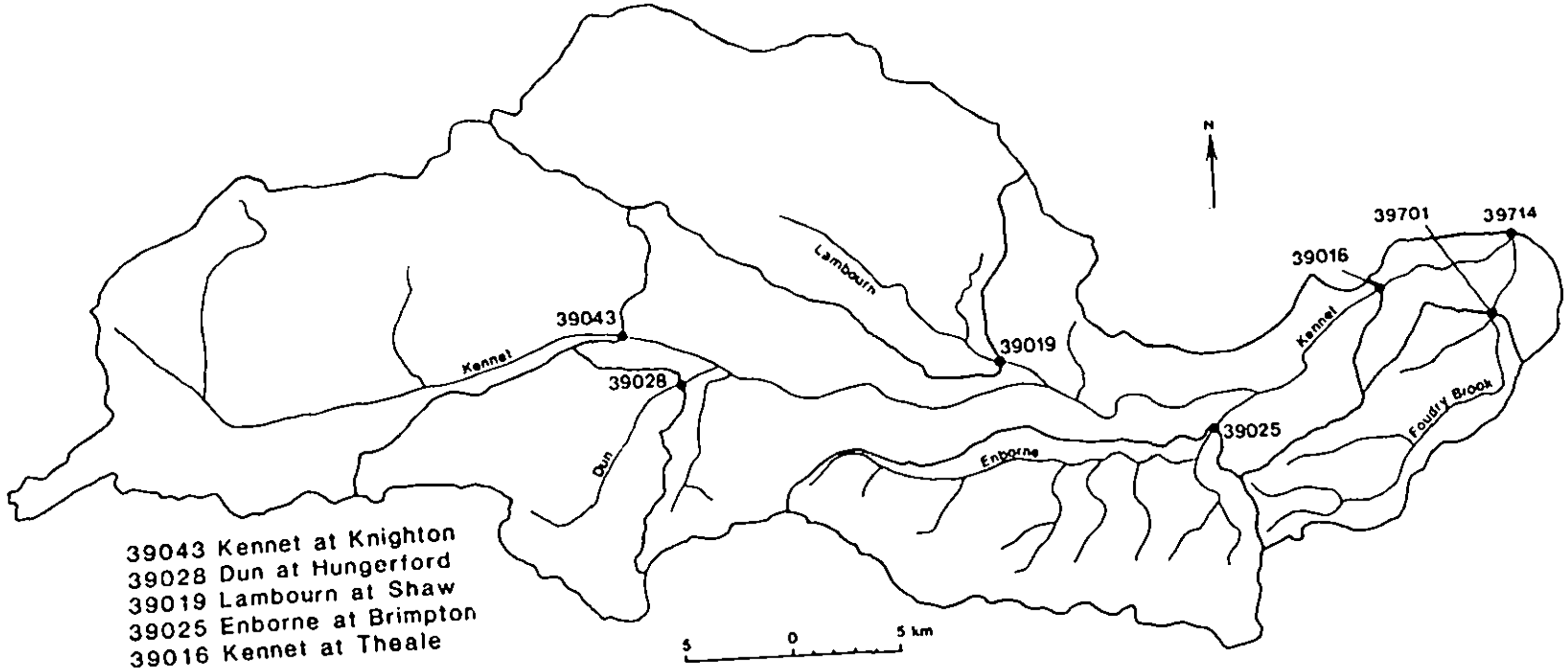


Fig. 3.4 Gauge Subcatchments of the Kennet.

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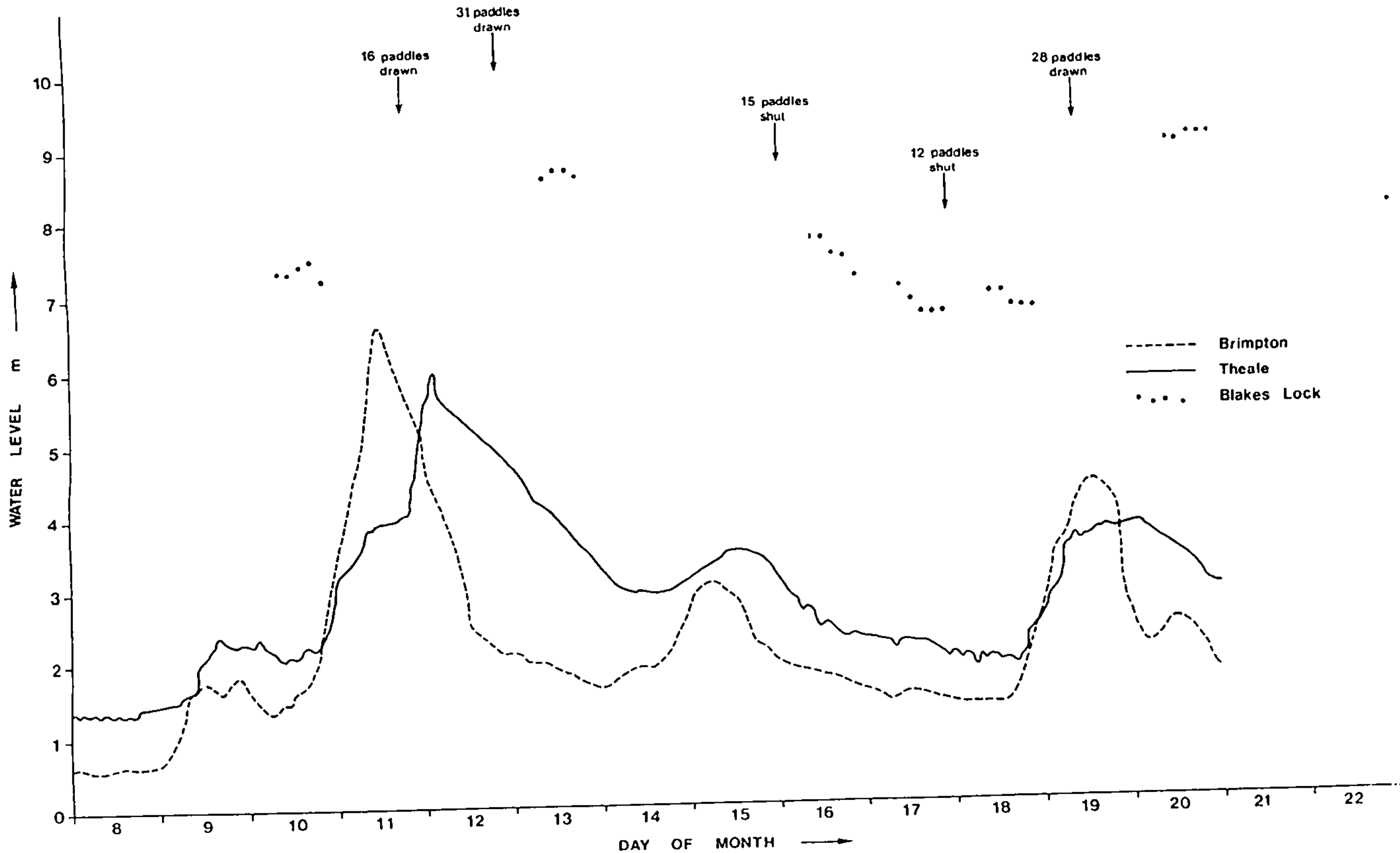


Fig. 3.5 Comparison of Brimpton, Theale and Blakes Lock Limnigraphs - June, 1971.

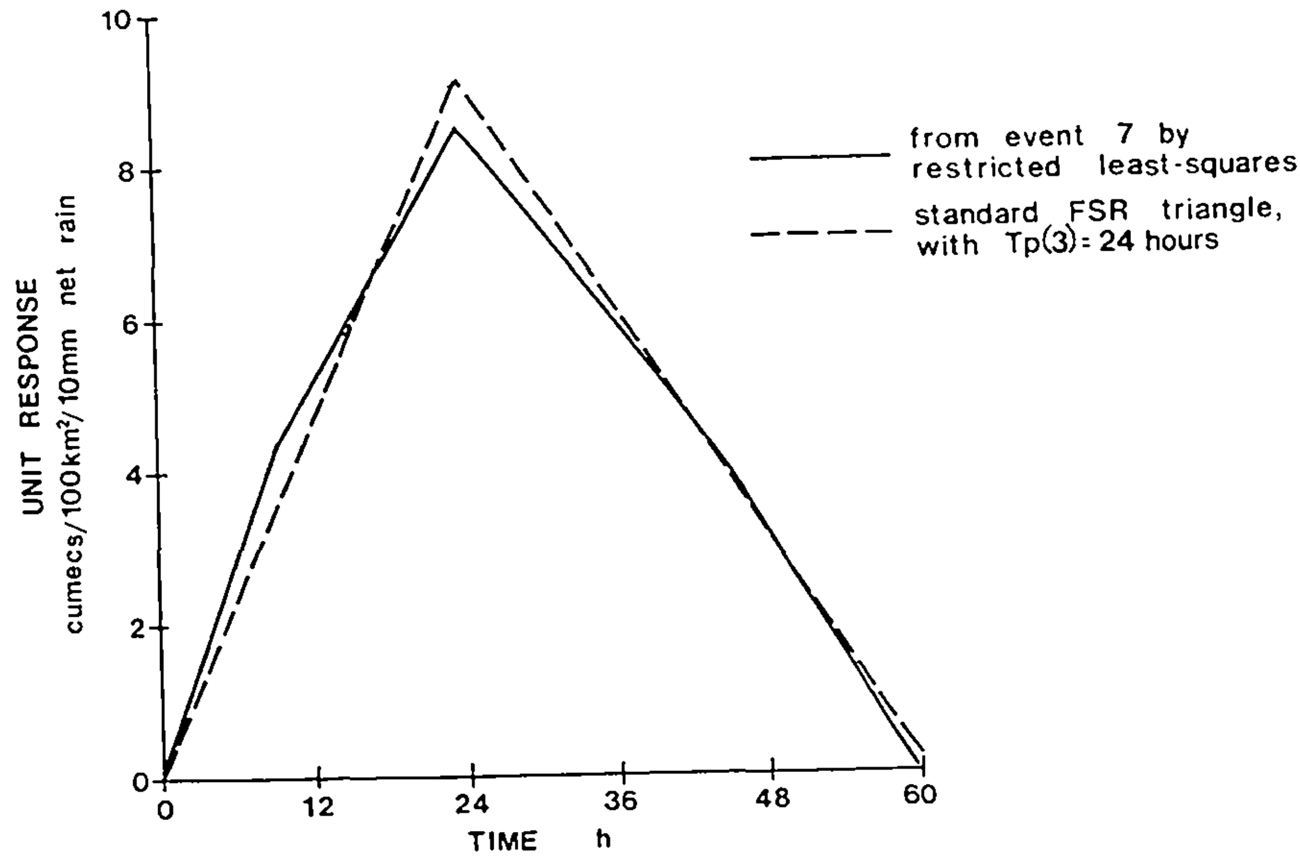


Figure 3.6 Unit Hydrograph f
Kennet at Theale.

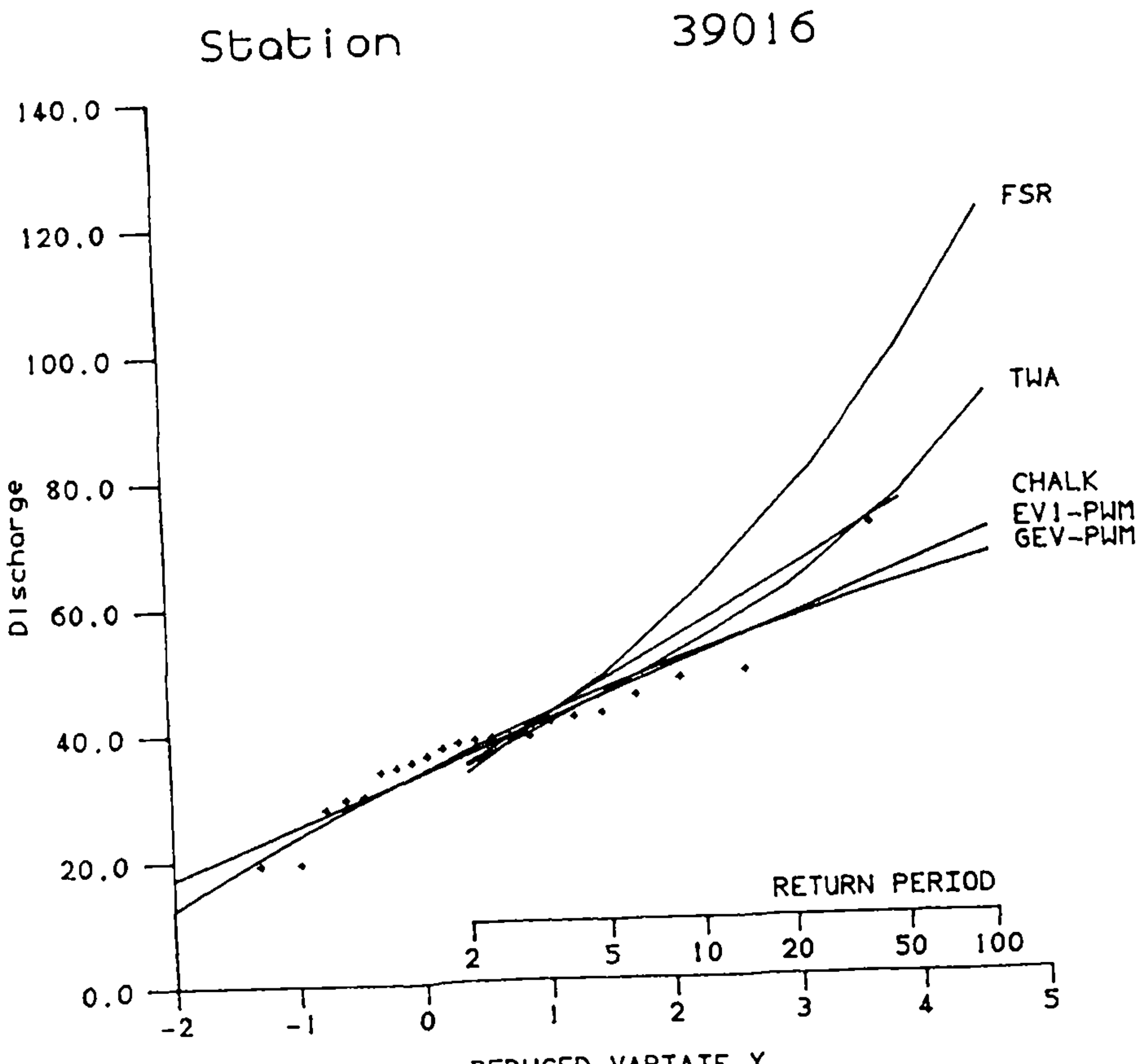


Fig. 3.7 Flood Frequency Curves for Kennet at Theale - Statistical

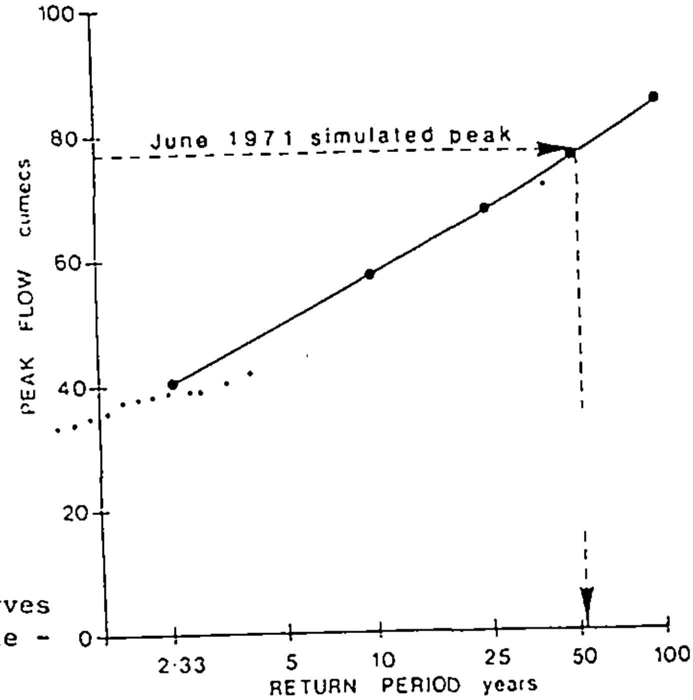


Figure 3.8 Flood frequency curves for Kennet at Theale - adopted.

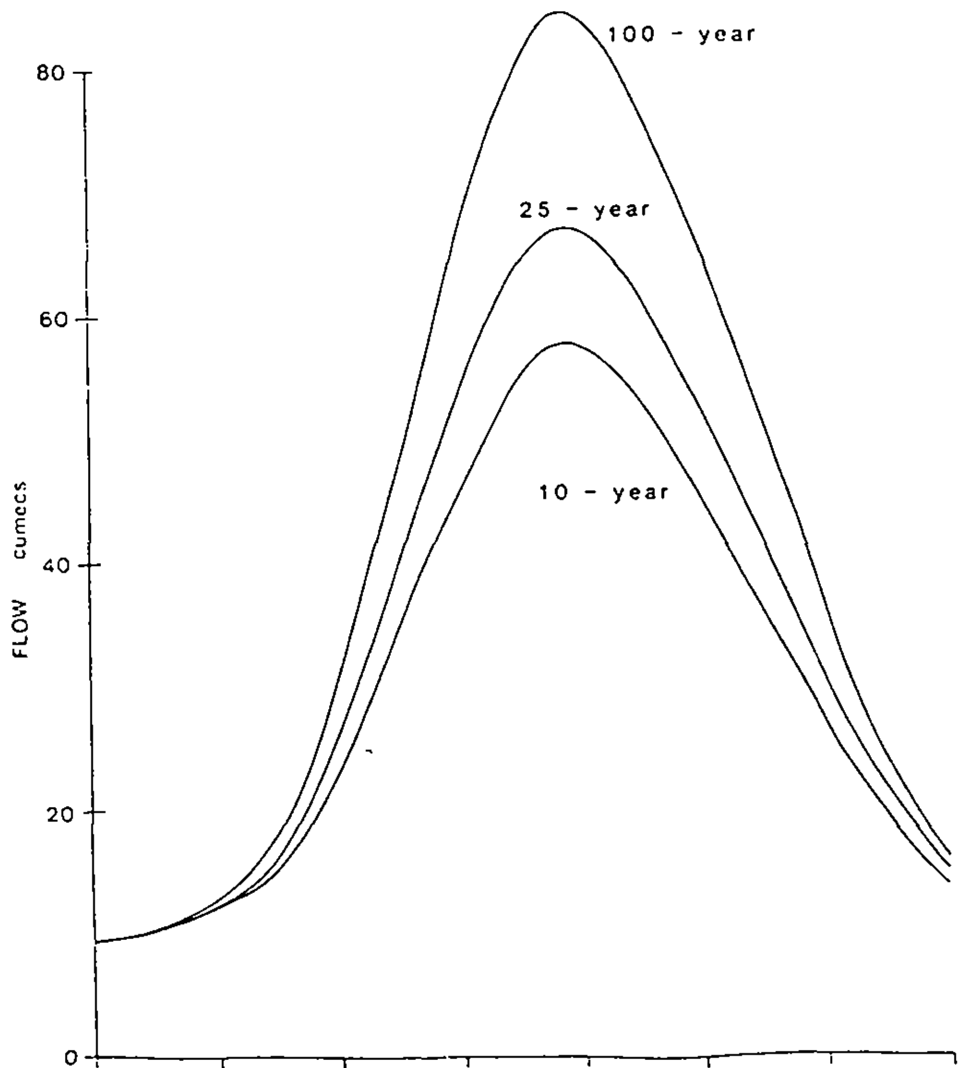


Figure 3.9 Design Hydrographs Kennet at Theale.

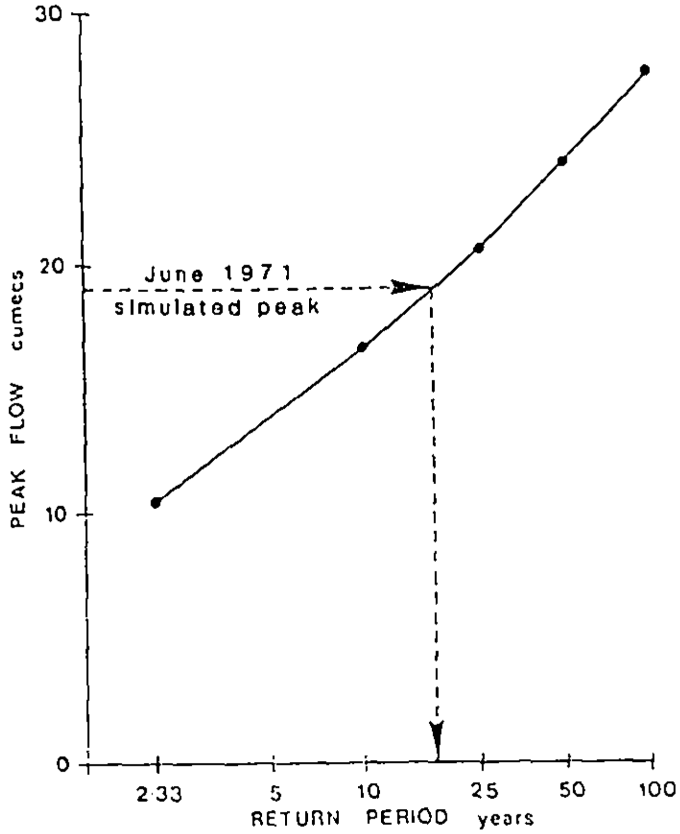


Figure 3.10 Flood frequency estimates - *Fobney at M4.*

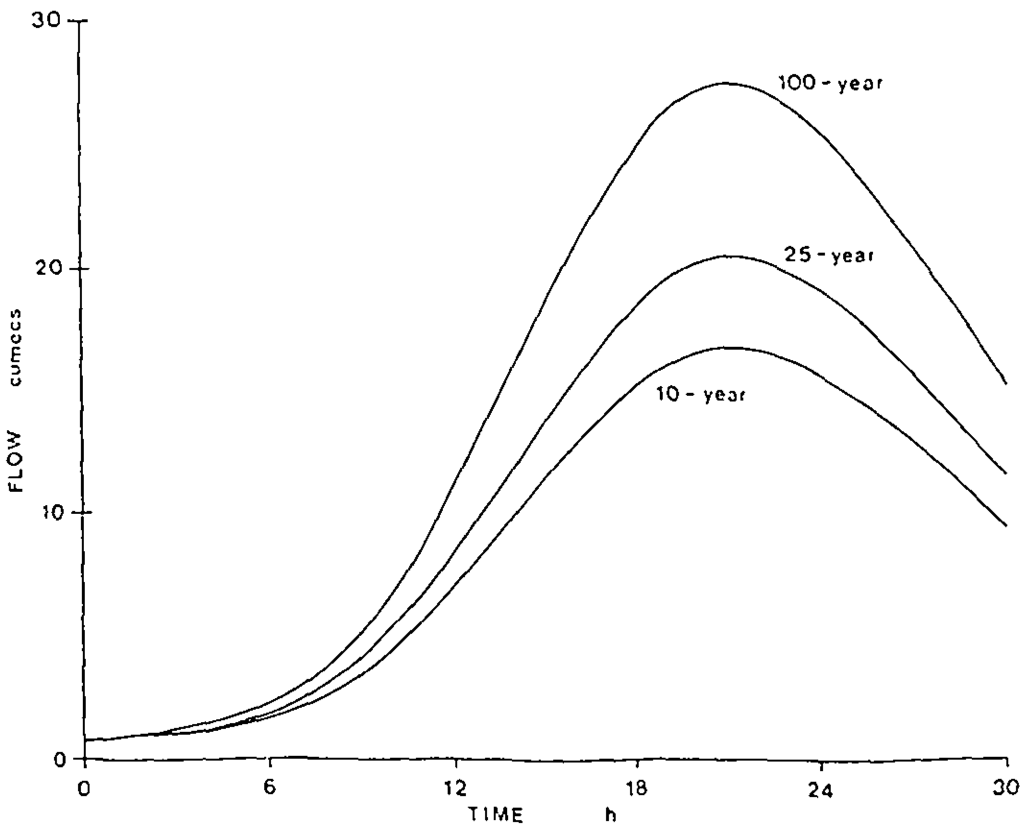


Figure 3.11 - Design Hydrographs Fobney at M4.

Figure 3.12 Combined catchment to flood plain Inflow and outflow flood frequency

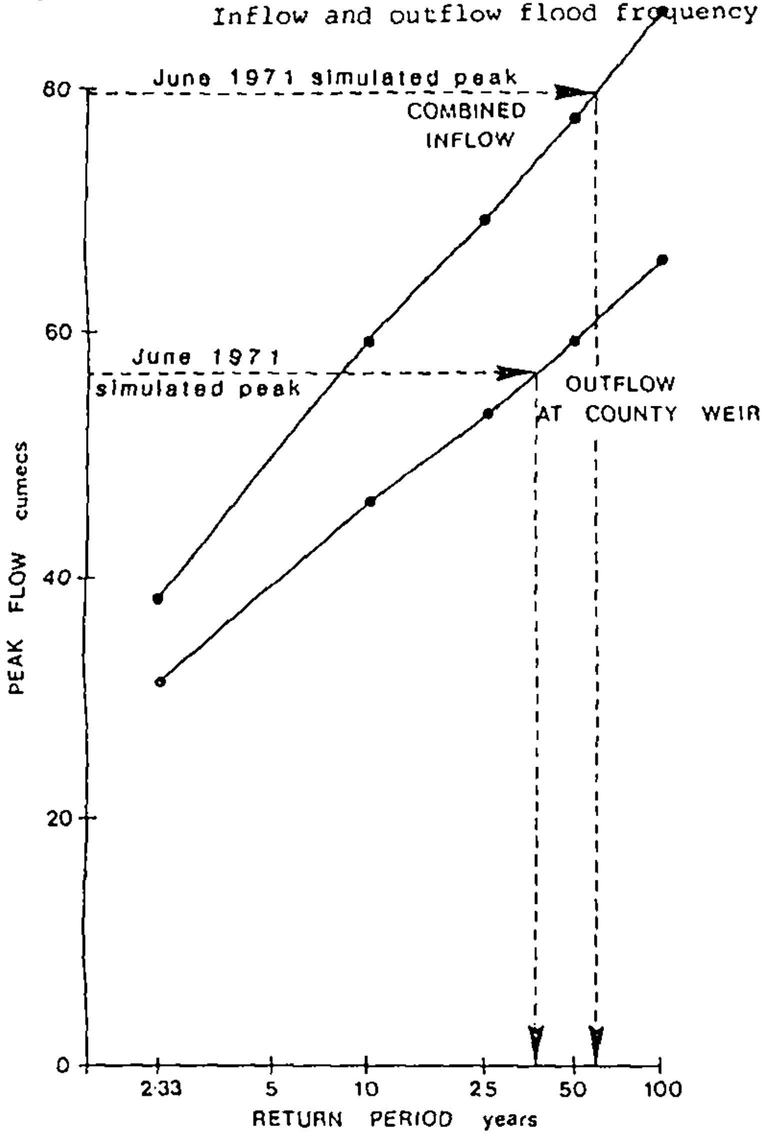


Figure 3.13 Inundation volume frequency. Kennet flood plain.

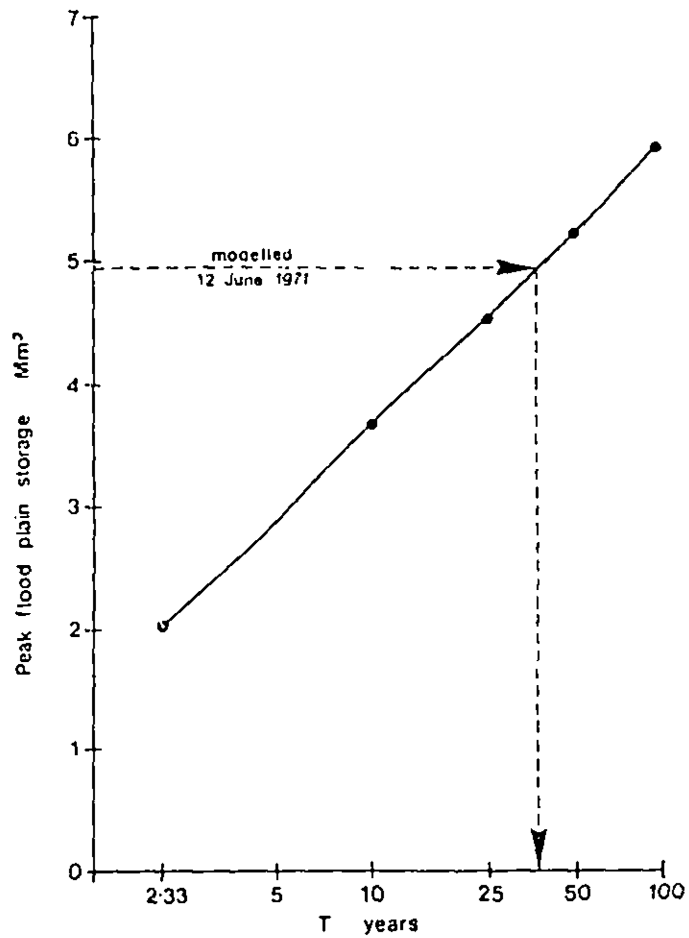
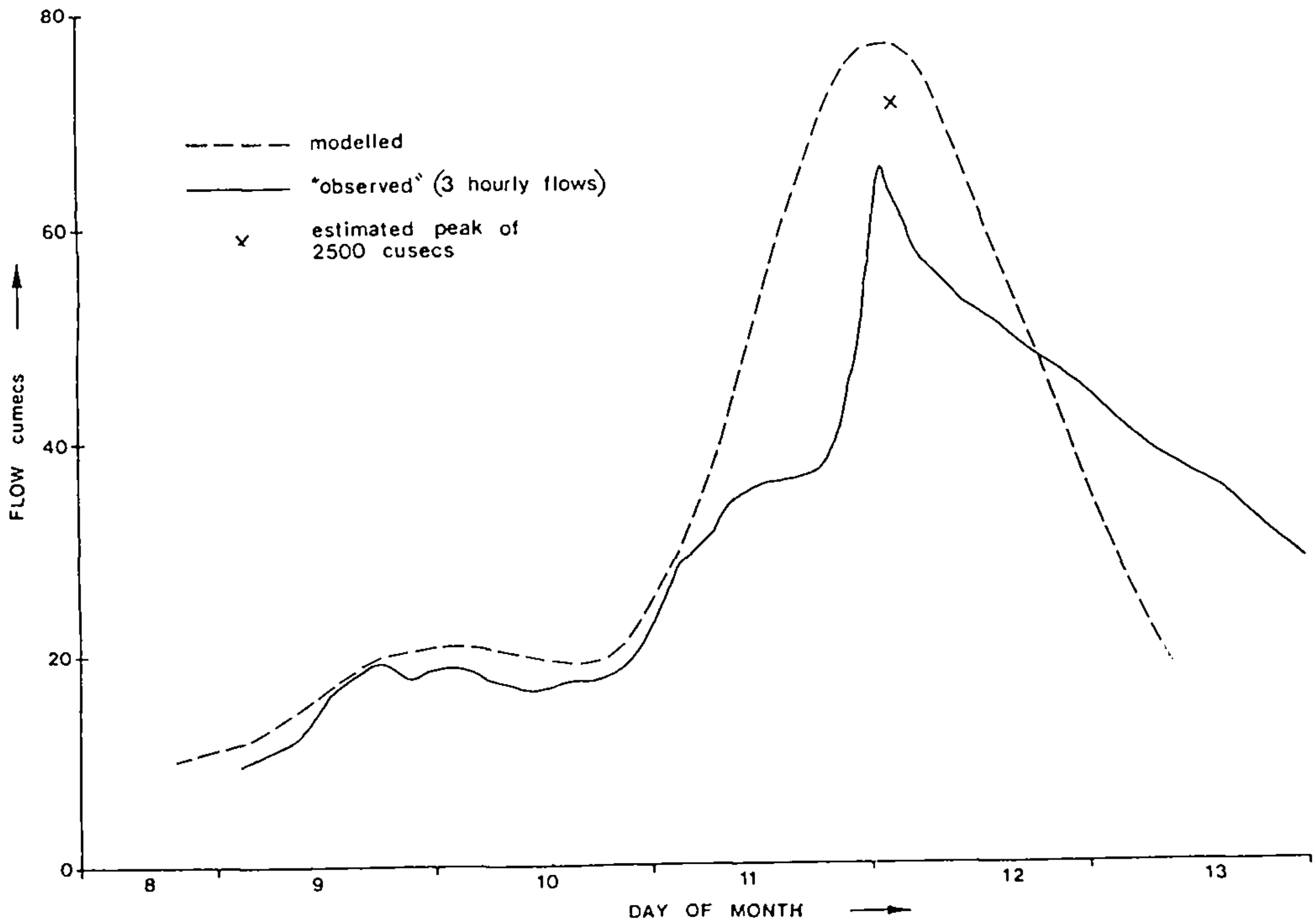


Figure 3.14 Observed and simulated Theale flows - June, 1971.



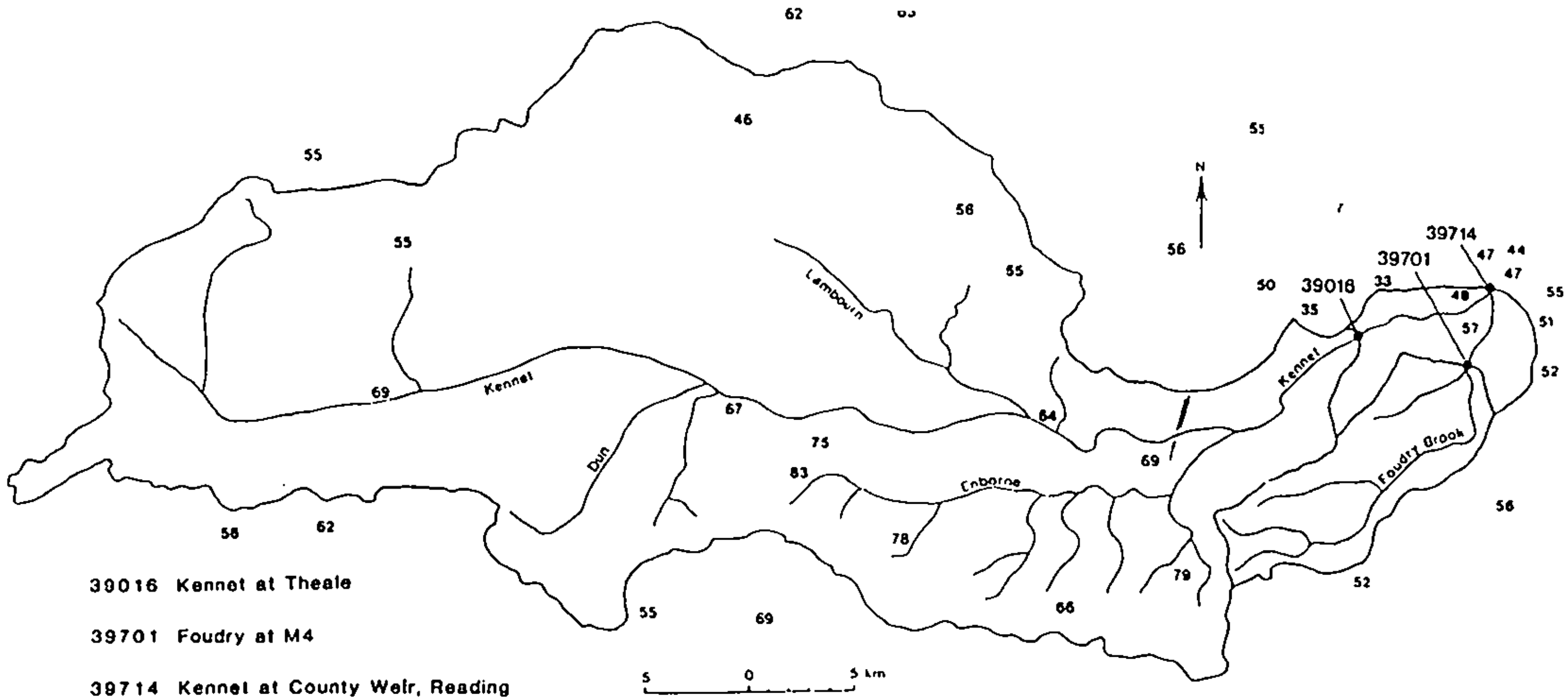


Fig. 3.15 Daily Rainfalls (mm)
10th June, 1971

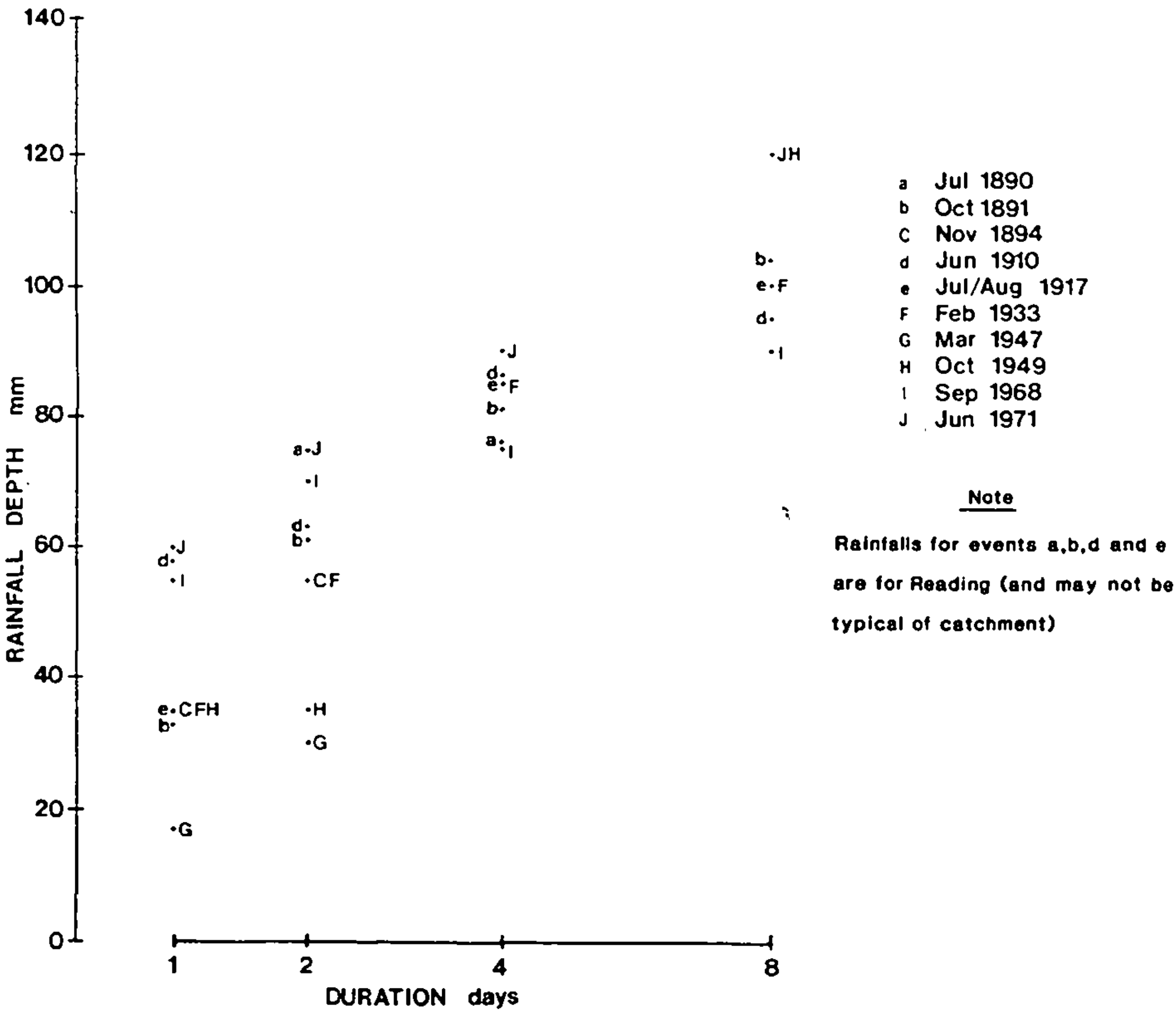


Figure 3.16 Notable 1, 2, 4, and 8 day rainfalls in the Kennet Catchment.

CHAPTER 4

FLOOD ENVELOPES

4.1 APPROACH

4.1.1 Objective

The objective of the work described in this chapter was to produce flood envelopes of different return periods based upon the storage frequency curve derived in Chapter 3. The storage frequency curve was produced by hydrological analysis but was calibrated by comparison with the volume calculated to have gone into storage during the 1971 event. The calculation of this storage volume is set out in this chapter, thus providing an estimate of the spatial distribution of the storage and allowing the flood envelopes for different storage volumes to be determined.

4.1.2 Calculation of storage volumes

For a particular flood event the maximum volume stored is that volume between the peak water surface profile and the flood plain. The calculation of this volume is complicated by the fact that the flood water surface profile on the Kennet has a steep gradient averaging about 1m per kilometre.

A survey of the flood plain with cross sections every 250m was carried out to provide the necessary data on the topography of the flood plain, as described in Section 2.2.1. Flood levels at various points along the study area were recorded during the 1971 event from which it was possible to estimate the peak water surface profile. Following consultation with Thames it was agreed that a water surface derived by joining recorded levels on the downstream side of weirs would probably give the best representation of conditions in the flood plain, although in the river channel itself the profile shown on Figure 2.1 is more realistic.

The approach adopted to estimate the volume between the water and land surfaces was to calculate an area-elevation curve for each cross section and then assume that this cross section applied for 250m along the valley in order to produce a volume-elevation curve for that reach. The volume stored under a particular water surface profile can then be calculated by summing the volumes flooded for each reach. The advantage of this approach is that it lends itself to computerisation allowing storage volumes for a range of water surface profiles to be determined rapidly.

4.1.3 Computer programs

Two programs were developed to carry out the above calculations. The first calculated the area elevation curve for each cross section from the survey data which was available in the form of listings giving the chainage and elevations for each point along the section. The second program calculated the total volume stored for a given water surface profile by summing the individual volumes flooded for each reach. It was assumed that the water surface would be horizontal perpendicular to the river.

4.2 STORAGE DURING 1971 FLOOD

An examination of the area flooded in 1971, as shown on Fig. 2.3, shows that the calculation of flood storage on the Kennet and the Foudry Brook can be treated separately for this event due to the high ground that separates the two rivers at their confluence. As measurements of peak flow on the Kennet were made at the Theale gauging station, the volumes stored along the Kennet upstream and downstream of this point have also been calculated separately.

4.2.1 Kennet downstream of Theale gauge

The survey cross sections downstream of the gauge are Nos 1.001 - 1.026. Some of these sections were adjusted so as to reproduce as nearly as possible the topography that existed in 1971. Thus the recently excavated Cottage Lane pit, the Smallmead pit and partially filled tip were all 'refilled' to avoid over-estimating the volume going into store.

The water surface profile was determined from the information available on Fig. 2.3. As discussed in 4.1.2 it was assumed that the water levels recorded downstream of the weirs would provide the best estimate of water levels on the flood plain. The results of the calculations are given in Table 4.1 below; 2.1Mm^3 went into storage in the flood plain downstream of Theale gauging station.

This figure excludes any flooding of the Searle's farm gravel pit.The pit is recorded to have been flooded and a comparison of survey data and flood levels confirms that there would have been two flood routes into the pit. The initial and final water level can only be estimated but it is considered that as much as 0.4Mm^3 could have entered the pit. This raises the estimate of total storage downstream of Theale gauging station to 2.5Mm^3.

4.2.2 Tyle Mill to Theale gauging station

The estimate of storage over this section of the Kennet is given in Table 4.1, but once again this does not include any allowance for storage in gravel pits. One of the flow routes observed in 1971 was through the Woolwich Green East Lake and across the road into Theale Lake.

An examination of the Berkshire County Council aerial photos flown in 1971 shows that the portion of the Theale Lake next to the road was being excavated at that time and was protected by a bund from the remainder of the pit which was filled with ground water. Photo No 25 taken during the helicopter reconnaissance of the flood ten hours after the peak suggests that the lake was still well below road level by perhaps several metres, while photo No 21 confirms that the bund protecting the excavations from the rest of the lake was not overtopped.

TABLE 4.1

STORAGE ALONG THE KENNET FOR THE 1971 EVENT.

Kennet Valley Study - Kennet River - 1971 Levels (d/s levels only)

Section Number	Chainage on River (km)	Water Level (m)	X-Sect Area (m^2)	Section Width (m)	Volume of Water (m^3)
1.001	10.800	38.29	447.0	130.0	58100
1.002	10.330	38.47	851.7	250.0	212900
1.003	10.060	38.57	748.5	250.0	187100
1.004	9.750	38.68	497.4	250.0	124400
1.005	9.500	38.73	410.4	250.0	102600
1.006	9.250	38.78	374.0	250.0	93500
1.007	8.900	39.07	538.7	250.0	134700
1.008	8.620	39.69	269.2	250.0	67300
1.009	8.330	40.01	318.5	250.0	79600
1.010	8.050	40.21	207.5	250.0	51900
1.011	7.750	40.42	194.6	250.0	48700
1.012	7.350	40.86	253.5	250.0	63400
1.013	7.070	41.41	381.7	250.0	95400
1.014	6.820	41.62	456.7	250.0	114200
1.015	6.570	41.76	362.6	250.0	90700
1.016	6.300	41.91	308.9	250.0	77200
1.017	6.040	42.05	137.4	250.0	34400
1.018	5.630	42.27	218.7	250.0	54700
1.019	5.390	42.62	58.9	250.0	14700
1.020	5.110	43.03	36.6	250.0	9100
1.021	4.860	43.40	133.5	250.0	33400
1.022	4.590	43.79	118.7	250.0	29700
1.023	4.220	44.26	352.7	250.0	88200
1.024	3.910	44.59	341.0	250.0	85200
1.025	3.650	44.86	305.5	250.0	76400
1.026	3.380	45.15	363.6	250.0	90900
			Sub-total	=	2118400
1.027	3.000	45.55	276.1	250.0	69000
1.028	2.490	46.08	294.6	250.0	73700
1.029	2.190	46.50	728.9	250.0	182200
1.030	1.920	46.89	909.2	250.0	227300
1.031	1.650	47.27	688.2	250.0	172000
1.032	1.330	47.49	508.2	250.0	127100
1.033	0.980	47.70	171.7	250.0	42900
1.034	0.450	48.03	308.8	250.0	77200
1.035	0.110	48.24	138.5	250.0	34600
			Sub-total	=	1006000
			Total Volume	=	3124400

Nevertheless the excavations were probably 4 to 5 metres deep at the time and it is estimated that the area of 20 ha under excavation at the time may have absorbed as much as $0.4Mm^3$.

Allowing also for the flooding over Woolwich Green East and West Lakes, an allowance of $0.5Mm^3$ has been made for flooding of gravel pits, bringing the total volume estimated to have been stored between Tyle Mill and Theale gauging station to $1.5Mm^3$.

4.2.3 Foudry Brook

Although the flooding on the Kennet would have interacted with the flooding on the Foudry Brook, the calculation of storage volumes on the two rivers can be treated separately. The survey cross sections were roughly perpendicular to the Foudry Brook and the same approach as described for the Kennet has been used. There are no recorded flood water levels available for the Foudry and the water surface profile has been deduced from the extent of the flooding.

The volume estimated to have been stored above 1986 topographic conditions is $0.6Mm^3$, the detailed results being given in Table 4.2. A substantial amount of storage has been lost since 1971 due to infilling and this is estimated in section 4.3 to be about $0.5Mm^3$, with the result that the total volume stored in the Foudry Brook flood plain during the 1971 event is estimated to have been $1.1Mm^3$.

TABLE 4.2 STORAGE IN FOUDRY BROOK FLOOD PLAIN IN 1971

(topography as surveyed in February 1986)

Section Number	Chainage on River (km)	Water Level m	X - Sect Area (m^2)	Section Width (m)	Volume of Water m^3
2.001	2.230	38.47	318.5	250.0	79600
2.002	1.960	38.49	198.5	125.0	12800
2.003	1.660	38.52	645.1	250.0	161300
2.004	1.240	38.55	284.8	250.0	71220
2.005	0.890	38.58	377.3	250.0	94300
2.006	0.570	38.60	512.6	250.0	128200
2.007	0.250	38.63	121.2	250.0	30300
2.008	0.010	38.65	9.7	250.0	2400
			Total Volume =		592100 m^3

4.2.4 <u>Summary for the 1971 event</u>

Storage in the flood plain during the June 1971 flood is estimated to have been 5.1Mm^3 distributed as follows:

Kennet d/s of Theale	
- flood plain	2.1
- gravel pits	0.4
Kennet u/s of Theale	
- flood plain	1.0
- gravel pits	0.5
Foudry Brook	1.1
	5.1 Mm^3

4.3 STORAGE FOR OTHER EVENTS

4.3.1 1947 flood

The 1947 event was a more serious event on the Thames although 1971 appears to have been the more severe of the two for the Kennet. Only limited information on levels is available comprising records at Blake's Lock, County Lock and Burghfield Bridge. The level at County Lock was 0.5m higher than for 1971 and that at Burghfield Bridge 0.1m lower. Flooding has been linearly interpolated between these two points and levels upstream of Burghfield Bridge assumed to be 0.1m lower than for the 1971 event.

The results for the Kennet are given in Table 4.3. No gravel pits had been excavated by 1947 and almost no infilling of the Foudry flood plain had taken place. Allowing for these factors, and assuming flooding on the Foudry to have been about 0.2m higher than in 1971, it is estimated that the total storage in the 1947 event was 5.1Mm^3 distributed as follows:

Kennet d/s of Theale	2.5	
Kennet u/s of Theale	0.8	
Foudry	1.8	
	Total	5.1 Mm^3

TABLE 4.3

STORAGE ALONG THE KENNET FOR THE 1947 EVENT.

Kennet Valley Study - Kennet River - 1947 Levels

Section Number	Chainage on River (km)	Water Level (m)	X-Sect Area (m^2)	Section Width (m)	Volume of Water (m^3)
1.001	10.800	38.80	767.8	130.0	99800
1.002	10.330	38.98	1320.9	250.0	330200
1.003	10.060	39.08	1206.4	250.0	301600
1.004	9.750	39.18	960.9	250.0	240200
1.005	9.500	39.23	909.8	250.0	227500
1.006	9.250	39.28	695.0	250.0	173800
1.007	8.900	39.42	794.9	250.0	198700
1.008	8.620	39.67	252.6	250.0	63200
1.009	8.330	39.89	247.7	250.0	61900
1.010	8.050	40.09	160.8	250.0	40200
1.011	7.750	40.30	129.1	250.0	32300
1.012	7.350	40.74	192.9	250.0	48200
1.013	7.070	41.29	308.7	250.0	77200
1.014	6.820	41.50	374.5	250.0	93600
1.015	6.570	41.64	280.6	250.0	70200
1.016	6.300	41.79	215.7	250.0	53900
1.017	6.040	41.93	90.5	250.0	22600
1.018	5.630	42.15	146.1	250.0	36500
1.019	5.390	42.50	44.3	250.0	11100
1.020	5.110	42.91	15.6	250.0	3900
1.021	4.860	43.28	105.0	250.0	26300
1.022	4.590	43.67	73.9	250.0	18500
1.023	4.220	44.14	280.9	250.0	70200
1.024	3.910	44.47	268.3	250.0	67100
1.025	3.650	44.74	242.6	250.0	60600
1.026	3.380	45.03	286.5	250.0	71600
			Sub-total	=	2500900
1.027	3.000	45.43	204.5	250.0	51100
1.028	2.490	45.96	236.2	250.0	59000
1.029	2.190	46.38	644.9	250.0	161200
1.030	1.920	46.77	834.7	250.0	208700
1.031	1.650	47.15	577.3	250.0	144300
1.032	1.330	47.37	403.7	250.0	100900
1.033	0.980	47.58	90.7	250.0	22700
1.034	0.450	47.91	222.5	250.0	55600
1.035	0.110	48.12	87.4	250.0	21800
			Sub-total	=	825300
			Total Volume	=	3326200

The storage in the area downstream of the Basingstoke railway line was $1.2Mm^3$ greater than the 1971 flood, while the storage upstream of this point was $1.2Mm^3$ less than in 1971. The very different distribution of storage between the 1971 and 1947 events may be explained by the storage provided by gravel pits excavated after 1947 and the backwater effect of the Thames which would have raised levels in the Kennet in 1947 relative to those in 1971.

4.3.2 Flood volumes parallel to 1971 surface

The storage characteristics of the valley have been determined by using the computer models to calculate the volumes stored under water profiles parallel to the 1971 event but varied by intervals of ± 0.1m. A summary of the results are presented in Table 4.4 together with a graph of the storage elevation curve.

4.4 CHANGES IN THE FLOOD PLAIN

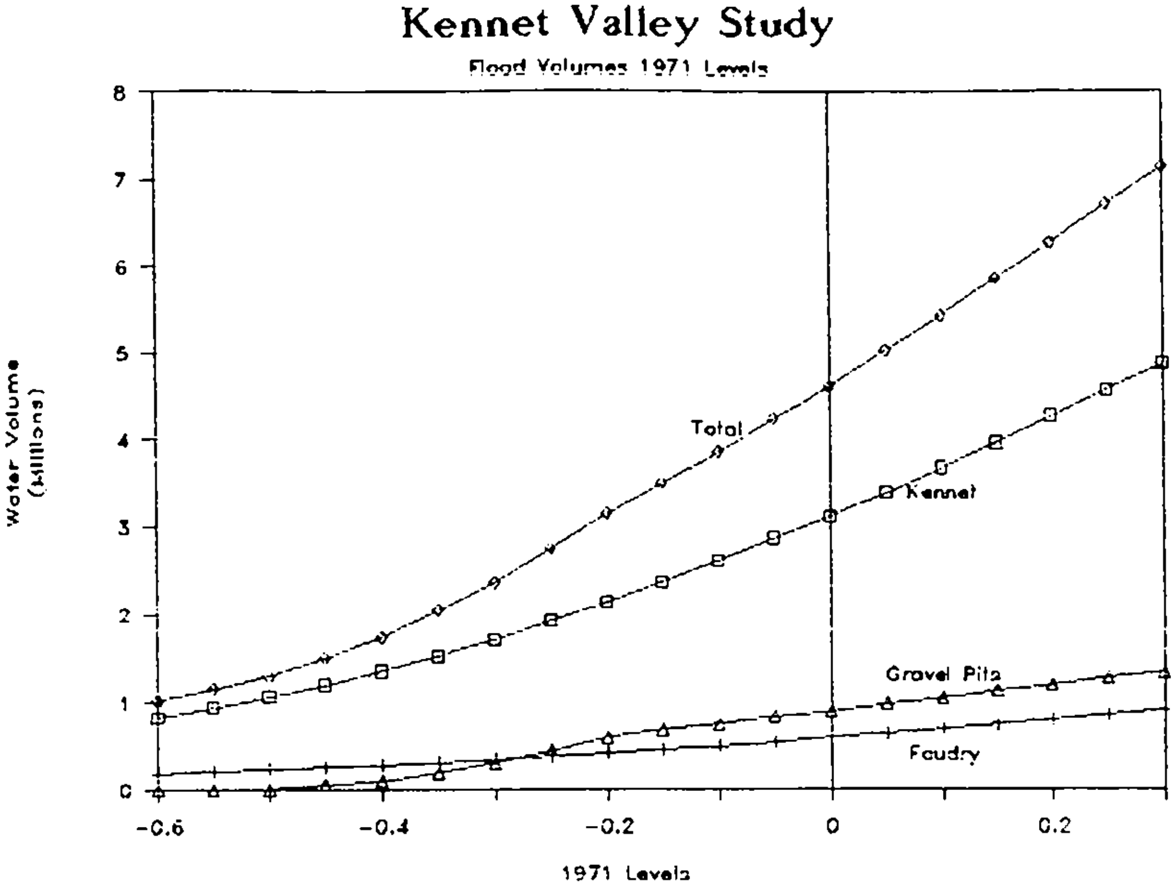
4.4.1 Methodology

The changes in storage capacity within the flood plain in recent years has been studied to provide a perspective of both the global alterations and the rates of change. Changes arising from development or infilling have been treated separately from changes due to gravel excavation which may have the effect of adding to storage capacity.

The largest floods in recent years are those of 1947 and 1971, and the changes in the flood plain have therefore been monitored over the two periods 1947-71 and 1971-86. This has been done using aerial photographs that were flown for Berkshire County Council in 1947, 1971 and 1986.

TABLE 4.4

STORAGE ELEVATION CURVE



Flood Level	Volume Kennet	Volume Foudry	Volume in Gravel Pits	Volume Total
1971 Level-0.60	833300	191700	0	1025000
1971 Level-0.55	942600	211600	0	1154200
1971 Level-0.50	1065900	233200	0	1299100
1971 Level-0.45	1204300	256800	50000	1511100
1971 Level-0.40	1359900	282800	100000	1742700
1971 Level-0.35	1531400	311900	200000	2043300
1971 Level-0.30	1717000	344600	300000	2361600
1971 Level-0.25	1918400	379800	450000	2748200
1971 Level-0.20	2133100	417400	600000	3150500
1971 Level-0.15	2362000	457300	687500	3506800
1971 Level-0.10	2603800	500500	750000	3854300
1971 Level-0.05	2858500	545300	837500	4241300
1971 Level 0.00	3124400	592100	900000	4616500
1971 Level 0.05	3399600	640700	987500	5027800
1971 Level 0.10	3683700	693200	1050000	5426900
1971 Level 0.15	3973600	747900	1137500	5859000
1971 Level 0.20	4268600	803400	1200000	6272000
1971 Level 0.25	4568400	859800	1287500	6715700
1971 Level 0.30	4872200	917100	1350000	7139300

4.4.2 Infilling of the flood plain

The changes identified due to road construction, housing and general development and landfill in the study area are as follows:

Category	1947 - 71	1971 - 86
Roads	M4 (under construction 1971)	Rosekiln Lane
Housing	Southcote	Fords Farm
		Beansheaf Farm
General	Arrowhead Rd industrial	Extension of Arrowhead Rd
Development	area, Theale	New water treatment works
	Sludge beds/Sewage works	Green Lane
		New Courage brewery
Landfill	Confluence Kennet/Foudry	Old Smallmead tip
	Knights Farm, Berry Lane	New Smallmead tip

Not all of the above developments fall within the flood plain, but the areas and volumes that have been lost are set out in Table 4.5.

The table suggests that about $0.5Mm^3$ of storage capacity has been lost through development relative to the 1971 flood levels in each of the periods 1947-71 and 1971-86; 80% of this volume has been within the flood plain of the Foudry Brook.

TABLE 4.5

INFILLING OF THE FLOOD PLAIN

Site	Area (ha)	Storage lost under 1971 flood level (m^3)
	1947 - 71	
Kennet		
M4	12	50 000
Arrowhead Road	7	30 000
Knights Farm/Berry's Lane	12	-
	31	80 000
Foudry		
M4	10	30 000
Sludge beds	20	200 000
Infill Kennet/Foudry	15	150 000
	45	380 000
Total	76	460 000
	1971 - 86	
Kennet		
Green Lane	1.5	1 000
Rosekiln Lane	2	25 000
New water treatment works	5	70 000
	8.5	96 000
Foudry		
Old Smallmead tip	50	250 000
New Smallmead tip	37	170 000
Gravel pit to be filled	27	-
	114	420 000
	122.5	516 000

4.4.2 Gravel pits

Gravel extraction has changed the topography of the flood plain over large stretches of the study area. The pits that have been excavated are:

1947 - 1971	1971 - 86
Woolwich Green West	Completion Theale Lake
Woolwich Green East	Hosehill Farm Lake
Theale Lake (partially excavated 1971)	Completion Wellman's Farm
Wellman's Farm Lake (partially excavated 1971)	Field Farm (current)
Searle's Farm Lake	Smallmead (to be filled)
Pingewood Lake	Cottage Lane (current)

The water levels in the lakes are generally set by natural ground water levels and seepage through the gravels to or from the Kennet, but are also controlled in some cases by culverts and overflow weirs. A number of the lakes were flooded in 1971 and thus provided additional storage capacity. Ground water levels are generally 1 to 1.5m below ground level in this area with the result that at least 1m of additional storage depth should be available. The resultant increase in storage capacity is tabulated in Table 4.6

TABLE 4.6

ADDITIONAL STORAGE CAPACITY FROM GRAVEL PITS

Pit	Area ha	Normal water level 11/2/87 (m)	Est 1971 flood level (m)	Storage Volume (m^3)
Haywards Farm++	7	44.5	46.5	140 000
Woolwich Green East	13	46.11	46.5	50 000
Woolwich Green West	8	46.3*	47.1	60 000
Hosehill Farm++	14	44.92	46.1	160 000
Theale	87	43.2	n.a	
Wellman's Farm++	27	41.76	n.a	
Searle's Farm	39	39.34	40.0	250 000
Farnham Flint	10	39.3*	40.0	70 000
Englefield	15	38.37+	40.0	100 000

* estimate

\+ drawn down by Tarmac for gravel washing water

++ excavated after 1971

The volumes given in the above table are approximate only and will not necessarily reflect additional capacity available during the peak of the flood because seepage from the river through the gravel may have resulted in some filling before the peak.

The additional capacity provided between original ground level and normal lake level is estimated to have been about 0.1Mm^3 during the 1971 event for those lakes upstream of the Theale gauge. As described in 4.2, it is also estimated that as much as 0.4Mm^3 might have entered the newly excavated Theale pit.

Changes in storage downstream of the Theale gauge are limited to the Searles Farm complex of lakes. On the basis that the road round the lake was not flooded, the lake level is estimated not to have exceeded 40.0m and some 0.4Mm^3 are estimated to have flowed into the complex. This does not necessarily represent an increase in storage capacity relative to the situation before the excavation of the lake as the original ground levels are not known.

4.4.3 Net Changes to the flood plan

It is estimated that in 1971 some 0.4 Mm^3 may have been stored in the Searle's Farm pit and some 0.5 Mm^3 in the Theale/Woolwich Green East and West pits. Had those pits been excavated at the time it is probable that more water would have been stored in the flood plain, although substantially less than the 0.9 Mm^3 estimated to have been stored in the pits. The excavations since 1971 (Hosehill Farm, Completion of Theale and Wellmany Farm) would not significantly alter those estimates were a similar event to occur at the present time since the hydraulic connections between the pits are not designed for flood flows and the Theale pit would still fill from overtopping over the Theale-Sheffield Bottom road. The net gain in storage resulting from the excavation of the gravel pits is estimated to be in the range 0.5 - 0.9 Mm^3.

The infilling of the flood plain has resulted in a total loss of about 1 Mm^3 below 1971 flood levels of which about 0.5 Mm^3 has occurred since 1971. The loss in storage volume would be substantially greater for a flood event similar to that of 1947 when water levels were considerably higher in the downstream reach. The majority of this loss in storage volume (80%) has occurred in the Foudry flood plain.

At the time of the 1971 flood it is probable that the loss of storage was approximately counterbalanced by the gain from gravel pits. The gravel pits added since that time have not contributed significantly to the storage volume and the result has been a net loss of storage as infilling has continued. There does remain scope, however, for better utilisation of the storage provided by the Theale/Wellman's Farm pits by designing the hydraulic interconnections for flood flows. It should also be noted that gravel extraction is continuing and further lakes will be created in the reach between Theale and Tyle Mill.

4.5 FLOOD ENVELOPES

4.5.1 Approach

Flood envelopes have been derived for the 1 in 10 year flood, the 1971 flood and the 1 in 100 year flood. The 1971 flood has been used because the extent of the flooding was carefully recorded and it corresponded to about a 1 in 50 year event at Theale and 1 in 35 year event at Reading.

The envelopes have been determined using the storage frequency curves derived in Section 3.6 to estimate the volume going into storage for a particular return period event, and the storage characteristics to set the flood levels required to accommodate that volume of storage.

The volumes going into storage according to the storage frequency curve are:

1 in 10 year	$3.7Mm^3$
1971 flood (1 in 40 year)	$4.9Mm^3$
1 in 100 year	$5.9Mm^3$

4.5.2 Results

Relative to the 1971 flood levels, the 1 in 10 year flood storage gives a level about 0.15 m - 0.2m lower whilst the 1 in 100 year event is about 0.1m - 0.15m higher. The implications of these level differences have been studied on Figures 4.1 to 4.4, on which the survey information is presented at a scale of 1/5000 with contours at 1m intervals. The flood envelopes so determined are shown in colour on Figure 4.5, but due to the topography of the flood plain and the small differences in level between the events the three envelopes lie very close together.

The 1971 flood envelope has been reproduced from the survey of that event, modified to take into account the changes in topography that have taken place, such as those on the Foudry flood plain, the completion of the M4 and expansion of Theale.

The 1 in 100 year envelope is intended to approximate to the outside limit of the flood plain and this has been estimated where the survey had not provided adequate information. Between Theale and Tyle Mill for instance, it has been assumed that the area between the railway and the A4/M4 link road would be flooded, as was apparently the case in 1947 according to maps consulted at Reading Borough Council. It has also been assumed that flood waters could rise sufficiently in Searle's Farm Lake to cross Berry's lane at an elevation of about 40.0m and inundate Kirton's Farm and Pingewood Lakes.

CHAPTER 5

HISTORICAL DEVELOPMENT IN THE STUDY AREA

Discussions were held with Berkshire County Council, Reading Borough Council and Newbury District Council in order to establish:

the history of the submission of relevant planning applications and the response to them

current attitudes to long term planning

published plans

The response by THAMES to planning applications going back into the 1960s has also been reviewed by consulting the correspondence records.

The information obtained is presented in the form of an overall review of published plans for the study area, and a summary of specific proposals relating to gravel extraction, waste tipping, and general development.

5.1 REVIEW OF PLANNING DOCUMENTATION

5.1.1 Planning Authorities

Responsibility for planning within the Study area is divided between three local councils and the County Council. The geographical boundaries between the local councils are indicated on the 1/10 000 scale maps. Broadly speaking Reading Borough Council is responsible for the area east of the Burghfield bridge excluding Searle's Farm lake, and Newbury District Council for the area west of the bridge. Wokingham District Council is responsible for only a very small portion of the study area by the Foudry brook on the M4.

Berkshire County Council has a specific responsibility for mineral extraction, waste disposal and highways. The County Council is nevertheless bound to seek the views of the local authorities on these matters.

5.1.2 Berkshire County Council

Proposals concerning the study area have been reviewed in the following documents:

Central Berkshire Structure Plan	- September, 1980
Review of Berkshire's Structure Plans	- Submission Document
	- January, 1986
Berkshire Minerals Local Plan	- September, 1984
Countryside Recreation Local Plan	- February, 1985

The proposals that directly affect the study area are as follows:

Industrial Development

Theale (20 ha). An area to the south of Theale-by-Pass between the existing industrial area and the M4 Motorway is proposed for industrial development.

South Reading (80 ha). An area to the South of Reading, north of the M4 and west of the A33 is proposed for industrial development. The Structure Plan states that 'because of the complexity of the issues in this area, the number of agencies and local authorities involved and the County Council's specific responsibility for highways and minerals, the County Council proposes to prepare, in conjunction with the relevant District Councils, strategic guidance for the general development of the area, indicating how the various issues may be resolved'.

A major flood relief channel, together with improvements to the Foudry Brook, are identified as being necessary for this development to proceed.

Road Improvements

Proposed road improvements include:

M4 Junction 11	- Improvements to deal with the present problem.
Access onto Theale-by-Pass	- The proposed new industrial development south of Theale will necessitate a new two way access onto Theale-by-Pass.
Link Road - A33	- Relief Road to Burghfield Road - A link road to improve accessibility to the Burghfield Area and the Southcote and Tilehurst Areas.

The area between Junctions 11 and 12 is also within the area of search for a new motorway service station.

The County Council expresses the view that there should be no further major housing development south of Reading and that the motorway should be regarded as the limit of the built up area of Reading.

Minerals Plan

The fundamental policy regarding mineral extraction is that the County Council will seek to avoid the sterilisation of sand and gravel deposits. The study area forms one of the prospect areas within the plan. Approximately 620 ha have received planning permission for extraction in the Lower Kennet Valley, of which about 110 ha remain to be worked. Gravel extraction is discussed in more detail in Section 5.3.

Waste Tipping

It is mentioned in the Minerals Plan that a waste disposal plan is to be prepared by the County Council but that it will not be available for sometime.

The majority of the land to be reinstated after gravel extraction will be filled with inert material, with in some cases a small proportion of industrial waste. Any areas to be filled with household waste would normally first be sealed with a clay lining. Only inert material is generally allowed to be tipped within the flood plain.

Recreation Plan

The Plan lists three areas of ecological importance which might impose constraints upon any proposed development, namely Manor Farm Sewage Farm, Searle's Farm (the north western portion of the lake) and Woolwich Green Lake, south of Theale.

They have been identified by the Nature Conservancy Council as being of particular value for nature conservation.

5.1.3 Reading Borough Council

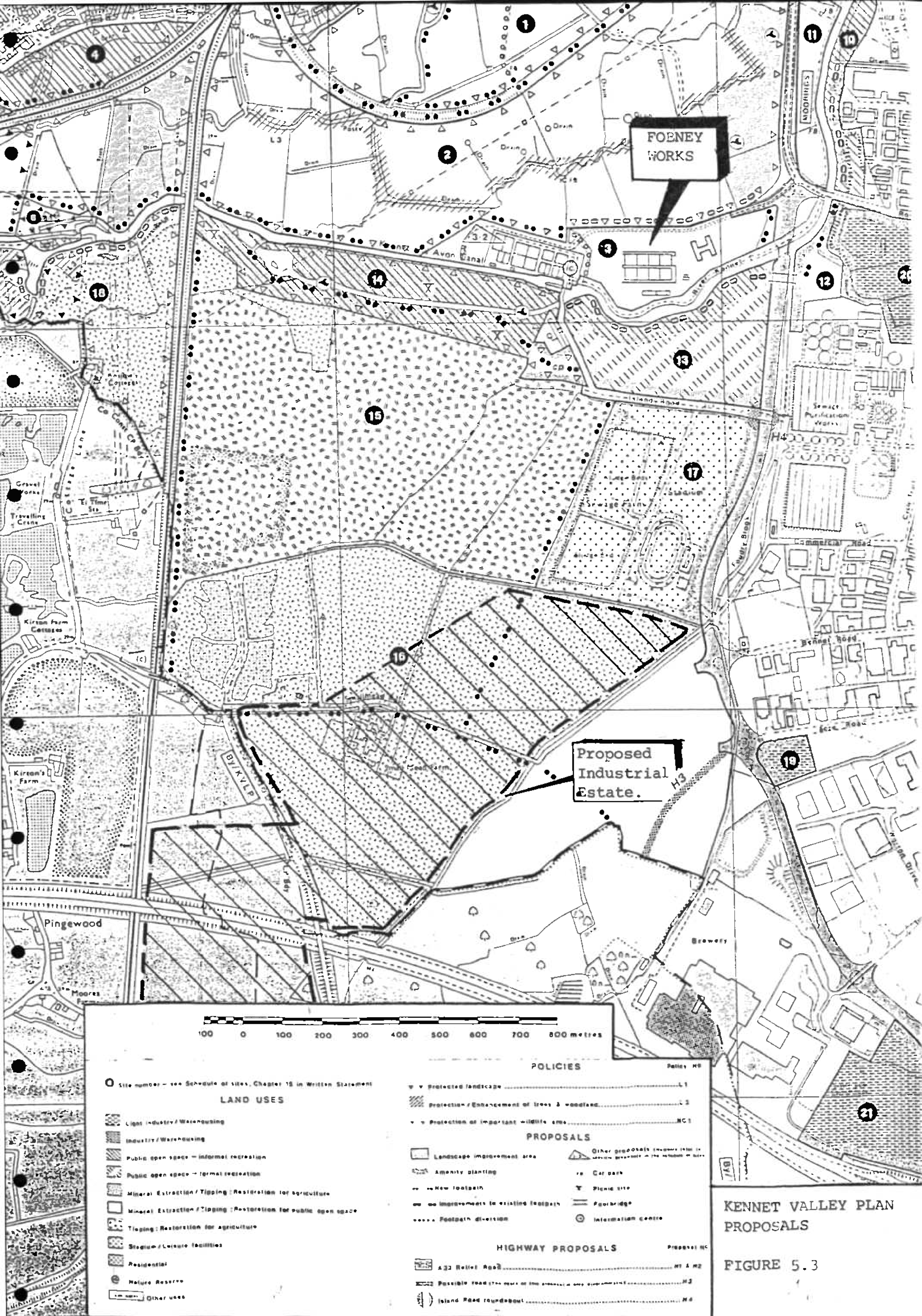
The council has published two documents which relate to the area:

Reading Waterways	- A Plan for the River Landscape
	- Approved January, 1979
Kennet Valley Local Plan	- Deposit Copy - August, 1985

The proposals put forward for the area by the Kennet Valley Local Plan are presented on Figure 5.3. The area covered by a planning application for industrial development that is presently under consideration is also shown.This corresponds broadly to the industrial development for South Reading proposed in the Structure Plan.

5.1.4 Newbury District Council

The Lower Kennet Water Park draft study report published in 1977 put forward policies and proposals for encouraging the optimum use of the opportunities in the Lower Kennet Valley for the development of recreational facilities, nature conservation and education, and landscape rehabilitation.



KENNET VALLEY PLAN PROPOSALS

FIGURE 5.3

The study examined 540 ha that had received planning permission for gravel extraction and identified nine lakes which had physical characteristics suitable for sailing. A presumption against activities which generate noise or attract large crowds was proposed for the areas at Pingewood, Kirton's Farm, Hosehill and Theale (western part), whereas it was considered they could be encouraged at Theale (east), Wellman's Farm and Knights Farm.

The Newbury District Local Plan which is currently being prepared will include the Study Area, and it is understood that it will reflect the policies expressed in the Lower Kennet Water Park draft.

5.2 GRAVEL EXTRACTION

5.2.1 General

The extraction of gravels in the Lower Kennet Valley has dramatically changed the landscape within the flood plain over the course of the last forty years. Of the 620 ha for which permission for extraction has been granted, some 250 ha have been restored to Lakes.

In those areas restored to agricultural land, the replacement of gravels with inert material creates drainage problems which make it impossible to restore the land to the original levels. It has either to be domed and taken out of the flood plain, or a ridge and furrow system is used which restores it more closely (but not completely) to the original ground level.

Figure 5.1 shows those areas of land for which planning permission for gravel extraction has been granted, is currently under consideration, has been refused, or could be applied for in the future. This covers virtually the entire flood plain. Extraction has been carried out principally by three companies, namely ARC, Tarmac and Hall Aggregates/RMC, each operating in geographically distinct portions of the study area. A brief history of the workings will be given before reviewing possible future developments.

5.2.2 Historical background

ARC

The ARC plant is located at Sheffield Bottom just south of Theale. The original permission dates from 1949, and the complex now totals over 260 ha, the most recent addition being the Field Farm area (50.7 ha). The areas dug to date have been restored to lakes, namely Haywards Farm, Woolwich Green East, Woolwich Green West, Hosehill Farm (Hall Aggregates), Theale, Theale East and Wellman's Farm. Culverts have been constructed so that the Woolwich Green and Hosehill Farm Lakes drain into the Theale Lake.

The area currently being worked is the Field Farm site only a portion of which is within the flood plain. Once this is completed the Wellman's Farm lake will be extended, the whole operation being due to last some six years. Permission has also been granted for extraction in the area south of Hayward's Farm lake on the north bank of the Kennet as far as Tyle Mill, and this is due to be restored to lakes.

Tarmac

Tarmac have their plant on the Pingewood road near Knight's Farm. The Searle's Farm complex of lakes were excavated by a number of companies in the 1960s with only one small area just downstream of Burghfield Bridge at Green Lane being refilled and restored to the original levels.

Tarmac are currently working the Cottage Lane site between the Kennet and the electricity substation. This is due to be returned to agricultural land using the ridge and furrow method, the original proposal to dome part of the area and restore the rest to a lake having been rejected.

Tarmac have recently lodged an application to extract gravels from the Holy Brook Farm/Coley Meadows between the Kennet and Holy Brook. They propose to restore the area downstream of the Burghfield Bridge controlled by Reading Borough Council to agricultural land, doming the land for drainage and providing a low lying area close to the river for flood routing. The area upstream of the bridge controlled by Newbury District Council would be returned to lakes. The proposals are illustrated on Figure 5.4.

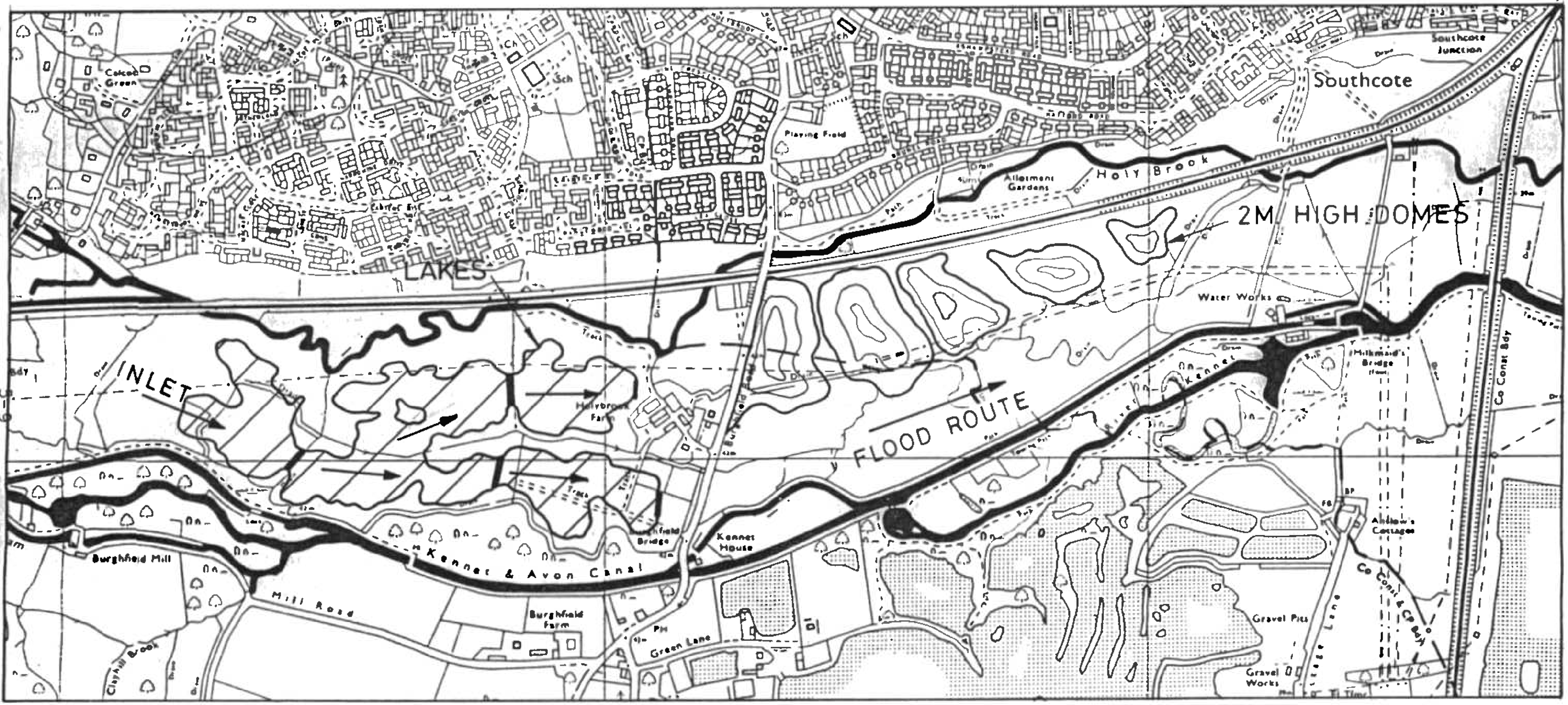
RMC/Hall Aggregates

The Hall Aggregate plant is situated in Cottage Lane as it served part of the Searle's Farm complex. Gravels are currently still being extracted from the Smallmead site on the other side of the railway embankment.

An application by Hoveringham to extract gravels from the Fobney Meadows north of the water works was refused at an appeal in 1971. The restoration proposed was to lakes.

5.2.3 Future developments

Substantial areas of gravels still exist which could be developed but for which applications have yet to be made. These are shown on Figure 5.1. and are in addition to those areas such as Coley Meadows for which applications are presently under consideration. However, whilst in the past the excavations have almost all been restored to lakes, recent applications such as Cottage Lane and Coley Meadows have proposed restoration to agricultural land. This is due to the large area of existing lakes and resistance on planning grounds to creating more. Such proposals require careful evaluation as to their impact upon floods.



TARMAC PROPOSALS FOR HOLY BROOK AND COLEY MEADOWS

Figure 5.4

5.3 WASTE DISPOSAL AND LANDFILL

The excavations created by the gravel workings have in some cases been used as landfill sites. Whilst in principle only inert material is allowed to be tipped in the flood plain, domestic waste tips have been allowed in the area between the Kennet and the Foudry Brook which was flooded in 1971. Domestic waste tips are domed to allow for drainage and prevent groundwater pollution and the ground is therefore effectively removed from the flood plain. The Smallmead tip for example, stands 4m above original ground level.

Figure 5.2 details those areas that have been filled in the past, differentiating between restoration to original ground levels or above; future planned infilling is also shown.

5.4 RESIDENTIAL AND INDUSTRIAL DEVELOPMENT

Details of a number of past and present proposals for development within the study area have been collected and are summarised below.

5.4.1 Past development

Southcote

An application for residential development at Southcote Junction just north of where the Holy Brook passes under the railway embankment was refused on grounds of flooding.

Fords Farm and Beansheaf Farm

Whilst the Fords Farm and Beansheaf Farm developments have not encroached upon the area flooded in 1971, changes to the flood plain were made for drainage purposes.

5.4.2 Future development

Axiom 4

The Axiom 4 scheme, also known as Reading Business Park, is the 80 ha industrial development in South Reading referred to in Section 5.2.1. It has been approved by Berkshire County Council and Wokingham District Council and now only needs the backing of Reading Borough Council to proceed. The scheme, which is illustrated on Figure 5.5 would extend existing development west of the Basingstoke Road from the Foudry Brook to the railway embankment, and would occupy land flooded in 1971.

A flood relief channel has been proposed to discharge flood waters that would otherwise have been stored on the land to be developed. The channel begins at a control structure on the Foudry Brook just north of the M4 and runs almost parallel to the Brook about 300m to the west discharging into the Kennet opposite the new Water Treatment Works. In addition to the channel, 16 ha of land at or below existing ground level is to be provided to retain some flood storage capacity and the two developers participating in the scheme plan to provide 50% each of this capacity. One area of land is to be provided south of Smallmead Farm and the other on the filled gravel pit immediately south of the M4 west of Berry's Lane, this latter area being connected to the Foudry Brook via a culvert.

Theale

20 ha of industrial development at Theale is envisaged in the Berkshire Structure Plan to the south of the Theale-by-Pass between the existing industrial area and the M4. This land was flooded in 1971. A planning application has been submitted, but objections to the road scheme will have to be overcome before it is granted.

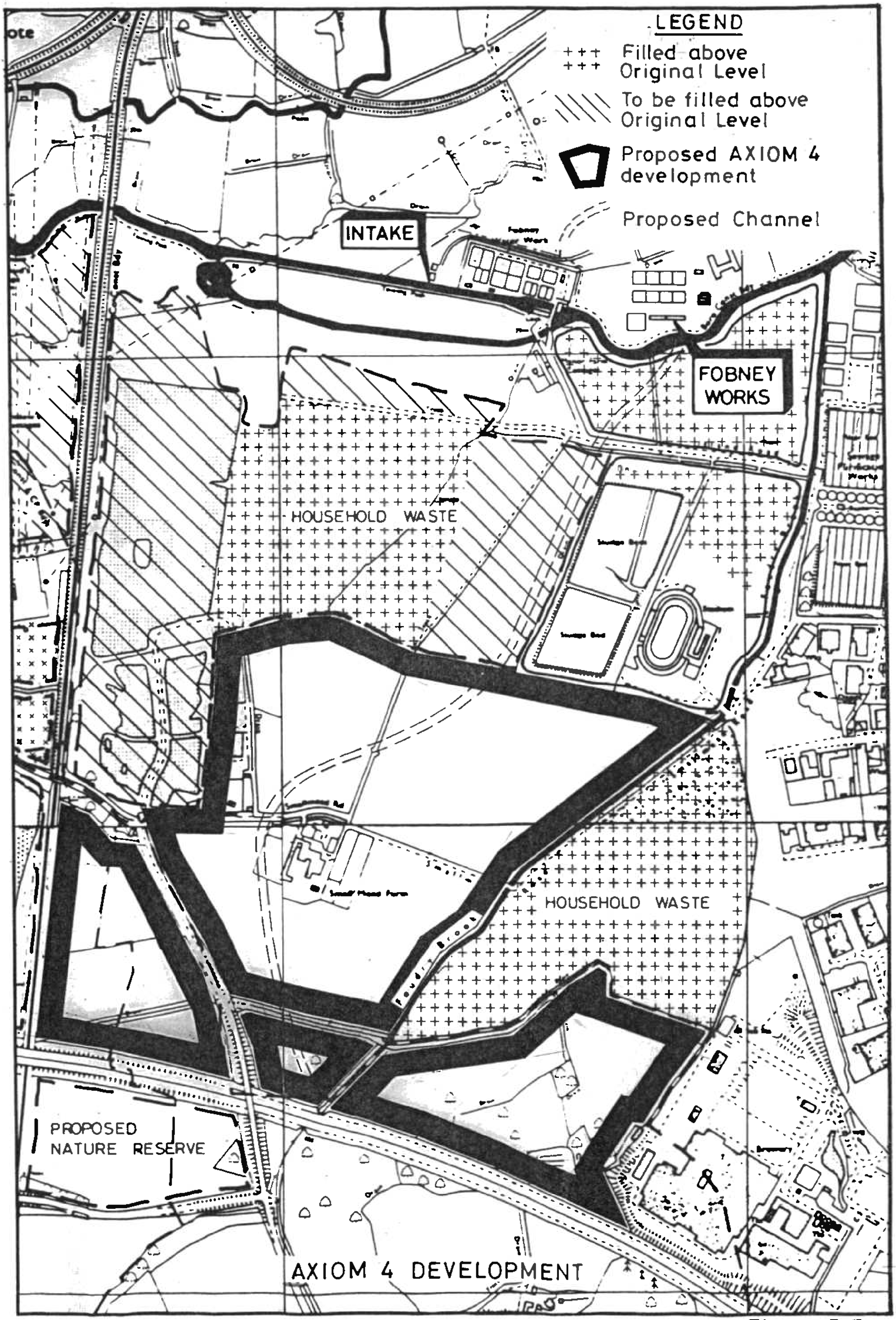

LEGEND
Filled above Original Level
To be filled above Original Level
Proposed AXIOM 4 development
Proposed Channel
INTAKE
FOBNEY WORKS
HOUSEHOLD WASTE
HOUSEHOLD WASTE
PROPOSED NATURE RESERVE
AXIOM 4 DEVELOPMENT

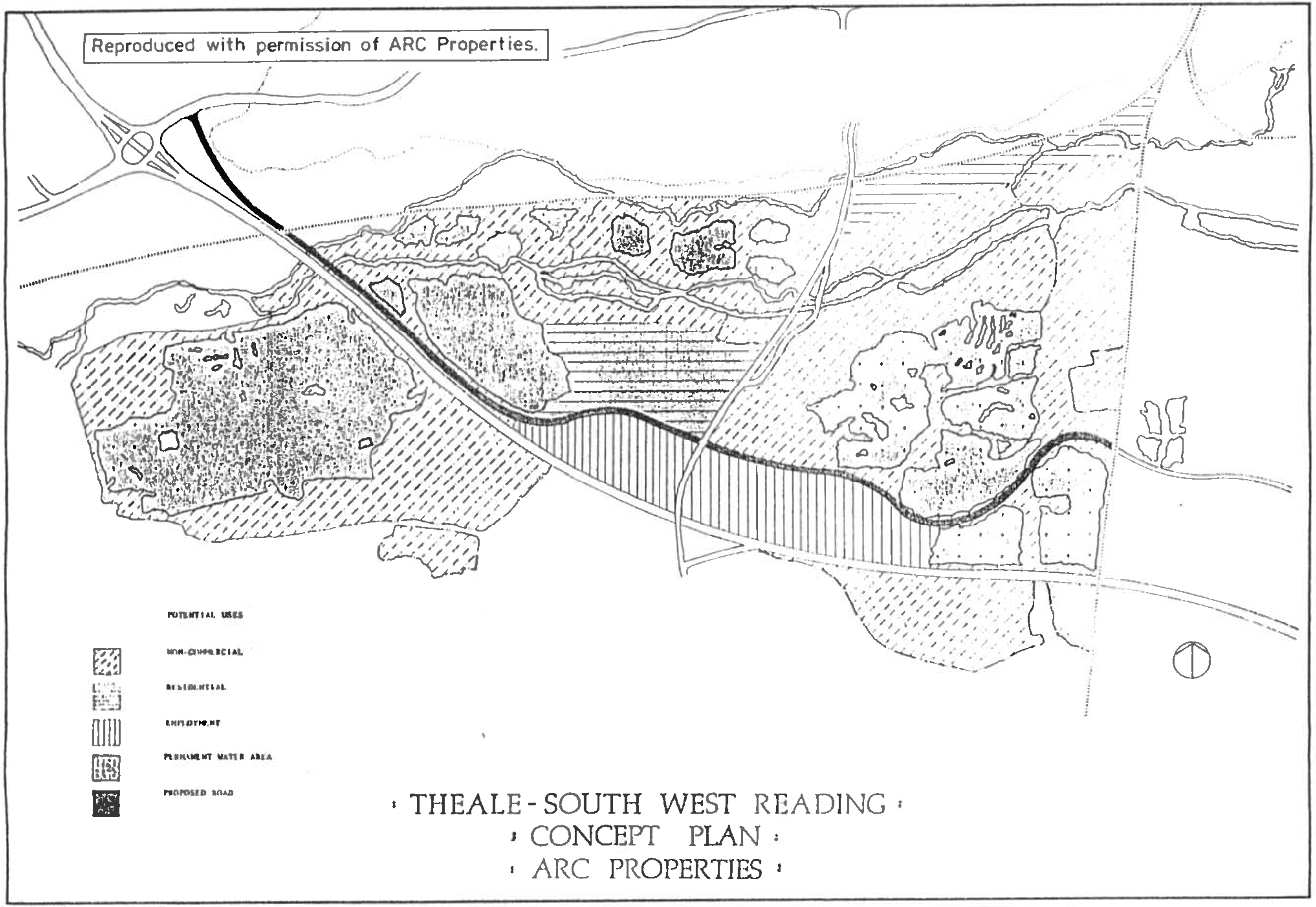
Figure 5.5

Speyhawk

The area south of the motorway by the Foudry Brook at Great Lea has been the subject of an application for residential development by Speyhawk. This has been refused and is due to go to appeal.

ARC Long Term Proposals

ARC made public in January 1987 outline proposals for long term development in the study area on land owned by the gravel companies. These are reproduced in Figure 5.6. Their only proposals directly affecting the flood plain is some residential development in the Fobney Meadows south of the railway embankment. This is where Tarmac propose to dome the area for which they have submitted a gravel extraction application in Southcote Meadows.



LONG TERM PROPOSALS FOR STUDY AREA

Published by ARC in Jan 1987

FIG. 5.6

CHAPTER 6

FUTURE POLICY TOWARDS DEVELOPMENT

6.1 INTRODUCTION

6.1.1 Objectives

The objective of this chapter is to consider future policy with regard to the management of the flood plain in the light of known and anticipated development particularly gravel extraction and reinstatement proposals.

General principles of flood plain management are discussed, the effect of both localised and global changes in flood storage reviewed, and the implications for future policy evaluated.

6.1.2 Summary of hydrology

The hydrological analysis has assessed the June 1971 flood to have been a 50 year event on the Kennet at Theale but more like a 35 year event in terms of flow at County Weir and flood plain inundation; this follows from statistical analysis of annual maximum recorded flows and an analysis of rainfall records with a unit hydrograph approach. The inflow hydrograph for this event provided the input to a flood routing model, and this shows that significant attenuation was provided by the Kennet flood plain below Tyle Mill, reducing the flood peak by about 29 per cent at the lower end of the flood plain where the Kennet passes through Reading.

6.1.3 Flood envelopes

The availability of reasonably complete water level profiles for the June 1971 event not only provides a means of testing the flood routing model between Theale and Reading, but also gives an envelope which can be related to the return period of the inflow peak. This in turn has enabled level envelopes to be drawn for floods of other return periods as described in Chapter 4. It should be borne in mind that the profile of the flood envelope, especially where it approaches the Reading outfall, will be affected to some extent by the downstream control and possibly the shape of the flood hydrograph at Theale. Because the June 1971 event was a summer event of relatively short duration, it was not unduly influenced by downstream conditions.

However, by providing a consistent set of hydrographs for different return periods, and subsequent routing to give volumes of flood plain storage, a set of coherent flood envelopes for different return periods has been provided. This set of flood level envelopes provides the basic tool for objective flood plain management.

6.1.4 Flood plain storage

The hydrological flood routing, calibrated on the volume estimated to have been stored in the 1971 event, has enabled the volumes stored in the valley for different return periods to be estimated:

Return Period	Volume
2.33 year	2.0 Mm^3
10 year	3.7 Mm^3
25 year	4.5 Mm^3
50 year	5.2 Mm^3
100 year	5.9 Mm^3

The above quantities of storage are large and have a significant attenuating effect on flood flows, and thus on levels at the lower end of the study reach. Whilst limited flooding will occur on an annual basis, a large area of the flood plain will be inundated at irregular intervals, without any realistic possibility of total prevention short of major channel reconstruction.

6.2 PRINCIPLES OF FLOOD PLAIN MANAGEMENT

6.2.1 Objectives

The objectives of management of development in the flood plain should be to relate the location, nature and level of any development to the risk of flooding as expressed by the return period, but should also be based on the need to maintain flood plain storage as a protection to existing urban areas.

Because complete inundation is not an annual event, it is inevitable that perception of flooding risk is dependent on long-term records and hydrological analysis. In these circumstances, pressure for the development of the flood plain will continue to be strong, especially because of the proximity of the area to Reading.

It is necessary to bear in mind that, for example, a 50 year recurrence interval gives no assurance about the timing of the next major event. The risk of a T year event occurring within the next L years (say the life of a project) is:

$$1 - (1 - {}^{1}/_{T})^{L}$$

so that the risk of a 50 year return period flood occurring within the next 5 years is

$$1 - (0.98)^{5} = 0.10 \text{ or } 10 \text{ per cent}$$

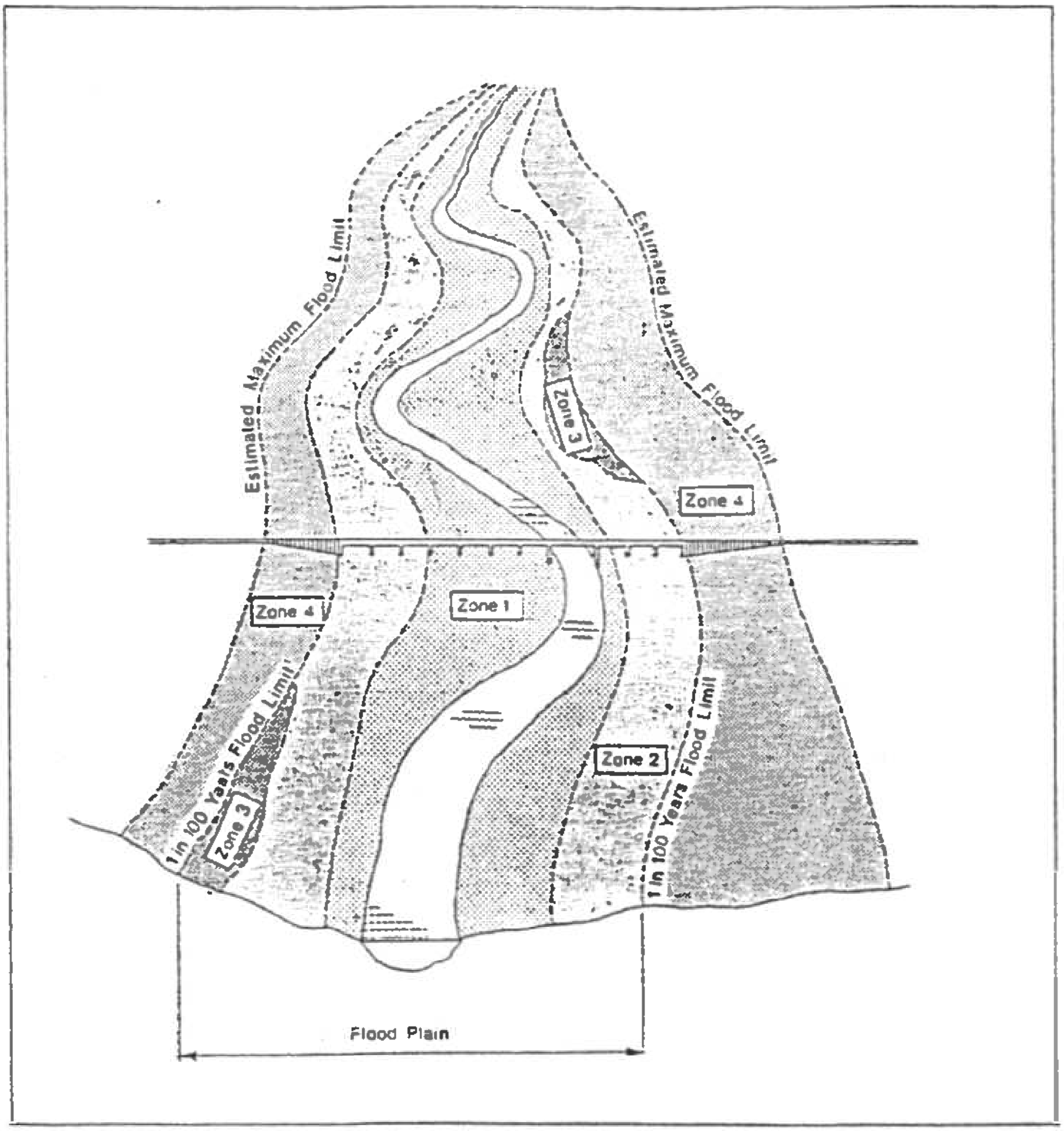
6.2.2 Flood plain zoning

It is recommended that the development of the flood plain should be linked to the risk of flooding as embodied by the envelopes for the 10, 35 and 100 year return period floods. An approach which has been advocated (Aberdein et al. 1981) is to classify zones in terms of return period and to limit development within these zones accordingly.

This zoning is illustrated by Figure 6.1, where Zones 1-3 lie within the limit of the 100 year flood, with Zone 1 nearest the river. Zone 1 is not defined precisely in terms of return period but is closest to the watercourse and thus flooded most frequently; it not only acts as a storage area for flood waters but flow velocities may be high. No new buildings should be permitted and essential developments like motorways should have adequate openings. Near urban areas, this zone is particularly important for recreation and can be used to provide boating pools, parks and playing fields. The outer bounds of this zone are generally determined jointly by planning and water authorities but in this case it will be seen later that Zones 1 and 2 are virtually coincident.

Zone 2 which lies within the 100 year period flood envelope, provides essential storage for flood waters and any change in the available storage in this zone will affect flood levels to a greater or lesser extent. Certain developments could be permitted provided there is no reduction in flood plain capacity and no risk to life. Such developments could include ground level car parks and office blocks with the first floor raised above flood level with effective flood warning and evacuation procedures. However, developments should show positive benefits by comparison with developments in other areas not subject to flooding.

It may be possible to create a Zone 3 within the 100 year flood envelope, where development could be permitted if ground levels could be raised above the 100 year level or protected to this level with negligible effect on water levels, or with compensatory channel works to ensure that existing flood levels are not increased.



FLOOD PLAIN ZONES

FIG. 6·1

6.2.3 Application to study area

These principles have to be interpreted and put into the context of local conditions. Although the ultimate decisions on development must rest with the planning authorities and the water authority, this report provides the technical information on which these decisions may be based.

The risk of inundation at any site on the flood plain is indicated by the flood envelopes related to return period, and decisions on development must be related to this risk. It should be remembered that downstream control may affect the levels at the lower end of the reach, especially if floods coincide on the Kennet and the Thames. The reliability of the results may be affected by the lack of complete records. The relative rarity of complete inundation of the flood plain can affect local perception of the flooding risk, but the analysis presented in this report should assist in an objective assessment of the risk.

On the other hand, different types of development would have different effects on the risk of flooding in other parts of the flood plain. Gravel extraction where the area is left unfilled and becomes a lake whose normal water level is controlled by groundwater level, will increase the volume available for storage and attenuation. The increased storage is somewhat lower than the volume of gravel extracted, as the gravel itself would have had a coefficient of storage of say 20%. This fraction of the volume would have been available to accept water during floods. The overlying soils would probably have had a lower coefficient of storage. At the same time, opportunities for some controlled flood alleviation through storage may be presented. On the other hand, replacement by impermeable material or restoration to agriculture by doming will decrease the storage available, and it is important to preserve the attenuating effect of this storage.

6.3 CHANGES IN FLOOD PLAIN STORAGE

6.3.1 General

The objective of the present section is to evaluate the importance of both global and localised changes in flood storage.

Significant changes to the flood plain have taken place since the 1940's both in terms of gravel extraction and general infilling. It has been estimated in Chapter 4 that during the 1971 event up to 0.5Mm^3 may have been stored in the Theale gravel lakes and 0.4Mm^3 in the Searle's Farm Lake. The creation of these lakes has added to the storage available in the valley but infilling in the downstream portion of the study area has exceeded the volume gained. The vast majority of the volume lost has been within the Foudry flood plain, and this is discussed separately below.

6.3.2 Foudry flood plain

The levels of the Foudry flood plain are below historical flood levels close to the confluence with the Kennet even for a short distance upstream of the M4. The Foudry flood plain therefore acts as a part of the overall Kennet flood plain and the two have been considered as a single entity for the purpose of this present study.

It is estimated that about 1.8Mm^3 were stored in the Foudry flood plain during the 1947 flood, and that this represented 35% of the total storage volume attenuating flooding. Since that time some 1.1Mm^3 of storage are estimated to have been lost below the 1947 flood levels. This large reduction in storage is likely to have an impact on water levels in the Foudry area and downstream. This could result in water levels up to 0.1-0.3m above the 1947 levels in order to discharge the same flood.

The proposed Reading Business Park would further significantly reduce the storage in the flood plain by developing the land at Smallmead Farm on the left bank of the Foudry, and result in increased flows through Reading. It would also further constrain the flood channel of the Foudry and result in increased flooding due to obstruction of the flow route down the Foudry itself. This latter problem has been addressed by proposing the provision of a duplicate flood channel so as to more than double the capacity of the existing Foudry Brook system. This would not, however, overcome the problem of the reduction in storage to the Kennet system as a whole which would result in higher levels downstream.

It is important to emphasis that flood levels on the Foudry flood plain will be influenced by the Thames and cannot be predicted from the return period of a flood on the Kennet alone. Thus the 1971 event, which apparently had a higher return period on the Kennet than the 1947 event, resulted in significantly lower levels on the Foudry Brook flood plain due to the influence of the Thames on the 1947 event.

6.3.3 Localised changes

The problem faced by THAMES on a day-to-day basis is the evaluation of the effect of specific proposals on flooding. Such proposals are judged against the following two criteria: -

- there should be no reduction of storage on a level for level basis
- there should be no obstruction to flow routes

No reduction of storage on a level for level basis means that it is unacceptable to reduce storage at a higher level by providing an equal or greater amount at a lower level. This criterion is considered below using the example of the Tarmac proposals for doming in the Coley Meadows.

The difficulty in analysing changes in water depth arising from a localised change in storage is due to the fact that flood water does not flow unimpeded across the flood plain but is partly in storage. It is helpful to view the problem from two extremes, namely that on the one hand the flood water is absorbed totally into dead storage and that on the other it flows unimpeded across the flood plain. These two cases are examined below.

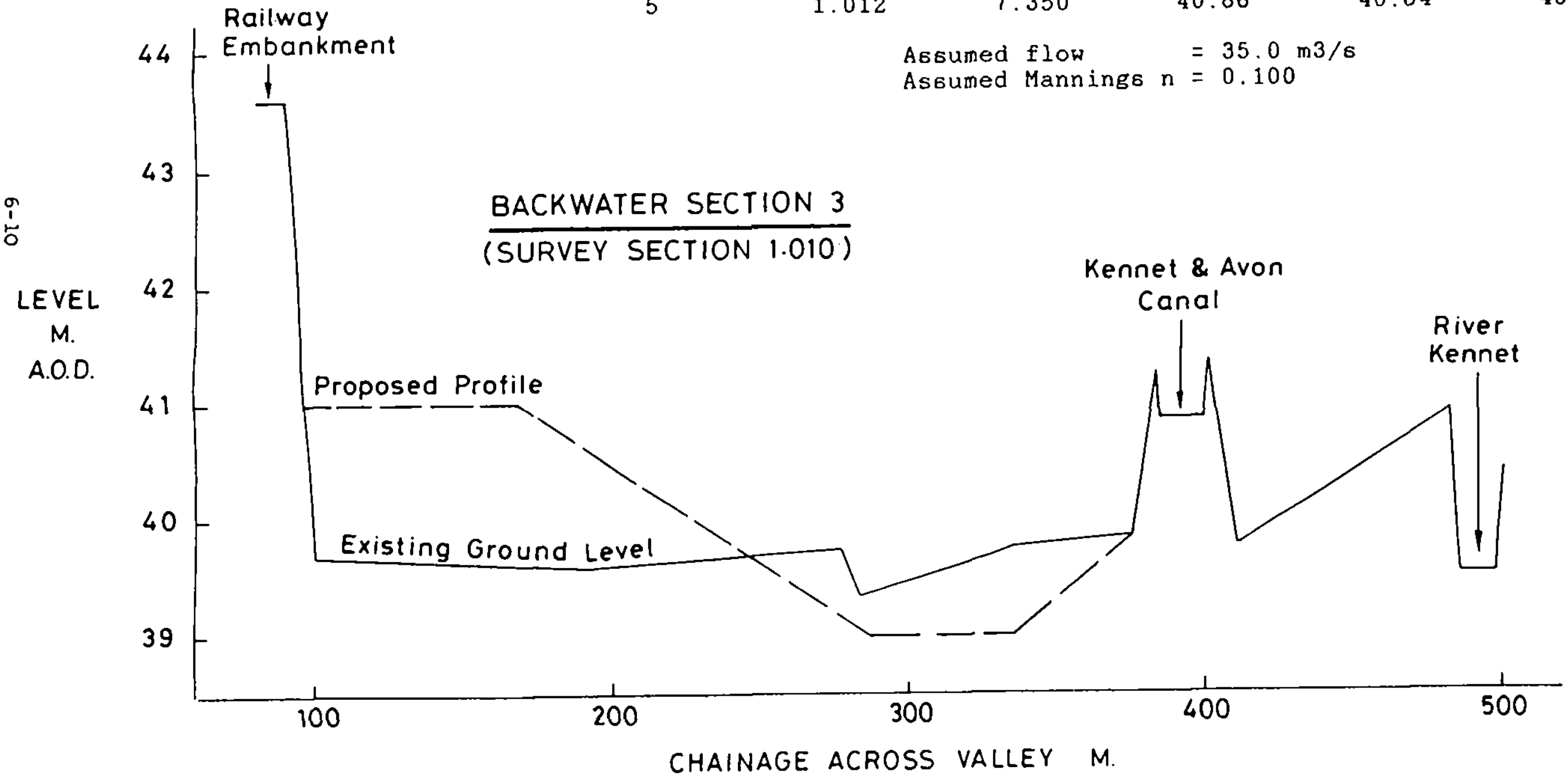
If the flood water is stored in dead storage, then reducing the storage available at a high level and increasing it at a low level will cause a larger proportion of the available storage to be filled earlier in the flood. It is therefore possible that less storage would be available to attenuate the peak of the flood than would have been the case previously and that as a result flood levels would be higher. This argues in favour of preserving storage on a level for level basis.

If the flood water flows unimpeded across the flood plain, then the impact of changes on the hydraulic section can be determined from backwater analysis. The reach between the Burghfield Road and the Basingstoke railway has been modelled using a backwater analysis programme to determine water levels before and after a development similar to the Tarmac scheme. The proposed scheme would dome the area after excavation of the gravels leaving a flood route close to the river. The post-development cross section has been modelled assuming that the volume lost would be compensated by excavation close to the river. There would therefore be no net change in storage in the profile of the valley cross section.

The results of the analysis are given in Figure 6.2. A good correlation with the 1971 flood levels was obtained assuming flood plain flow to be $35m^3/s$. Almost no change in water level resulted from altering the cross section to increase storage at a lower level and reduce it at a higher level.

Backwater Section Number	Survey Section Number	Chainage from Tyle Mill	Assumed Water Level (1971)	Backwater Analysis: Existing Sections	Backwater Analysis: Proposed Sections
1	1.008	8.620	39.69	39.69	39.69
2	1.009	8.330	40.01	39.97	39.97
3	1.010	8.050	40.21	40.22	40.19
4	1.011	7.750	40.42	40.51	40.53
5	1.012	7.350	40.86	40.84	40.78

Assumed flow = 35.0 m3/s
Assumed Mannings n = 0.100



CROSS SECTIONS AND RESULTS OF BACKWATER ANALYSIS

Figure 6.2

Whilst at one extreme when flows across the flood plain are unimpeded, transposing storage from high to lower levels would not seem to significantly alter water levels for the example examined, at the other extreme when flood water enters directly into storage, water levels could rise. The Kennet flood plain has considerable obstructions to flood flows and the storage element is important. The requirement for there to be no reduction in storage on a level for level basis is therefore prudent and guards against the possibility of a cumulative loss of storage arising from a number of localised changes, the impact of which might be difficult to assess individually.

6.4 FUTURE POLICY

6.4.1 Implications of flood envelopes

The combination of the hydrological analysis, which related flood plain storage to return period, and the field survey, which relates storage volume to level and location, has enabled flood envelopes to be drawn for different return periods.

This analysis shows that the areal extent of flooding does not vary greatly within the range of return period from 10 to 100 years. The main difference between these limits and the known flood limit of June 1971 is in depth; the 10 year flood is on average about 15-20 cm below the 1971 flood and the 100 year flood is about 10-15 cm higher.

The finding that the areal extent of flooding is not very variable within the range studied is not unreasonable in view of the fact that the limits of the Kennet flood plain are fairly well defined topographically. On the other hand the maximum elevation appears to be relatively insensitive to return period and at the lower end of the reach near Reading the effects of downstream levels and control are likely to be dominant.

Thus when fixing zones for control of development the precise boundary in terms of return period between Zone 1 where no development should be allowed, and Zone 2, where some may be allowed under certain conditions, becomes academic as the two zones coalesce. In effect the outline of the 1971 flood determines the area within which housing or office development should not be permitted.

6.4.2 Reductions in storage

The attenuating effect of storage on downstream flows is important, being estimated as a reduction of 29% in 1971, and priority should be given to maintaining storage.

Whereas gravel extraction without reinstatement has increased the storage available in the reach near Theale, the flood plain near the Foudry Brook has been encroached upon steadily and cumulatively. In effect a Zone 3 has been created where development has been based on raising land above the level of flooding, but compensatory measures have not been taken to counteract the effect on levels downstream.

Current proposals for the Axiom 4 scheme would virtually complete the infilling of the Foudry flood plain, which has to be regarded as an integral part of the Kennet flood plain. It is considered that the proposed new flood channel would only help to overcome the rise in flood levels that will result from this development.

Current developments within the Foudry flood plain would appear to be contrary to policy FC1 expressed in the Kennet Valley Plan developed by Reading Borough Council. This states that no development which would reduce the capacity of the flood plain to store water would be permitted unless satisfactory compensatory storage measures are provided.

CHAPTER 7

FLOOD ALLEVIATION

7.1 GENERAL

The study of flood alleviation measures on the Kennet and the Foudry Brook does not form part of the Terms of Reference for the present study, but certain opportunities for providing flood protection have been identified and are described in this chapter.

Reduction in flooding may be achieved either by improving the carrying capacity of the river channel, by excavating new channels or by storing some of the flood upstream of the area requiring protection. It is the latter method that could be readily implemented on the Kennet as a result of gravel extraction activities at the upstream end of the study area. These have lead to the formation of a number of artifical lakes close to the river.

7.2. GRAVEL PITS

The gravel pits that could be used for flood storage and their areas are as follows:

Haywards Farm Lake	7 ha
Woolwich Green East Lake	13 ha
Woolwich Green West Lake	8 ha
Hosehill Farm Lake	14 ha
Theale Lake	87 ha
Wellman's Farm Lake	27 ha
Searle's Farm Lake	39 ha

Searle's Farm Lake provided flood storage during the 1971 event, now estimated to have been about $0.4Mm^3$. Water was also stored in the partially excavated Theale pit during this event, flowing over Woolwich Green East Lake into the pit.

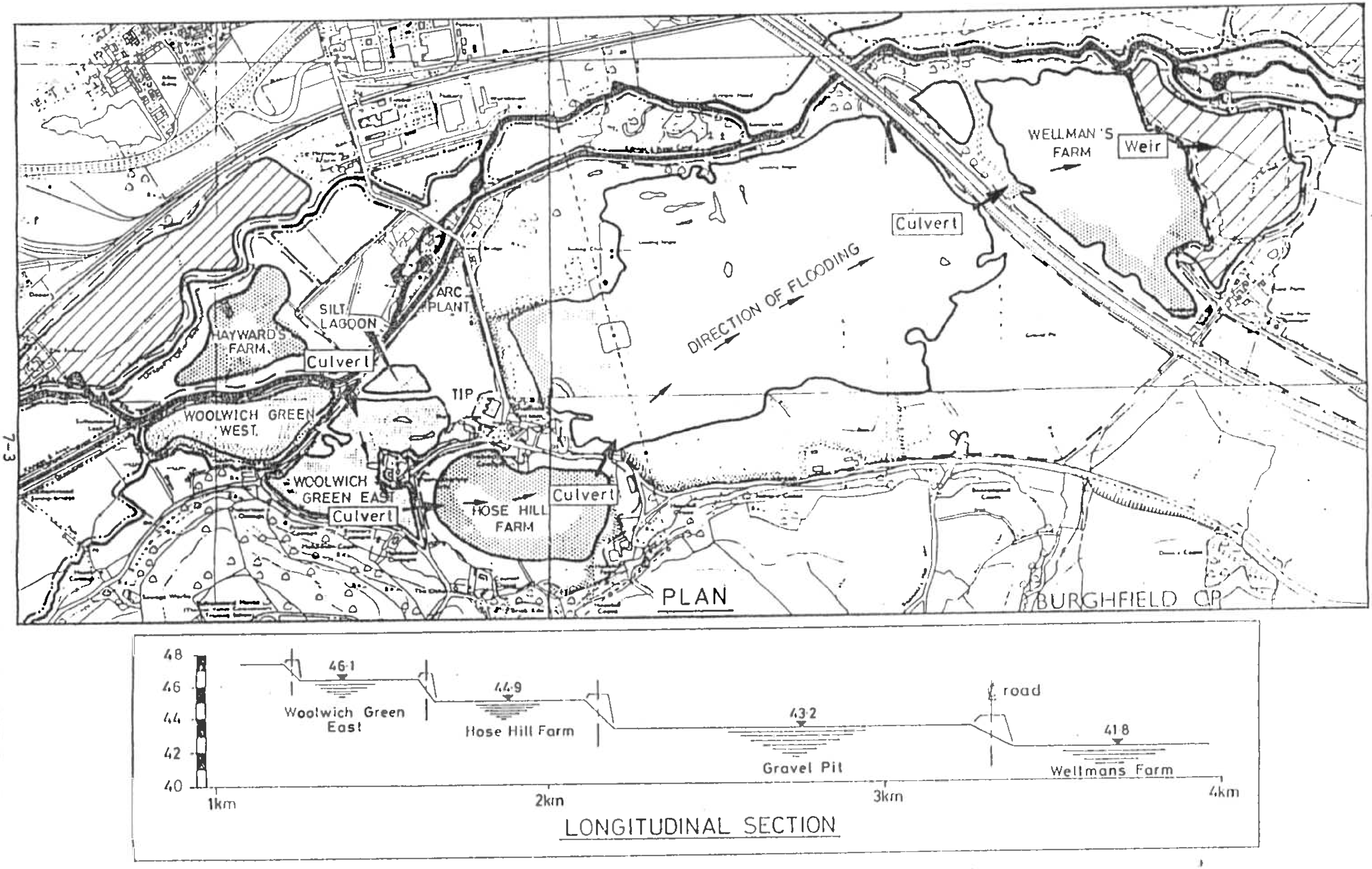
The latter flood route has now been substantially increased by the addition of the Hosehill Farm and Wellman's Farm Lakes, and the completion of the Theale pit.

The latter flood route was reported on in Section 2.5 and is illustrated on Figure 7.1. It was confirmed in practice on the 5th April 1987 when with a flow of $28m^3/s$ in the Kennet, flooding into Woolwich Green East lake was observed. A culvert allows water to flow from Woolwich Green East Lake under the road into Hosehill Farm Lake which in turn discharges into Theale Lake. Theale Lake is connected to Wellman's Farm Lake via a culvert under the M4 and an overflow weir allows water to return to the Kennet via the Clayhill Brook.

There is therefore a natural flood flow route that directs water via a series of four lakes before returning it to the Kennet once flows start to exceed about $25m^3/s$. A longitudinal section of the 3 km of lakes is given in Figure 7.1 which demonstrates the substantial fall in level between them.

The total area of the lakes into which water could be directed is presently 1.41 km^2 with Wellman's Farm Lake to be extended by $0.12km^2$ over the next six years. Although surveys of the lake perimeters are not available, it is likely that the average water level could be raised during a flood by at least 1m. Visual examination of Theale Lake, the biggest of the four, confirms this. It ought therefore to be possible to direct at least $2Mm^3$ through the gravel pits and provide considerable flood alleviation, as this volume approximates to nearly half the volume estimated to have gone into flood plain storage in 1971.

The feasibility of the above method of flood alleviation is examined below.



FLOOD ROUTE THROUGH GRAVEL PITS

FIG 7·1

7.3 FLOOD ROUTING

Approach

Precise modelling of the effect of storage on a cascade of four lakes on the flood hydrology would require a specific mathematical model. The objective in the present chapter is to evaluate the feasibility of the flood alleviation scheme using a simplified approach.

The lakes have been aggregated into a single reservoir and a flood routed through it in order to estimate the attenuation of the hydrograph. A key factor in this will be the inflow to the lake which will be a function of the flood diversion structure provided.

7.3.2 Flood Diversion

A level of 46.93m was recorded just downstream of Woolwich Green East Lake in 1971 for a flow in excess of $71m^3/s$. The recent survey indicates that the bank level between the lake and and the river is about 46.8m. Bank full conditions were observed at $28m^3/s$ on the 5th April 1987.

It has been assumed for the present exercise, the objective of which is to estimate the inflow hydrograph into the reservoir, that a weir will be provided to divert $30m^3/s$ into the lake under a head of 0.3m above a sill level of 46.6m. A free overflow or syphon weir could be considered, but the former is preferred on grounds of safety. In order to minimise the spillway length, a 3:1 ratio labyrinth weir of 30m length has been selected.

An approximate combined stage discharge curve for the river and the weir has been derived and used to determine the inflow into the lake and the effect on the hydrograph of the Kennet at Theale. This has been done for the 1971 modelled hydrograph with up to $30m^3/s$ flood peak being directed into the lake over the weir and is illustrated on Figure 7.2.

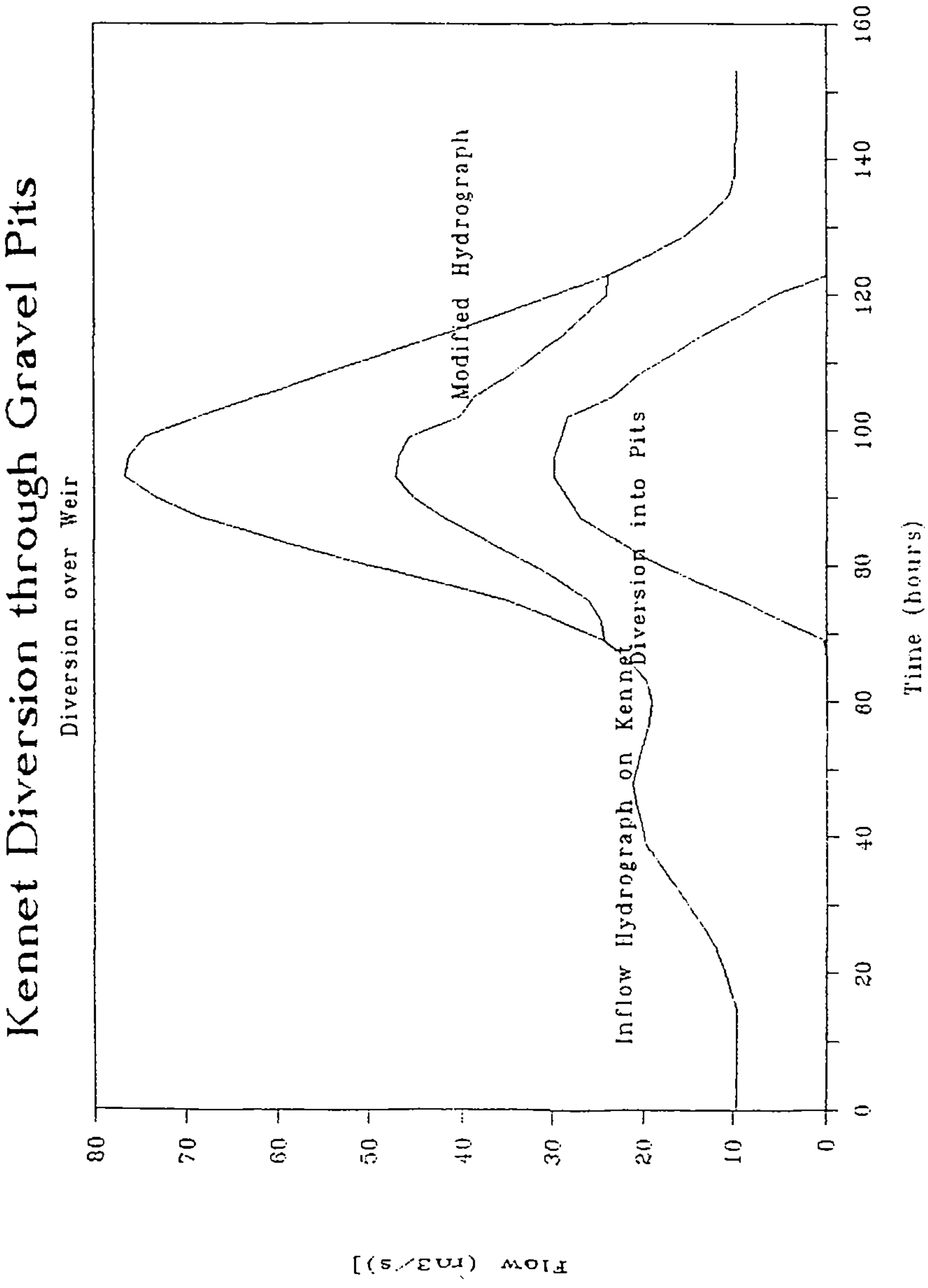

Kennet Diversion through Gravel Pits
Diversion over Weir
Modified Hydrograph
Diversion into Pits
Inflow Hydrograph on Kennet
Time (hours)
Flow (m3/s)
0
20
40
60
80
100
120
140
160
0
10
20
30
40
50
60
70
80

Figure 7.2

7.3.3 Reservoir Routing

A standard reservoir flood routing programme has been used to determine the attenuation provided by the lakes on the flood discharged over the labyrinth weir. This is dependent on the volume elevation curve for the lake and on the outflow discharge characteristics.

The spillway provided to release water from Wellman's Farm Lake back into the Kennet has been selected after a number of trials to be a 3.5m long free overflow weir which would route the flood with a rise in water level of 1.6m. The area of the lake has been assumed to remain constant over this range.

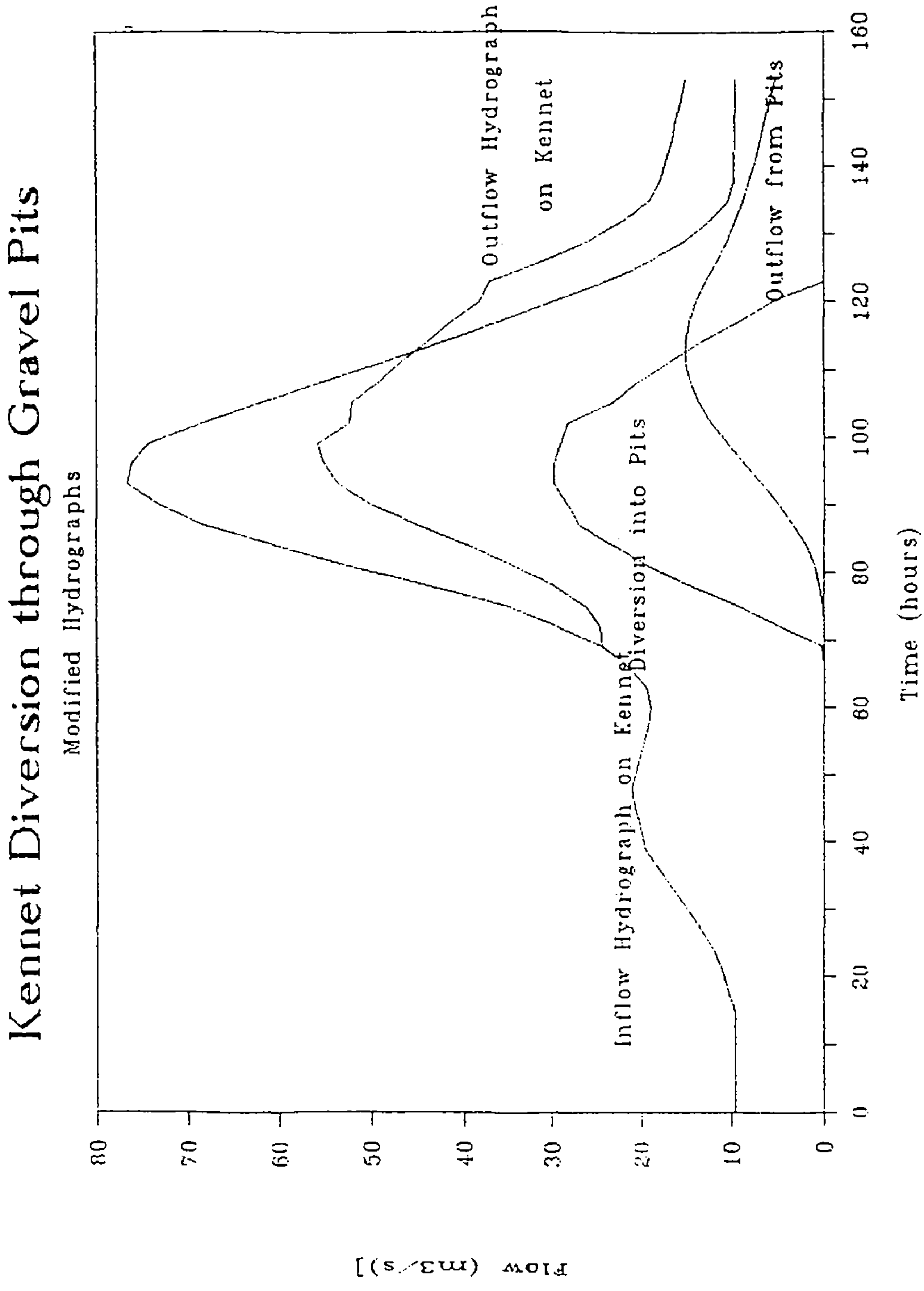
The modifications to the hydrograph of river flows are indicated on Figure 7.3. This shows the original inflow hydrograph to the study area, the hydrograph routed into the lake, the outflow from the lake back to the Kennet and the resultant attenuated outflow hydrograph. The peak flow has been reduced by $21m^2/s$ from $76m^3/s$ to $55m^3/s$. This was achieved by storing $2.3Mm^3$ in the lake and delaying the flood peak out of the lake by 15 hours relative to the peak flow into the lake.

7.4 ENVIRONMENTAL IMPACT

The use of the gravel lakes for flood storage might conflict with existing or proposed uses of the lakes.

Woolwich Green East and Hosehill Farm

These lakes are presently subject to flooding on an annual basis and the situation would not therefore be worsened. Woolwich green East is used extensively for fishing. Some bunding of Hosehill Farm Lake along the road separating it from Theale Lake might be necessary and would improve the storage characteristics.



Kennet Diversion through Gravel Pits
Modified Hydrographs
Outflow Hydrograph on Kennet
Outflow from Pits
Diversion into Pits
Inflow Hydrograph on Kennet
Time (hours)
Flow (m3/s)
0 20 40 60 80 100 120 140 160
0 10 20 30 40 50 60 70 80

Figure 7.3

Theale Lake

Theale Lake is used for sailing and windsurfing and ARC have recently published proposals for building floating homes within the Lake. Consultations would need to be held with these interested parties. A significant increase in water level would also raise the reservoir to the foot of the M4 embankment, the stability of which should be checked.

Wellman's Farm Lake

The lake is used for water skiing and windsurfing and some building would be necessary at the south-eastern end to protect properties.

7.5 CONCLUSIONS

Diversion of the flood peak through the four lakes - Woolwich Green East, Hosehill Farm, Theale and Wellman's Farm - offers the possibility of providing significant flood attenuation that would protect both Reading and Theale. This would be simply improving an existing flood route. The preliminary analysis carried out for the 1971 flood suggests that the diversion could reduce the severity of the flood from a 1 in 50 year event at Theale to below a 1 in 10 year event. The attenuation might not be so effective at more extreme events when the gravel pits would be flooded by other routes.

Additional investigations would be required to determine the topography of the lakes and the allowable rise in water level in more detail. Once these have been carried out more detailed modelling of the flood route may be justified.

CHAPTER 8

CONCLUSIONS

The conclusions of the study are set out below:

8.1 HYDROLOGY

The 1971 flood is estimated to have been a 1 in 50 year event at Theale and a 1 in 35 year event at Reading. The different response times of the Kennet and the Foudry Brook account for this difference, the Foudry Brook being sensitive to appreciably shorter duration storms than the Kennet.

Very little data is available to make an estimate of the 1947 flood return period, but on the basis of gauging at Reading it was a 1 in 50 year event.

Flood plain storage during the 1971 event is estimated to have been about $5Mm^3$ downstream of Tyle Mill. Calibration of a flood routing model on this value suggests the storage associated with events of different return periods to be as follows:

Return period (years)	Storage (Mm^3)
2.33	2.0
10	3.7
100	5.9

Limited flooding occurs several times annually and in major events storage plays an important part in attenuating flows. The attenuation of peak flows due to storage during the 1971 event is estimated to have been 29% between Tyle Mill and County Lock.

8.2 EXTENT OF FLOOD PLAIN

The flood plain is well defined by natural and man made boundaries and flood envelopes for different return periods over the range 1 in 10 to 1 in 100 years are very close to one another.

The distribution of storage along the valley has been determined and it is estimated that the 1 in 100 years flood would result in levels approximately 0.1 - 0.15m higher than those in 1971 and the 1 in 10 year flood approximately 0.15 - 0.2m lower. The actual areas flooded for the three events are almost identical. The above differences in level do not apply for the area downstream of the Basingstoke railway line due to the influence of the Thames.

8.3 EFFECT OF DEVELOPMENT.

Two major forms of development have taken place in the flood plain over the last forty years. Gravel extraction has resulted in the creation of a large number of lakes and waste tipping close to the Foudry has resulted in substantial infilling.

The creation of the lakes is estimated to have increased flood plain storage capacity by 0.5 to 1.0Mm^3 in a major event, whereas infilling has reduced it by about 1.0Mm^3 below 1971 levels. The gravel pits were in existence in 1971, since when about 0.5Mm^3 of capacity has been lost due to infilling or development. Present proposals to develop a Business Park close to the Foudry would result in a further reduction in flood plain storage.

It is concluded that a recurrence of the 1947 or 1971 events would result in higher levels in the downstream portion of the study area and through Reading as a result of the storage capacity that has been lost.

8.4 FUTURE POLICY TOWARDS DEVELOPMENT

Policies with respect to flood plain management should be orientated towards the protection of flood plain storage capacity which has been shown to be important in attenuating flooding. The fact that the flood envelopes for different return periods lie so close to one another leaves little scope for developing policies that link development to the risk of flooding. The only area which could be developed without a significant loss of storage is that between the A4 and the Newbury railway line west of the M4 at Theale.

Whilst there has been little encroachment upon the flood plain in the upper part of the study area, there has been considerable development in the Foudry Brook flood plain which forms an integral part of the Kennet flood storage capacity. This is contrary to policies expressed in the Kennet Valley Plan prepared by Reading Borough Council. The proposed Reading Business Park would remove the greater part of the remaining Foudry flood plain. Due to the backing up effect of the Thames and the interaction of the Thames/Kennet/Foudry Brook at this point it is not considered that the proposed Foudry flood relief channel will of itself overcome the higher water levels that are likely to result due to this loss of storage. There is a need to quantify the effects of this development and to develop a coherent policy for the combined Kennet and Foudry flood plain.

There is a danger that localised changes in the flood plain might occur which although not necessarily significant individually could result in a cumulative reduction in storage. The present policy of preserving storage on a level for level basis prevents this and safeguards against the possibility that storage at a higher level is replaced with storage at a lower level thus reducing the degree of attenuation of peak flows.

8.5 FLOOD ALLEVIATION

An opportunity for providing some flood attenuation by routing the flood peak through four existing gravel lakes in the upper portion of the study area has been identified. Preliminary studies suggest that it could reduce the flood peak for an event similar to that of 1971 by about $20m^3/s$, transforming it from a 1 in 50 year event to less than a 1 in 10 year event, and thus afford significant protection to both Reading and Theale.

Additional studies would be required to evaluate this opportunity in detail in the form of:

- surveys to determine volume - elevation characteristics of the lakes
- flood routing studies for a range of design floods to dimension hydraulic structures, and evaluate attenuation.
- costing of civil engineering works

8.6 FURTHER STUDIES

8.6.1 Review of Present Study

The present study has confirmed the importance of flood plain storage within the Kennet Valley in attenuating flood flows through Reading, and has assessed the magnitude and distribution of this storage. The extent of the flood plain has been broadly established with a coarse survey for a range of return periods. Development within the flood plain has been reviewed and the infilling of the Foudry flood plain contrasted with the additional storage provided by the creation of gravel lakes, suggesting that there has been a net loss in storage.

The study has not been able to provide a precise evaluation of flood level differences due to the changes in storage or to provide a means of evaluating the impact of localised changes. This is because the methodology employed considered the storage of the valley as a global entity for the purposes of the flood routing and can not represent specific hydraulic features of the Kennet/Holy Brook/Canal/Foudry conglomerate of channels. It is not considered that this methodology could be developed further in order to provide a more accurate assessment or as a tool for evaluating the impact of specific developments. One method that could be considered for providing additional precision is mathematical modelling.

8.6.2 Mathematical Modelling

Mathematical modelling should allow the effect of changes in the flood plain to be simulated. The hydrological inputs that would be required for the model have been developed in the present study and the model could be calibrated approximately against the 1971 flood event. The impact of the gravel lakes and infilling of the Foudry flood plain could then be evaluated so as to give an indication of relative changes even if the data available for the model is not adequate to have full confidence in absolute values.

However, the reach of the Kennet between Theale and Reading would be complex to model because of the following factors:

- the division of flows between Holy Brook and Kennet, and the inflow from the Foudry
- the number of hydraulic structures (weirs, locks, sluices)
- the influence of the Thames
- railway and road embankments.

The time and money required to undertake such an exercise is therefore likely to be considerable and it is worth considering whether an alternative approach could be used. In particular it may be worth while first to give some study of the consequences of higher flows through Reading in order to assess the risks that are being guarded against by protecting storage in the Kennet flood plain.

The methodology used in the present study could be used to derive the increase in flows through Reading for different return periods that would result from reductions in the storage capacity. Backwater analysis of the stretch upstream of County Weir could then be used to determine the associated rise in water level for a range of downstream levels set by the River Thames. This analysis could be used in conjunction with the HRS physical model of the Kennet through Reading to assess the risk of flooding. Some additional survey of the Kennet through Reading is likely to be necessary.

8.6.3 Other Studies

Study of the Holy Brook

It has been observed that the Holy Brook is liable to flooding before the Kennet and that this is the mechanism of the annual flooding of the Southcote and Fobney meadows. The Holy Brook is in part a very old artificial channel and there are a number of small arch bridges across it which restrict its carrying capacity. It is possible that either the channel capacity if the Holy Brook could be improved, or that the division of flows between the Kennet and the Holy Brook could be better distributed, such that the flow threshold at which flooding occurs could be raised. It is recommended that some hydraulic studies of the Holy Brook be undertaken to examine this possibility.

Hydrometric Monitoring

There is a lack of gauged water level or flow records in the flood plain area, and the important Foudry tributary is completely ungauged. Intensive experimental monitoring of water levels in the Kennet (especially from Fobney to Blakes Lock), the Holy Brook, the Kennet and the Thames would enhance understanding of the extent to which flood levels are interlinked. Installation of a flow gauging station on the Foundry (e.g. at a suitable site close to the M4 crossing) should also be considered.

The outcome of such a gauging investment would be subject to the vagaries of nature; clearly the data would be of considerable use in refining hydrological or hydraulic models of the behaviour of the flood plains and watercourses if data for an exceptional event were captured. The more flashy nature of the Foudry catchment response is such that collection of a relatively short period of record (e.g. 1 to 3 years) would allow much greater confidence in estimating design floods on the Foudry (and its contribution to composite design inflows to the Kennet/Foudry flood plain). Further collection of hydrometric data is therefore strongly recommended.

Survey

The only part of the flood plain in which a large area of housing is close to the flood envelopes is along the Calcot/Southcote/Ford's Farm/Beansheaf developments which have all been built close to the flood plain boundary. There may be some properties that might be at risk in an extreme event and this could only be ascertained by a detailed survey along this boundary paying particular attention to re-entrants.

Flood Alleviation

A more detailed study of possible flood alleviation by routing flows through the existing gravel pits near Theale may be worthwhile.

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A F Aberdein, J V Sutcliffe, J L Yates A rational approach to land use planning in flood plains, Eleventh Congress of the International Commission on Irrigation and Drainage.

ANNEXE A

LIST OF DOCUMENTATION

ANNEXE A

LIST OF DOCUMENTATION

MAPS

Ordnance Survey Maps at 1/10 000 scale with contours at 5m intervals.

SU66NW

SU66NE

SU67SW

SU67SE

SU76NW

SU77SW

Ordnance Survey Maps at 1/2500 and 1/1250 scales without contours.

1/2500 Scale

SU6269	SU6369	SU6370	SU6469
SU6470	SU6569	SU6570	SU6571
SU6669	SU6670	SU6671	SU6769
SU6770	SU6771	SU6869	SU6870
SU6871	SU6969	SU6970	SU6971
SU7069	SU7070	SU7071	

1/1250 Scale

SU7072SE	SU7169SW	SU7169NW	SU7170SW
SU7170NW	SU7171SW	SU7171NW	SU7172SW
SU7172SW	SU7172NW		

SURVEY

Plan of the rivers at 1/2500 scale with cross sections every 100m at 1/100.

Holy Brook	967/111/0/1	Plan + Long Sect. Sheet 1
		Sheet 2
	967/111/0/1/2	to 16 inclusive
	967/111/0/1/20	to 31 inclusive
Foudry Brook	11063/106/0/1	Plan + Long Sect.
	11063/106/0/1/1	
	11063/106/0/1/2	
River Kennet	967/103/A/1 Sheet 1 Plan + Long Sect.	
	967/103/A/1 Sheet 2 Plan + Long Sect.	
	967/103/A/1/6 to 13 inclusive Sheet 1	
	967/103/A/1/23 to 29 inclusive Sheet 1	
	967/103/A/1/1 to 18 inclusive Sheet 2	
	967/103/A/Z Plan and Long Sect.	
	967/103/A/Z/1 to 36 inclusive.	

AERIAL PHOTOGRAPHS

Berkshire County Survey flown by J.A. Story and Partners, 6th November 1986. 1/10 000 scale in colour.

Berkshire County Survey flown by Clyde Surveys Ltd on 14th June 1981, 1/1200 scale in black and white.

Photocopies of 1947 and 1971 photographs.

PLANNING DOCUMENTS

Central Berkshire Structure Plan, Royal County of Berkshire, Approved April, 1980

Review of Berkshire's Structure Plans, Submission Document, Royal County of Berkshire, January, 1986

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Countryside Recreation Local Plan for Berkshire, Royal County of Berkshire, February, 1985.

The Lower Kennet Water Park, Draft Study Report, September, 1972.

Reading Waterways, A Plan for the River Landscape April, 1978.

Kennet Valley Local Plan, Reading Borough Council, August, 1985.

ANNEXE B

REPORT ON THE 1971 FLOOD

Mr. Davis : Sample DR.

NAVIGATION AND WORKS COMMITTEE - 12TH JULY, 1971 Item No.
LAND DRAINAGE COMMITTEE - 12TH JULY, 1971 Item No.

THAMES CONSERVANCY,
De Bohun Road,
READING, Berks.

1st July, 1971

THE CONSERVATORS OF THE RIVER THAMES
NAVIGATION AND WORKS COMMITTEE
LAND DRAINAGE COMMITTEE

Gentlemen,

REPORT ON HEAVY RAINFALLS IN THE THAMES CATCHMENT AND FLOODING IN THE KENNET VALLEY AND ADJACENT AREAS. 10TH - 15TH JUNE 1971

METEOROLOGICAL CONDITIONS

A depression centred south of Pembrokeshire at midnight on Tuesday, 8th June, 1971, moved south and later south east, deepening slowly. There was rain over various parts of central and southern England and Wales associated with this system.

2. A depression centred over the north east of France at midnight on Wednesday, 9th June, 1971, moved at first almost due north, then north west and west north west across the Thames Estuary and central southern England to South Wales. This depression reached its lowest pressure at about 0600 hours on Friday, 11th June, when centred over the Thames Catchment area. Moderate to heavy amounts of rainfall occurred over the whole of the period 9th to 11th June, details of which are given in the Appendix A to this report.

3. The heaviest falls occurred on the south western fringes of the catchment, affecting particularly the middle Kennet valley from Hungerford to Reading and the Rivers Pang, Enborne and Loddon, and to a lesser extent the upper River Thames and Rivers Whitewater and Blackwater.

4. The heaviest falls occurred as follows, which should be compared with the standard average for the month of 1.79 inches :-

	24 hour period total to 0900 hours on:			TOTAL 3 Days
	9th June	10th June	11th June	
	ins.	ins.	ins.	ins.
Inkpen	1.73	0.55	3.26	5.54
Hungerford	1.18	0.40	2.63	4.21
Upper Basildon	1.24	0.39	2.50	4.13
Lockeridge	0.60	0.45	2.64	3.69
Boxford	0.78	0.41	2.18	3.37

FLOW CONDITIONS

5. The rainfalls of Wednesday, 9th June, though heavy in some isolated areas, were not exceptional in themselves, and falling on a relatively dry catchment, appeared unlikely to give rise to flooding. Further light to moderate falls on Thursday did, however, produce instances of local flooding.

6. At 2130 hours on Thursday, the Flood Duty Officer received a heavy rainfall warning that had been issued by the Meteorological Office for the following 12 hours. This related to the passage of the second depression previously referred to. During the night, the available Autodiallers were interrogated and information on rainfall was obtained from those rainfall stations which were manned. Between 0530 and 0700 hours, visual inspection was made of the River Blackwater, where the Autodialler had failed at 0500, and of the Cove Brook and north River Wey at Farnham. Levels, though high, were not attaining bank full conditions except in the lower River Blackwater downstream of Yateley, and those in the River Wey did not seem likely to do so.

7. Divisional Engineers had previously been informed of conditions and first reports of flooding from the River Kennet reached the Reading Divisional Engineer at 0530. Weir running was commenced, continuing throughout the day, the last report being received by the Flood Duty Officer at 2330.

8. During Friday morning, the telephone lines out of my headquarters were affected by rain and at one time, only one direct line to the flood duty room was available. More seriously, the land line link to the radio transmitter was out of action until after 1700 hours and again for intermittent periods on the following day. As a result, the greatest difficulty was experienced in obtaining information.

FLOOD WARNINGS

9. Nevertheless, with the heavy rain persisting through the morning, it was considered advisable to issue an AMBER warning for the River Kennet from Newbury to Reading at 1310 hours on Friday. As further reports of rising levels were obtained with continuing rain, a RED warning was issued for the same area at 1643 hours.

RIVER THAMES

10. The early period of rainfall had no significant effect on Thames levels. Mainly as a result of Friday's rainfall, levels rose rapidly during that day at St. Johns, continuing at a high level until Sunday. Some flooding of riverside land occurred in these upper reaches, but danger levels were not approached at Oxford. In the middle river, levels rose below Caversham from Friday to Sunday as a result of flood flows from the Kennet and Loddon. Urgent action was necessary on Friday to move Thames Conservancy craft moored upstream of Marsh weir in connection with the reconstruction of the Upper Horse Bridge. Although flows were high for the time of year and it was necessary for the Chief Navigation Inspector to issue a warning of navigation hazard, levels again did not reach excessive heights and no flood warning was considered necessary.

KENNET VALLEY

11. Throughout Friday, clearance of debris from sluices was carried out both by British Waterways and by the Reading Divisional Engineer's workmen, in response to the many requests although in some cases, only partial clearance could be effected. This work continued in the area Padworth to Reading until 2300 hours and was resumed early on Saturday and again on Sunday.

12. At 0015 hours on Saturday, it was reported that flooding was assuming serious proportions at Burghfield Bridge, where overspill was threatening a caravan site, a smallholding and some properties. The Fire Brigade were in attendance throughout the night and during the following day, reinforcing the bank with sandbags and pumping out the low lying area into an adjacent ballast pit. My Deputy visited this area at 0745 hours, having inspected the River Pang, where flows were falling slightly, and the Sulham Brook. He continued visual inspection in the Kennet Valley to Aldermaston.

RIVER ENBORNE

13. With rainfall south of the River Enborne amounting to over 5 inches in the three days, extremely high flows were recorded. This is a relatively steep impervious catchment and high flow velocities were generated. This has resulted in many shoals being formed, one in particular of some hundred cubic yards of gravel being left on the lawn of a riverside property. Undoubtedly this catchment was a major contributor to the more serious flooding of the Kennet valley downstream of Brimpton.

FLOOD RECONNAISSANCE

14. It was quite clear at this stage that the volume of the flood was higher than any previously recorded, and that it would be necessary to obtain as much information as possible on its peak levels, the points where overspill had occurred and the extent of the flooded areas.

15. The River Kennet is a complex system, particularly in its lower reaches. Between Hunderford and Reading it is partly canalised, and there are numerous controls, both for the navigation and at the many mills. For long lengths the main channels are embanked and overspilling occurs. The flood plain is broad and access to the watercourses in times of flood is virtually impossible in many areas. For this reason, it was considered advisable to carry out an aerial reconnaissance, and authority was obtained from the Chairman of the Navigation and Works Committee to hire a helicopter to enable this to be done. Your approval to this action is requested.

16. Arrangements were made with the Thames Valley Constabulary for landing facilities at the Sulhampstead Police Training College and the flight commenced at 1200 hours, lasting approximately 1 hour 25 minutes.

17. Two members of my staff carried out the survey, one taking photographs and the other plotting the flood plain on large scale maps, noting points of overspill and the paths taken by flood waters. Altitude varied between 100 and 500 feet above ground level and most of the work was carried out at an air speed of 40 knots. The area covered extended from east of Thatcham on the River Kennet to south west of Reading on the River Loddon.

18. The information so gained was invaluable as a basis for more detailed ground survey which was carried out during the following week. The results of this survey, together with a selection of the photographs, will be exhibited at your meeting today.

FLOOD PEAK AND RECESSION

19. The peak of the Kennet flood occurred at Theale gauging station at 0230 hours on Saturday, 12th June. Flow through the weir is calculated to have been 2,000 cusecs. In addition, considerable flows by-passed the weir which have been subsequently estimated as approaching 1,000 cusecs, thus making the total flow of 3,000 cusecs the highest recorded. Levels did not fall appreciably for some hours, and were continuing to rise in the Southcote area at 0700 hours. Levels began to fall slightly during Saturday afternoon at Southcote and Fobney, although some local rises were recorded as weirs were cleared of further obstructions, releasing large volumes of water stored in the flood plain. Following a more steady fall overnight and the absence of appreciable rainfall, the RED warning reverted to AMBER at 1130 on Sunday, 13th June and to a YELLOW warning at 1015 on Wednesday, 16th June.

OTHER FLOOD OCCURRENCES

20. During the period described above, extensive flooding in the flood plains of the lower River Blackwater and the middle or lower River Loddon also occurred. An interesting sidelight of the aerial survey was the inspection of the M.4 motorway bridge crossing of the River Loddon flood plain near Sindlesham.

This shewed the adequacy of the provision made both for the permanent and temporary works and the suitability of the realignment of the river channels at this point.

21. There were many reports of local flooding, usually caused by the inability of flood water to reach the watercourses.

22. The receipt of flood reports from Local Authorities detailing the number of properties flooded is not yet complete, but will form an Appendix B. to this report. To date it is known that no abnormal flooding occurred in the Marlborough area, and no houses were flooded in Newbury.

23. Further heavy rainfalls occurred on the 14th-15th June and again on 19th June, particularly affecting the River Mole catchment. Although unusually high levels were reached at Sidlow Bridge on each occasion and AMBER warnings were issued for the River Mole as a result, the attenuation was remarkably quick and no flooding ensued. Because of the unusually heavy rainfall for the month, a YELLOW warning was issued for the whole of the Thames Catchment.

CONCLUSIONS

24. The basic cause of the flooding in the River Kennet was undoubtedly the unusually heavy rainfall spread over the three days, comprising the initial wetting up period and the final day's rain producing a high percentage of run-off. Weed growth does not appear to have been unusually prolific this year, but undoubtedly this had some effect in raising levels.

25. The operation of British Waterways' sluices was entirely satisfactory, while the operation of those in private ownership was reasonably so. In the latter cases, considerable assistance in operation and subsequent clearance was given both by British Waterways and your Divisional staff. Trouble was, however, experienced with the removal of lasher boards which it is customary to leave in position during the summer months and the customary design of which does not lend itself to easy removal, particularly under flood conditions. I must place on record that the assistance rendered by British Waterways staff, not only in operation but in liaison and providing information, was extremely valuable and I should particularly like to mention my appreciation of the services of Inspector Rogers.

26. It has not been possible at this stage to estimate the return period of this flood but its peak discharge is known to be 50% greater than that in 1947.

27. The large volume of flood plain storage evident from the plans and photographs must have had a significant effect in reducing peak flows, particularly downstream of Theale through Reading.

28. Bearing in mind the relatively few properties that were flooded, it is questionable whether any extensive improvements are likely to be required. Nevertheless, there are certain critical points which must be examined in detail and the results of my investigations will be reported to you in due course. The minimal flood damage is due in no small measure to the absence of any significant development in the flood plain, and the plans now produced will be of the greatest value in supporting your established policies in regard to development in the future.

29. Two further matters arise. The failure of the land lines at a critical stage suggests the advisability of establishing a transmitting aerial on the roof of the new office building and the feasibility of this will be considered.

30. Secondly, the use of a helicopter to obtain flood information was invaluable. The amount of detail that could be seen was quite remarkable, to the extent that obstructions could easily be pinpointed and in many cases, the position of sluices could be checked. This was quite apart from the prime purpose of delineating flooded areas and locating sources of trouble.

31. I am looking further into the possibilities of this type of survey, which has already been adopted by the Mersey and Weaver River Authority, and will be presenting a further detailed report on all aspects.

I am, Gentlemen,
your obedient servant,

E. J. BRETTELL

Chief Engineer

APPENDIX C

HYDROLOGY

APPENDIX 1 A note on the Enborne at Brimpton flow record

The Enborne at Brimpton gauging station is a compound Crump weir, originally designed to record up to 18 cumecs in the modular range. There is no crest tapping. Records from the station indicate several problems. Firstly, the modular limit is suspected to be much lower than 18 cumecs, perhaps around 12 cumecs. (Presumably in reality the limit is dependent on concurrent water levels downstream in the Kennet.) The gauging record shows some estimated corrections for non-modular flows but these are sporadic. There are references in station reports to backwater problems from the Kennet and to bypassing from upstream. From OS maps it appears that the sharp RH bend a few 100 metres upstream of the station is unnatural. Within the terms of the study it was impractical to make a survey of the stream or to research the gauging record in great detail.

At the outset of the study, Thames Water supplied a revised rating curve for the station. The effect of this is to reduce radically flows above 12 cumecs. For example, the flow for a level of 1.5m is reduced from 27.5 cumecs to 16.8 cumecs. The reduction is believed to be based on two gaugings carried out in November 1974 and in 1977.

Standard unit hydrograph analyses presented for the station in Appendix A of IH Report N° 94 indicate a standard percentage runoff (SPR) of about 25%. This is already rather lower than the value expected from soil mapping. Adoption of the revised rating would further magnify the discrepancy.

When the difficulties with the Enborne record were realized it was decided to abandon its analysis and to examine instead the Kennet at Theale record. (See Section 3.3 of report.) The Kennet at Theale record is more relevant to the flood plain under study. Moreover it has head, crest and tail tappings, providing hydrometry of a higher standard than at Brimpton.

APPENDIX C.2

Calculations for 50 year design flood at Theale using rainfall-runoff method

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UK DESIGN FLOOD ESTIMATION PACKAGE   Institute of Hydrology

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Run reference - theal

Catchment characteristics

Area	220	sq km	Soil 1	0
Length	35.5	km	Soil 2	0
Slope	2.23	m/km	Soil 3	0.4
SAAR	775	mm	Soil 4	0.6
M5-2D	53.5	mm	Soil 5	0
Jenkinson's r	0.36			
Urban	6e-02			
Smdbar	12	mm	RSMD 27.46	mm

Unit hydrograph option 9

Unit hydrograph time to peak 24.00 Data interval
Design storm duration 45 hours

Return Period for design flood 50.0 years
requires rainfall event depth of 81.0 years

M5-45.0hour/M5-2day = 1.04
MT/M5 = 1.70
ARF = 0.95

M5-2day = 53.5 mm
M5-45.0hour = 55.7 mm
M 81.0-45.0hour = 94.7 mm (point)
M 81.0-45.0hour = 89.6 mm (area)

Rainfall profile option 4

Design storm depth 89.6 mm

Design CWI 113.5

Percentage runoff 47.5 %   (PR option 1

Response hydrograph peak 66.23 cumecs
Baseflow 9.66 ~~13.63~~ cumecs   (Baseflow option 6

Design hydrograph peak 75.89 ~~79.86~~ cumecs

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UK DESIGN FLOOD ESTIMATION PACKAGE Institute of Hydrology

CONVOLUTION TABLE

10mm 3 hour unit hydrograph (cumecs)

Rain (cm)	net rain (cm)	1.15	2.29	3.44	4.58	5.73	6.88	8.02	9.17	8.41	7.66	6.91	6.15	5.40	4.64	3.89	3.14	2.38	1.63	0.87	0.12									
0.18	0.09	0.21	0.43	0.64	0.86	1.07	1.29	1.50	1.71	1.57	1.43	1.29	1.15	1.01	0.87	0.73	0.59	0.45	0.30	0.16	0.02									
0.22	0.11		0.27	0.54	0.80	1.07	1.34	1.61	1.88	2.14	1.97	1.79	1.61	1.44	1.26	1.09	0.91	0.73	0.56	0.38	0.20	0.03								
0.27	0.13			0.32	0.64	0.96	1.29	1.61	1.93	2.25	2.57	2.36	2.15	1.94	1.73	1.51	1.30	1.09	0.88	0.67	0.46	0.25	0.03							
0.34	0.16				0.41	0.82	1.23	1.64	2.05	2.47	2.88	3.29	3.02	2.75	2.48	2.21	1.94	1.67	1.39	1.12	0.85	0.58	0.31	0.04						
0.54	0.26					0.64	1.29	1.93	2.57	3.22	3.86	4.50	5.14	4.72	4.30	3.88	3.45	3.03	2.61	2.18	1.76	1.34	0.91	0.49	0.07					
0.91	0.43						1.09	2.18	3.27	4.35	5.45	6.54	7.63	8.72	8.00	7.28	6.57	5.85	5.13	4.42	3.70	2.98	2.27	1.55	0.83	0.11				
1.29	0.61							1.54	3.08	4.63	6.17	7.71	9.25	10.80	12.34	11.32	10.31	9.29	8.28	7.26	6.25	5.24	4.22	3.21	2.19	1.18	0.16			
1.49	0.69								1.74	3.48	5.22	6.95	8.69	10.43	12.17	13.91	12.77	11.62	10.48	9.33	8.19	7.05	5.90	4.76	3.61	2.47	1.33	0.18		
1.29	0.61									1.54	3.08	4.63	6.17	7.71	9.25	10.80	12.34	11.32	10.31	9.29	8.28	7.26	6.25	5.24	4.22	3.21	2.19	1.18	0.16	
0.91	0.43										1.09	2.18	3.27	4.36	5.45	6.54	7.63	8.72	8.00	7.29	6.57	5.85	5.13	4.42	3.70	2.98	2.27	1.55	0.83	0.11
0.54	0.26											0.64	1.29	1.93	2.57	3.22	3.86	4.50	5.14	4.72	4.30	3.88	3.45	3.03	2.61	2.18	1.76	1.34	0.91	0.45
0.34	0.16												0.41	0.82	1.23	1.64	2.05	2.47	2.88	3.29	3.02	2.75	2.48	2.21	1.94	1.67	1.39	1.12	0.85	0.59
0.27	0.13													0.32	0.64	0.96	1.29	1.61	1.93	2.25	2.57	2.36	2.15	1.94	1.73	1.51	1.30	1.09	0.88	0.67
0.22	0.11														0.27	0.54	0.80	1.07	1.34	1.61	1.88	2.14	1.97	1.79	1.61	1.44	1.26	1.09	0.91	0.72
0.18	0.09															0.21	0.43	0.64	0.86	1.07	1.29	1.50	1.71	1.57	1.43	1.29	1.15	1.01	0.87	0.73
	Baseflow	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60	13.60
	Total flow	13.81	14.30	15.10	16.32	18.17	21.12	25.61	31.84	39.25	47.31	55.49	63.39	70.54	76.16	79.43	79.83	77.66	73.69	69.65	62.93	56.80	50.39	43.84	37.54	31.64	26.42	22.16	19.02	16.92

FLOWS REDUCED BY 3.94 CUMECS — LOWER BASEFLOW ALLOWANCE.

- Percentage runoff is 47.46 %
- Peak of response hydrograph is 66.23 cumecs
- Baseflow ~~13.60~~ 9.66 cumecs
- Peak of design flood ~~79.83~~ 75.89 cumecs

files used
KFFtheal.PDF
UHYtheal.PDF

APPENDIX C.3

Calculations for 50 year design flood for the Foudry at M4 using rainfall-runoff method.

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UK DESIGN FLOOD ESTIMATION PACKAGE Institute of Hydrology
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Run reference - foud1

Catchment characteristics

Area	68	sq km	Soil 1	0.34
Length	20.4	km	Soil 2	0
Slope	2.27	m/km	Soil 3	0.235
SAAR	685	mm	Soil 4	0.425
M5-2D	48	mm	Soil 5	0
Jenkinson's r	0.4			
Urban	8e-02			
Smdbar	12	mm	RSMD 24.88	mm

Unit hydrograph option

Unit hydrograph time to peak 11.23 Data interval
Design storm duration 19 hours

Return Period for design flood 50.0 years
requires rainfall event depth of 81.0 years

M5-2day = 48 mm

M5-19.0hour/M5-2day = 0.85
MT/M5 = 1.80
ARF = 0.95

M5-19.0hour = 40.7 mm
M 81.0-19.0hour = 73.3 mm (point)
M 81.0-19.0hour = 69.3 mm (area)

Rainfall profile option 4

Design storm depth 69.3 mm

Design CWI 100.8

Percentage runoff 31.7 % (PR option 1)

Response hydrograph peak 23.27 cumecs
Baseflow 0.86 cumecs (Baseflow option

Design hydrograph peak 24.13 cumecs

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UK DESIGN FLOOD ESTIMATION PACKAGE   Institute of Hydrology

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CONVOLUTION TABLE

10mm 1 hour unit hydrograph (cumecs)

Rain	net rain	1.74	3.49	5.23	6.97	8.72	10.46	12.21	13.95	15.69	17.44	19.18	18.71	17.56	16.41	15.26	14.12	12.97	11.82	10.68	9.53	8.38	7.23	6.09	4.94	3.79	2.65	1.50	0.35	
-(cm)-																														
0.11	0.03	0.04	0.08	0.12	0.16	0.21	0.25	0.29	0.33	0.37	0.41	0.45	0.44	0.42	0.39	0.36	0.33	0.31	0.28	0.25	0.23	0.20	0.17	0.14	0.12	0.09	0.06	0.04	0.01	
0.11	0.04		0.04	0.09	0.13	0.17	0.22	0.26	0.30	0.35	0.39	0.43	0.48	0.46	0.44	0.41	0.38	0.35	0.32	0.29	0.26	0.24	0.21	0.18	0.15	0.12	0.09	0.07	0.04	0.01
0.16	0.05			0.06	0.12	0.19	0.25	0.31	0.37	0.43	0.49	0.56	0.62	0.68	0.66	0.62	0.58	0.54	0.50	0.46	0.42	0.38	0.34	0.30	0.26	0.22	0.18	0.13	0.09	0.05
0.17	0.05				0.06	0.13	0.19	0.25	0.32	0.38	0.44	0.51	0.57	0.63	0.70	0.68	0.64	0.59	0.55	0.51	0.47	0.43	0.39	0.35	0.30	0.26	0.22	0.18	0.14	0.10
0.21	0.07					0.08	0.16	0.24	0.32	0.39	0.47	0.55	0.63	0.71	0.79	0.87	0.85	0.80	0.74	0.69	0.64	0.59	0.54	0.48	0.43	0.38	0.33	0.28	0.22	0.17
0.31	0.10						0.12	0.24	0.35	0.47	0.59	0.71	0.83	0.95	1.06	1.18	1.30	1.27	1.19	1.11	1.03	0.96	0.88	0.80	0.72	0.65	0.57	0.49	0.41	0.33
0.45	0.14							0.17	0.34	0.51	0.68	0.86	1.03	1.20	1.37	1.54	1.71	1.88	1.83	1.72	1.61	1.50	1.38	1.27	1.16	1.05	0.93	0.82	0.71	0.60
0.68	0.22								0.26	0.51	0.77	1.02	1.28	1.53	1.79	2.04	2.30	2.56	2.81	2.74	2.57	2.41	2.24	2.07	1.90	1.73	1.56	1.40	1.23	1.06
0.80	0.26									0.30	0.61	0.91	1.21	1.51	1.82	2.12	2.42	2.73	3.03	3.33	3.25	3.05	2.85	2.65	2.45	2.25	2.05	1.85	1.66	1.46
0.90	0.29										0.34	0.68	1.01	1.35	1.69	2.03	2.37	2.70	3.04	3.38	3.72	3.63	3.40	3.18	2.96	2.74	2.51	2.29	2.07	1.65
0.80	0.26											0.30	0.61	0.91	1.21	1.51	1.82	2.12	2.42	2.73	3.03	3.33	3.25	3.05	2.85	2.65	2.45	2.25	2.05	1.85
0.68	0.22												0.26	0.51	0.77	1.02	1.28	1.53	1.79	2.04	2.30	2.56	2.81	2.74	2.57	2.41	2.24	2.07	1.90	1.73
0.45	0.14													0.17	0.34	0.51	0.68	0.86	1.03	1.20	1.37	1.54	1.71	1.88	1.83	1.72	1.61	1.50	1.38	1.27
0.31	0.10														0.12	0.24	0.35	0.47	0.59	0.71	0.83	0.95	1.06	1.18	1.30	1.27	1.19	1.11	1.03	0.96
0.21	0.07															0.08	0.16	0.24	0.32	0.39	0.47	0.55	0.63	0.71	0.79	0.87	0.85	0.80	0.74	0.69
0.17	0.05																0.06	0.13	0.19	0.25	0.32	0.38	0.44	0.51	0.57	0.63	0.70	0.68	0.64	0.59
0.16	0.05																	0.06	0.12	0.19	0.25	0.31	0.37	0.43	0.49	0.56	0.62	0.68	0.66	0.62
0.11	0.04																		0.04	0.09	0.13	0.17	0.22	0.26	0.30	0.35	0.39	0.43	0.48	0.46
0.11	0.03																			0.04	0.08	0.12	0.16	0.21	0.25	0.29	0.33	0.37	0.41	0.45
	Baseflow	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
	Total flow	0.90	0.98	1.13	1.34	1.63	2.03	2.61	3.45	4.58	6.06	7.83	9.81	11.89	14.00	16.07	18.09	19.99	21.66	22.99	23.84	24.13	23.91	23.25	22.28	21.08	19.74	18.29	16.74	15.13

```
***********************************************************
* Percentage runoff is                 31.75 %            *
* Peak of response hydrograph is       23.27 cumecs       *
* Baseflow                              0.86 cumecs       *
*                                     -------             *
* Peak of design flood                 24.13 cumecs       *
*                                     -------             *
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********************************
* files used                   *
*         RFPfoud1.PDF         *
*         UHYfoud1.PDF         *
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--APPENDIX C4 : 50 YEAR EVENT

Composite inflow hydrograph and flood routing for 50 year event.

kensim
0 1

SUBCATCHMENT

NET RAINS:	0.047	0.047	0.047	0.069	0.071	0.071	0.077	0.091
	0.126	0.148	0.174	0.268	0.306	0.333	0.372	0.395
	0.372	0.333	0.306	0.268	0.174	0.148	0.126	0.091
	0.077	0.071	0.071	0.069	0.047	0.047	0.047	
UH ORDS.	0.000	0.000	0.000	2.521	5.042	7.563	10.083	12.604
	15.125	17.646	20.167	18.514	16.861	15.208	13.556	11.903
	10.250	8.598	6.945	5.292	3.639	1.987	0.334	

SUBCATCHMENT 2

NET RAINS:	0.037	0.037	0.037	0.054	0.055	0.055	0.060	0.071
	0.098	0.116	0.136	0.209	0.239	0.260	0.289	0.307
	0.289	0.260	0.239	0.209	0.136	0.116	0.098	0.071
	0.060	0.055	0.055	0.054	0.037	0.037	0.037	
UH ORDS.	3.001	6.001	9.002	12.002	10.416	8.449	6.481	4.514
	2.547	0.580						

SUBCATCHMENT 3

NET RAINS:	0.035	0.035	0.035	0.051	0.052	0.052	0.057	0.067
	0.093	0.109	0.129	0.198	0.226	0.246	0.274	0.291
	0.274	0.246	0.226	0.198	0.129	0.109	0.093	0.067
	0.057	0.052	0.052	0.051	0.035	0.035	0.035	
UH ORDS.	4.617	9.235	9.698	6.671	3.644	0.617		

KENSIM FOR 103.0 mm, 93.0-hour STORM

TIME	RAIN	SUBCATCHMENT FLOWS			TOTAL
hr	mm/hr	cumecs	cumecs	cumecs	cumecs
0.0	0.032	9.75	0.97	0.51	11.23
3.0	0.032	9.75	1.19	0.83	11.78
6.0	0.032	9.75	1.52	1.17	12.45
9.0	0.047	9.87	2.02	1.48	13.36
12.0	0.048	10.11	2.51	1.76	14.37
15.0	0.048	10.47	2.98	1.95	15.39
18.0	0.053	11.00	3.45	2.09	16.54
21.0	0.062	11.71	3.87	2.25	17.83
24.0	0.086	12.60	4.31	2.52	19.44
27.0	0.101	13.68	4.83	2.97	21.48
30.0	0.119	15.00	5.51	3.54	24.05
33.0	0.183	16.43	6.54	4.41	27.38
36.0	0.209	18.04	7.88	5.58	31.50
39.0	0.227	19.89	9.52	6.80	36.22
42.0	0.253	22.14	11.48	7.93	41.55
45.0	0.269	24.85	13.46	8.92	47.22
48.0	0.253	28.12	15.24	9.55	52.90

51.0	0.227	31.99	16.66	9.70	58.35
54.0	0.209	36.48	17.54	9.41	63.44
57.0	0.183	41.38	17.75	8.79	67.93
60.0	0.119	46.51	17.18	7.78	71.46
63.0	0.101	51.67	16.02	6.53	74.23
66.0	0.086	56.40	14.41	5.33	76.14
69.0	0.062	60.34	12.47	4.30	77.11
72.0	0.053	63.35	10.55	3.46	77.36
75.0	0.048	65.20	8.82	2.87	76.89
78.0	0.048	65.75	7.33	2.48	75.56
81.0	0.047	65.05	6.18	2.26	73.48
84.0	0.032	63.26	5.31	2.09	70.65
87.0	0.032	60.49	4.70	1.90	67.09
90.0	0.032	56.92	4.24	1.73	62.89
93.0		52.94	3.75	1.46	58.15
96.0		48.70	3.27	1.08	53.06
99.0		44.33	2.77	0.73	47.84
102.0		40.00	2.21	0.50	42.71
105.0		35.83	1.75	0.37	37.95
108.0		31.91	1.39	0.35	33.65
111.0		28.30	1.14	0.35	29.79
114.0		25.04	0.98	0.35	26.37
117.0		22.21	0.88	0.35	23.44
120.0		19.74	0.86	0.35	20.95
123.0		17.59	0.86	0.35	18.80
126.0		15.90	0.86	0.35	17.11
129.0		14.52	0.86	0.35	15.73
132.0		13.41	0.86	0.35	14.62
135.0		12.50	0.86	0.35	13.71
138.0		11.76	0.86	0.35	12.97
141.0		11.15	0.86	0.35	12.36
144.0		10.66	0.86	0.35	11.87
147.0		10.29	0.86	0.35	11.50
150.0		10.03	0.86	0.35	11.24
153.0		9.86	0.86	0.35	11.07
156.0		9.77	0.86	0.35	10.98
159.0		9.75	0.86	0.35	10.96
162.0		9.75	0.86	0.35	10.96
165.0		9.75	0.86	0.35	10.96
168.0		9.75	0.86	0.35	10.96
171.0		9.75	0.86	0.35	10.96
174.0		9.75	0.86	0.35	10.96
177.0		9.75	0.86	0.35	10.96
180.0		9.75	0.86	0.35	10.96
183.0		9.75	0.86	0.35	10.96
186.0		9.75	0.86	0.35	10.96
189.0		9.75	0.86	0.35	10.96
192.0		9.75	0.86	0.35	10.96
195.0		9.75	0.86	0.35	10.96
198.0		9.75	0.86	0.35	10.96
201.0		9.75	0.86	0.35	10.96
204.0		9.75	0.86	0.35	10.96
207.0		9.75	0.86	0.35	10.96
210.0		9.75	0.86	0.35	10.96
213.0		9.75	0.86	0.35	10.96
216.0		9.75	0.86	0.35	10.96
219.0		9.75	0.86	0.35	10.96
222.0		9.75	0.86	0.35	10.96
225.0		9.75	0.86	0.35	10.96
228.0		9.75	0.86	0.35	10.96
231.0		9.75	0.86	0.35	10.96
234.0		9.75	0.86	0.35	10.96
237.0		9.75	0.86	0.35	10.96
240.0		9.75	0.86	0.35	10.96
243.0		9.75	0.86	0.35	10.96
246.0		9.75	0.86	0.35	10.96

249.0	9.75	0.86	0.35	10.96
252.0	9.75	0.86	0.35	10.96
255.0	9.75	0.86	0.35	10.96
258.0	9.75	0.86	0.35	10.96
261.0	9.75	0.86	0.35	10.96
264.0	9.75	0.86	0.35	10.96
267.0	9.75	0.86	0.35	10.96
270.0	9.75	0.86	0.35	10.96
273.0	9.75	0.86	0.35	10.96
276.0	9.75	0.86	0.35	10.96

FLOOD ROUTING ASSUMING THROTTLE OF 14.00 cumecs
AND FLOOD PLAIN STORAGE LAG OF 32.00 hours

TIME hr	INFLOW cumecs	Q2 cumecs	Q3 cumecs	OUTFLOW cumecs	STORAGE Mm3
0.00	11.23	0.00	0.00	11.23	0.000
3.00	11.78	0.00	0.00	11.78	0.000
6.00	12.45	0.00	0.00	12.45	0.000
9.00	13.36	0.00	0.00	13.36	0.000
12.00	14.37	0.37	0.02	14.02	0.002
15.00	15.39	1.39	0.09	14.09	0.011
18.00	16.54	2.54	0.26	14.26	0.030
21.00	17.83	3.83	0.52	14.52	0.060
24.00	19.44	5.44	0.89	14.89	0.103
27.00	21.48	7.48	1.39	15.39	0.160
30.00	24.05	10.05	2.05	16.05	0.236
33.00	27.38	13.38	2.91	16.91	0.336
36.00	31.50	17.50	4.03	18.03	0.465
39.00	36.22	22.22	5.45	19.45	0.628
42.00	41.55	27.55	7.19	21.19	0.828
45.00	47.22	33.22	9.27	23.27	1.067
48.00	52.90	38.90	11.66	25.66	1.344
51.00	58.35	44.35	14.35	28.35	1.653
54.00	63.44	49.44	17.26	31.26	1.988
57.00	67.93	53.93	20.34	34.34	2.343
60.00	71.46	57.46	23.50	37.50	2.707
63.00	74.23	60.23	26.67	40.67	3.072
66.00	76.14	62.14	29.75	43.75	3.428
69.00	77.11	63.11	32.70	46.70	3.767
72.00	77.36	63.36	35.43	49.43	4.081
75.00	76.89	62.89	37.91	51.91	4.367
78.00	75.56	61.56	40.08	54.08	4.618
81.00	73.48	59.48	41.91	55.91	4.828
84.00	70.65	56.65	43.36	57.36	4.995
87.00	67.09	53.09	44.39	58.39	5.114
90.00	62.89	48.89	44.98	58.98	5.182
93.00	58.15	44.15	45.12	59.12	5.198
96.00	53.06	39.06	44.80	58.80	5.161
99.00	47.84	33.84	44.06	58.06	5.075
102.00	42.71	28.71	42.91	56.91	4.943
105.00	37.95	23.95	41.43	55.43	4.772
108.00	33.65	19.65	39.67	53.67	4.570
111.00	29.79	15.79	37.71	51.71	4.344
114.00	26.37	12.37	35.59	49.59	4.100
117.00	23.44	9.44	33.38	47.38	3.846
120.00	20.95	6.95	31.13	45.13	3.586
123.00	18.80	4.80	28.87	42.87	3.326
126.00	17.11	3.11	26.64	40.64	3.069

129.00	15.73	1.73	24.47	38.47	2.819
132.00	14.62	0.62	22.39	36.39	2.579
135.00	13.71	0.00	20.41	34.12	2.351
138.00	12.97	0.00	18.58	31.56	2.141
141.00	12.36	0.00	16.92	29.28	1.949
144.00	11.87	0.00	15.41	27.28	1.775
147.00	11.50	0.00	14.03	25.53	1.616
150.00	11.24	0.00	12.77	24.02	1.471
153.00	11.07	0.00	11.63	22.70	1.340
156.00	10.98	0.00	10.59	21.56	1.220
159.00	10.96	0.00	9.64	20.60	1.111
162.00	10.96	0.00	8.78	19.74	1.011
165.00	10.96	0.00	7.99	18.95	0.921
168.00	10.96	0.00	7.28	18.24	0.838
171.00	10.96	0.00	6.63	17.59	0.763
174.00	10.96	0.00	6.03	16.99	0.695
177.00	10.96	0.00	5.49	16.45	0.633
180.00	10.96	0.00	5.00	15.96	0.576
183.00	10.96	0.00	4.55	15.51	0.525
186.00	10.96	0.00	4.15	15.11	0.478
189.00	10.96	0.00	3.78	14.74	0.435
192.00	10.96	0.00	3.44	14.40	0.396
195.00	10.96	0.00	3.13	14.09	0.361
198.00	10.96	0.00	2.85	13.81	0.328
201.00	10.96	0.00	2.59	13.55	0.299
204.00	10.96	0.00	2.36	13.32	0.272
207.00	10.96	0.00	2.15	13.11	0.248
210.00	10.96	0.00	1.96	12.92	0.226
213.00	10.96	0.00	1.78	12.74	0.205
216.00	10.96	0.00	1.62	12.58	0.187
219.00	10.96	0.00	1.48	12.44	0.170
222.00	10.96	0.00	1.35	12.31	0.155
225.00	10.96	0.00	1.23	12.19	0.141
228.00	10.96	0.00	1.12	12.08	0.129
231.00	10.96	0.00	1.02	11.98	0.117
234.00	10.96	0.00	0.93	11.89	0.107
237.00	10.96	0.00	0.84	11.80	0.097
240.00	10.96	0.00	0.77	11.73	0.088
243.00	10.96	0.00	0.70	11.66	0.080
246.00	10.96	0.00	0.64	11.60	0.073
249.00	10.96	0.00	0.58	11.54	0.067
252.00	10.96	0.00	0.53	11.49	0.061
255.00	10.96	0.00	0.48	11.44	0.055
258.00	10.96	0.00	0.44	11.40	0.050
261.00	10.96	0.00	0.40	11.36	0.046
264.00	10.96	0.00	0.36	11.32	0.042
267.00	10.96	0.00	0.33	11.29	0.038
270.00	10.96	0.00	0.30	11.26	0.035
273.00	10.96	0.00	0.27	11.23	0.032
276.00	10.96	0.00	0.25	11.21	0.029

INFLOW PEAK 77.37 cumecs AT 71.5 hours
OUTFLOW PEAK 59.13 cumecs AT 92.4 hours

PEAK STORAGE 5.199 Mm3 AT 92.4 hours
ATTENUATION 23.6 %
PEAK-PEAK LAG 20.9 hours
STOP

APPENDIX C5 : JUNE 1971 SIMULATION

Composite inflow hydrograph and flood routing for simulated 1971 event.

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SUBCATCHMENT

NET RAINS:   0.000   0.000   0.263   0.015   0.031   0.279   0.015   0.008
             0.023   0.000   0.000   0.062   0.000   0.031   0.003   0.006
             0.232   0.263   0.658   0.380   0.844   0.418   0.945   0.163

UH ORDS.     0.000   0.000   0.000   2.521   5.042   7.563  10.083  12.604
            15.125  17.646  20.167  18.514  16.861  15.208  13.556  11.903
            10.250   8.598   6.945   5.292   3.639   1.987   0.334

SUBCATCHMENT  2

NET RAINS:   0.000   0.000   0.145   0.009   0.017   0.154   0.009   0.004
             0.013   0.000   0.000   0.034   0.000   0.017   0.004   0.004
             0.128   0.145   0.364   0.210   0.466   0.231   0.522   0.090

UH ORDS.     3.001   6.001   9.002  12.002  10.416   8.449   6.481   4.514
             2.547   0.580

SUBCATCHMENT  3

NET RAINS:   0.000   0.000   0.102   0.006   0.012   0.108   0.006   0.003
             0.009   0.000   0.000   0.024   0.000   0.012   0.003   0.003
             0.090   0.102   0.254   0.147   0.326   0.161   0.365   0.063

UH ORDS.     4.617   9.235   9.698   6.671   3.644   0.617


KENSIM - SIMULATION OF JUNE 1971 FLOOD

TIME ORIGIN IS 09.00 ON  8 JUNE 1971
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TIME	RAIN	SUBCATCHMENT FLOWS			TOTAL
hr	mm/hr	cumecs	cumecs	cumecs	cumecs
0.0	0.000	9.75	0.86	0.35	10.96
3.0	0.000	9.75	0.86	0.35	10.96
6.0	0.189	9.75	1.30	0.82	11.87
9.0	0.011	9.75	1.76	1.32	12.83
12.0	0.022	9.75	2.27	1.45	13.47
15.0	0.200	10.41	3.25	1.69	15.36
18.0	0.011	11.12	3.58	1.90	16.60
21.0	0.006	11.90	3.83	1.63	17.36
24.0	0.017	13.38	4.04	1.24	18.67
27.0	0.000	14.91	3.54	0.90	19.35
30.0	0.000	16.45	2.94	0.55	19.93
33.0	0.044	18.05	2.42	0.53	21.00
36.0	0.000	19.65	2.03	0.61	22.29
39.0	0.022	20.15	1.80	0.64	22.59
42.0	0.006	20.75	1.60	0.63	22.98
45.0	0.006	21.21	1.48	0.59	23.29
48.0	0.167	20.59	1.84	0.92	23.34

51.0	0.189	19.92	2.56	1.74	24.23
54.0	0.472	19.24	4.38	3.37	26.99
57.0	0.272	19.05	6.80	4.97	30.83
60.0	0.606	19.53	10.04	6.68	36.24
63.0	0.300	21.66	13.30	7.65	42.60
66.0	0.678	24.49	16.42	8.65	49.56
69.0	0.117	29.45	18.73	8.44	56.62
72.0		35.34	18.85	6.82	61.01
75.0		43.92	17.73	4.18	65.83
78.0		52.99	14.31	2.20	69.49
81.0		61.13	10.55	0.80	72.49
84.0		68.55	7.36	0.39	76.30
87.0		73.34	4.66	0.35	78.35
90.0		76.56	2.73	0.35	79.64
93.0		76.29	1.39	0.35	78.04
96.0		74.29	0.91	0.35	75.55
99.0		68.33	0.86	0.35	69.54
102.0		61.78	0.86	0.35	62.99
105.0		55.25	0.86	0.35	56.46
108.0		48.76	0.86	0.35	49.97
111.0		42.30	0.86	0.35	43.51
114.0		35.84	0.86	0.35	37.05
117.0		29.69	0.86	0.35	30.90
120.0		23.97	0.86	0.35	25.18
123.0		19.21	0.86	0.35	20.42
126.0		15.16	0.86	0.35	16.37
129.0		12.36	0.86	0.35	13.57
132.0		10.39	0.86	0.35	11.60
135.0		9.80	0.86	0.35	11.01
138.0		9.75	0.86	0.35	10.96
141.0		9.75	0.86	0.35	10.96
144.0		9.75	0.86	0.35	10.96
147.0		9.75	0.86	0.35	10.96
150.0		9.75	0.86	0.35	10.96
153.0		9.75	0.86	0.35	10.96
156.0		9.75	0.86	0.35	10.96
159.0		9.75	0.86	0.35	10.96
162.0		9.75	0.86	0.35	10.96
165.0		9.75	0.86	0.35	10.96
168.0		9.75	0.86	0.35	10.96
171.0		9.75	0.86	0.35	10.96
174.0		9.75	0.86	0.35	10.96
177.0		9.75	0.86	0.35	10.96
180.0		9.75	0.86	0.35	10.96
183.0		9.75	0.86	0.35	10.96
186.0		9.75	0.86	0.35	10.96
189.0		9.75	0.86	0.35	10.96
192.0		9.75	0.86	0.35	10.96
195.0		9.75	0.86	0.35	10.96
198.0		9.75	0.86	0.35	10.96
201.0		9.75	0.86	0.35	10.96
204.0		9.75	0.86	0.35	10.96
207.0		9.75	0.86	0.35	10.96
210.0		9.75	0.86	0.35	10.96
213.0		9.75	0.86	0.35	10.96

FLOOD ROUTING ASSUMING THROTTLE OF 14.00 cumecs
AND FLOOD PLAIN STORAGE LAG OF 32.00 hours

TIME	INFLOW	Q2	Q3	OUTFLOW	STORAGE

hr	cumecs	cumecs	cumecs	cumecs	mm3
0.00	10.96	0.00	0.00	10.96	0.000
3.00	10.96	0.00	0.00	10.96	0.000
6.00	11.87	0.00	0.00	11.87	0.000
9.00	12.83	0.00	0.00	12.83	0.000
12.00	13.47	0.00	0.00	13.47	0.000
15.00	15.36	1.36	0.06	14.06	0.007
18.00	16.60	2.60	0.23	14.23	0.027
21.00	17.36	3.36	0.48	14.48	0.055
24.00	18.67	4.67	0.79	14.79	0.092
27.00	19.35	5.35	1.17	15.17	0.135
30.00	19.93	5.93	1.57	15.57	0.181
33.00	21.00	7.00	2.01	16.01	0.231
36.00	22.29	8.29	2.51	16.51	0.290
39.00	22.59	8.59	3.04	17.04	0.351
42.00	22.98	8.98	3.56	17.56	0.410
45.00	23.29	9.29	4.06	18.06	0.467
48.00	23.34	9.34	4.53	18.53	0.522
51.00	24.23	10.23	5.00	19.00	0.576
54.00	26.99	12.99	5.59	19.59	0.644
57.00	30.83	16.83	6.42	20.42	0.740
60.00	36.24	22.24	7.60	21.60	0.875
63.00	42.60	28.60	9.19	23.19	1.059
66.00	49.56	35.56	11.24	25.24	1.295
69.00	56.62	42.62	13.73	27.73	1.582
72.00	61.01	47.01	16.51	30.51	1.902
75.00	65.83	51.83	19.46	33.46	2.242
78.00	69.49	55.49	22.52	36.52	2.594
81.00	72.49	58.49	25.60	39.60	2.950
84.00	76.30	62.30	28.72	42.72	3.308
87.00	78.35	64.35	31.82	45.82	3.665
90.00	79.64	65.64	34.78	48.78	4.007
93.00	78.04	64.04	37.47	51.47	4.317
96.00	75.55	61.55	39.74	53.74	4.578
99.00	69.54	55.54	41.42	55.42	4.772
102.00	62.99	48.99	42.39	56.39	4.884
105.00	56.46	42.46	42.69	56.69	4.918
108.00	49.97	35.97	42.38	56.38	4.882
111.00	43.51	29.51	41.52	55.52	4.783
114.00	37.05	23.05	40.15	54.15	4.626
117.00	30.90	16.90	38.35	52.35	4.418
120.00	25.18	11.18	36.17	50.17	4.167
123.00	20.42	6.42	33.72	47.72	3.885
126.00	16.37	2.37	31.10	45.10	3.583
129.00	13.57	0.00	28.42	41.99	3.274
132.00	11.60	0.00	25.88	37.48	2.981
135.00	11.01	0.00	23.56	34.58	2.714
138.00	10.96	0.00	21.45	32.41	2.472
141.00	10.96	0.00	19.53	30.49	2.250
144.00	10.96	0.00	17.79	28.75	2.049
147.00	10.96	0.00	16.19	27.15	1.866
150.00	10.96	0.00	14.75	25.71	1.699
153.00	10.96	0.00	13.43	24.39	1.547
156.00	10.96	0.00	12.22	23.18	1.408
159.00	10.96	0.00	11.13	22.09	1.282
162.00	10.96	0.00	10.13	21.09	1.167
165.00	10.96	0.00	9.23	20.19	1.063
168.00	10.96	0.00	8.40	19.36	0.968
171.00	10.96	0.00	7.65	18.61	0.881
174.00	10.96	0.00	6.97	17.93	0.802
177.00	10.96	0.00	6.34	17.30	0.731
180.00	10.96	0.00	5.77	16.73	0.665
183.00	10.96	0.00	5.26	16.22	0.606
186.00	10.96	0.00	4.79	15.75	0.551
189.00	10.96	0.00	4.36	15.32	0.502

192.00	10.96	0.00	3.97	14.93	0.457
195.00	10.96	0.00	3.61	14.57	0.416
198.00	10.96	0.00	3.29	14.25	0.379
201.00	10.96	0.00	3.00	13.96	0.345
204.00	10.96	0.00	2.73	13.69	0.314
207.00	10.96	0.00	2.48	13.44	0.286
210.00	10.96	0.00	2.26	13.22	0.260
213.00	10.96	0.00	2.06	13.02	0.237

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 INFLOW PEAK    79.65 cumecs   AT   89.8 hours
OUTFLOW PEAK    56.69 cumecs   AT  105.0 hours

PEAK STORAGE    4.918 Mm3   AT 105.0 hours
ATTENUATION     28.8 %
PEAK-PEAK LAG   15.1 hours
STOP
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APPENDIX C6

Composite inflow hydrographs and flood routing for 10, 25 and 100 year events.

10 Year Event

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SUBCATCHMENT

NET RAINS:	0.035	0.035	0.035	0.050	0.052	0.052	0.056	0.066
	0.092	0.108	0.127	0.196	0.223	0.243	0.271	0.286
	0.271	0.243	0.223	0.196	0.127	0.108	0.092	0.066
	0.056	0.052	0.052	0.050	0.035	0.035	0.035	
UH ORDS.	0.000	0.000	0.000	2.521	5.042	7.563	10.083	12.604
	15.125	17.646	20.167	18.514	16.861	15.208	13.556	11.903
	10.250	8.598	6.945	5.292	3.639	1.987	0.334	

SUBCATCHMENT 2

NET RAINS:	0.027	0.027	0.027	0.038	0.040	0.040	0.043	0.051
	0.071	0.083	0.098	0.150	0.171	0.187	0.208	0.221
	0.208	0.187	0.171	0.150	0.098	0.083	0.071	0.051
	0.043	0.040	0.040	0.038	0.027	0.027	0.027	
UH ORDS.	3.001	6.001	9.002	12.002	10.416	8.449	6.481	4.514
	2.547	0.580						

SUBCATCHMENT

NET RAINS:	0.025	0.025	0.025	0.036	0.038	0.038	0.041	0.048
	0.067	0.079	0.092	0.142	0.162	0.177	0.197	0.209
	0.197	0.177	0.162	0.142	0.092	0.079	0.067	0.048
	0.041	0.038	0.038	0.036	0.025	0.025	0.025	
UH ORDS.	4.617	9.235	9.698	6.671	3.644	0.617		

KENSIM FOR 78.9 mm, 93.0-hour STORM

TIME	RAIN	SUBCATCHMENT FLOWS			TOTAL
hr	mm/hr	cumecs	cumecs	cumecs	cumecs
0.0	0.032	9.75	0.94	0.47	11.16
3.0	0.032	9.75	1.10	0.70	11.55
6.0	0.032	9.75	1.34	0.94	12.03
9.0	0.047	9.84	1.69	1.16	12.69
12.0	0.048	10.01	2.04	1.36	13.42
15.0	0.048	10.27	2.38	1.50	14.15
18.0	0.053	10.66	2.72	1.60	14.98
21.0	0.062	11.18	3.02	1.72	15.92
24.0	0.086	11.83	3.34	1.91	17.08
27.0	0.101	12.62	3.71	2.23	18.56
30.0	0.119	13.57	4.20	2.65	20.42
33.0	0.183	14.62	4.94	3.27	22.83
36.0	0.209	15.79	5.90	4.11	25.80
39.0	0.227	17.14	7.09	4.99	29.22
42.0	0.253	18.78	8.49	5.80	33.07
45.0	0.269	20.76	9.91	6.51	37.18
48.0	0.253	23.14	11.20	6.96	41.29

51.0	0.227	25.96	12.21	7.07	45.25
54.0	0.209	29.24	12.85	6.86	48.95
57.0	0.183	32.81	13.00	6.42	52.22
60.0	0.119	36.54	12.59	5.69	54.82
63.0	0.101	40.31	11.75	4.79	56.86
66.0	0.086	43.75	10.60	3.93	58.28
69.0	0.062	46.63	9.20	3.19	59.02
72.0	0.053	48.82	7.83	2.58	59.23
75.0	0.048	50.17	6.58	2.16	58.91
78.0	0.048	50.57	5.51	1.88	57.96
81.0	0.047	50.06	4.68	1.72	56.46
84.0	0.032	48.75	4.06	1.60	54.40
87.0	0.032	46.74	3.62	1.46	51.82
90.0	0.032	44.14	3.29	1.34	48.77
93.0		41.23	2.94	1.15	45.32
96.0		38.14	2.60	0.87	41.61
99.0		34.96	2.23	0.62	37.82
102.0		31.80	1.83	0.46	34.08
105.0		28.76	1.50	0.37	30.62
108.0		25.90	1.24	0.35	27.50
111.0		23.27	1.06	0.35	24.68
114.0		20.90	0.94	0.35	22.19
117.0		18.83	0.88	0.35	20.06
120.0		17.03	0.86	0.35	18.24
123.0		15.47	0.86	0.35	16.68
126.0		14.23	0.86	0.35	15.44
129.0		13.23	0.86	0.35	14.44
132.0		12.41	0.86	0.35	13.62
135.0		11.76	0.86	0.35	12.97
138.0		11.22	0.86	0.35	12.43
141.0		10.77	0.86	0.35	11.98
144.0		10.41	0.86	0.35	11.62
147.0		10.14	0.86	0.35	11.35
150.0		9.96	0.86	0.35	11.17
153.0		9.83	0.86	0.35	11.04
156.0		9.76	0.86	0.35	10.97
159.0		9.75	0.86	0.35	10.96
162.0		9.75	0.86	0.35	10.96
165.0		9.75	0.86	0.35	10.96
168.0		9.75	0.86	0.35	10.96
171.0		9.75	0.86	0.35	10.96
174.0		9.75	0.86	0.35	10.96
177.0		9.75	0.86	0.35	10.96
180.0		9.75	0.86	0.35	10.96
183.0		9.75	0.86	0.35	10.96
186.0		9.75	0.86	0.35	10.96
189.0		9.75	0.86	0.35	10.96
192.0		9.75	0.86	0.35	10.96
195.0		9.75	0.86	0.35	10.96
198.0		9.75	0.86	0.35	10.96
201.0		9.75	0.86	0.35	10.96
204.0		9.75	0.86	0.35	10.96
207.0		9.75	0.86	0.35	10.96
210.0		9.75	0.86	0.35	10.96
213.0		9.75	0.86	0.35	10.96
216.0		9.75	0.86	0.35	10.96
219.0		9.75	0.86	0.35	10.96
222.0		9.75	0.86	0.35	10.96
225.0		9.75	0.86	0.35	10.96
228.0		9.75	0.86	0.35	10.96
231.0		9.75	0.86	0.35	10.96
234.0		9.75	0.86	0.35	10.96
237.0		9.75	0.86	0.35	10.96
240.0		9.75	0.86	0.35	10.96
243.0		9.75	0.86	0.35	10.96
246.0		9.75	0.86	0.35	10.96

249.0	9.75	0.86	0.35	10.96
252.0	9.75	0.86	0.35	10.96
255.0	9.75	0.86	0.35	10.96
258.0	9.75	0.86	0.35	10.96
261.0	9.75	0.86	0.35	10.96
264.0	9.75	0.86	0.35	10.96
267.0	9.75	0.86	0.35	10.96
270.0	9.75	0.86	0.35	10.96
273.0	9.75	0.86	0.35	10.96
276.0	9.75	0.86	0.35	10.96

FLOOD ROUTING ASSUMING THROTTLE OF 14.00 cumecs
AND FLOOD PLAIN STORAGE LAG OF 32.00 hours

TIME hr	INFLOW cumecs	Q2 cumecs	Q3 cumecs	OUTFLOW cumecs	STORAGE Mm3
0.00	11.16	0.00	0.00	11.16	0.000
3.00	11.55	0.00	0.00	11.55	0.000
6.00	12.03	0.00	0.00	12.03	0.000
9.00	12.69	0.00	0.00	12.69	0.000
12.00	13.42	0.00	0.00	13.42	0.000
15.00	14.15	0.15	0.01	14.01	0.001
18.00	14.98	0.98	0.06	14.06	0.007
21.00	15.92	1.92	0.18	14.18	0.021
24.00	17.08	3.08	0.39	14.39	0.045
27.00	18.56	4.56	0.70	14.70	0.080
30.00	20.42	6.42	1.13	15.13	0.130
33.00	22.83	8.83	1.71	15.71	0.197
36.00	25.80	11.80	2.48	16.48	0.285
39.00	29.22	15.22	3.46	17.46	0.399
42.00	33.07	19.07	4.69	18.69	0.540
45.00	37.18	23.18	6.16	20.16	0.710
48.00	41.29	27.29	7.87	21.87	0.906
51.00	45.25	31.25	9.78	23.78	1.127
54.00	48.95	34.95	11.87	25.87	1.367
57.00	52.22	38.22	14.08	28.08	1.622
60.00	54.82	40.82	16.36	30.36	1.884
63.00	56.86	42.86	18.64	32.64	2.147
66.00	58.28	44.28	20.87	34.87	2.404
69.00	59.02	45.02	23.00	37.00	2.649
72.00	59.23	45.23	24.98	38.98	2.877
75.00	58.91	44.91	26.78	40.78	3.084
78.00	57.96	43.96	28.36	42.36	3.267
81.00	56.46	42.46	29.68	43.68	3.420
84.00	54.40	40.40	30.74	44.74	3.541
87.00	51.82	37.82	31.49	45.49	3.627
90.00	48.77	34.77	31.92	45.92	3.677
93.00	45.32	31.32	32.02	46.02	3.688
96.00	41.61	27.61	31.79	45.79	3.662
99.00	37.82	23.82	31.25	45.25	3.599
102.00	34.08	20.08	30.41	44.41	3.504
105.00	30.62	16.62	29.33	43.33	3.379
108.00	27.50	13.50	28.06	42.06	3.232
111.00	24.68	10.68	26.63	40.63	3.068
114.00	22.19	8.19	25.09	39.09	2.890
117.00	20.06	6.06	23.48	37.48	2.705
120.00	18.24	4.24	21.84	35.84	2.516
123.00	16.68	2.68	20.20	34.20	2.327
126.00	15.44	1.44	18.57	32.57	2.140

129.00	14.44	0.44	16.99	30.99	1.958
132.00	13.62	0.00	15.49	29.12	1.785
135.00	12.97	0.00	14.11	27.07	1.625
138.00	12.43	0.00	12.84	25.27	1.480
141.00	11.98	0.00	11.70	23.68	1.347
144.00	11.62	0.00	10.65	22.27	1.227
147.00	11.35	0.00	9.70	21.05	1.117
150.00	11.17	0.00	8.83	19.99	1.017
153.00	11.04	0.00	8.04	19.08	0.926
156.00	10.97	0.00	7.32	18.29	0.843
159.00	10.96	0.00	6.66	17.62	0.768
162.00	10.96	0.00	6.07	17.03	0.699
165.00	10.96	0.00	5.52	16.48	0.636
168.00	10.96	0.00	5.03	15.99	0.579
171.00	10.96	0.00	4.58	15.54	0.528
174.00	10.96	0.00	4.17	15.13	0.480
177.00	10.96	0.00	3.80	14.76	0.437
180.00	10.96	0.00	3.46	14.42	0.398
183.00	10.96	0.00	3.15	14.11	0.363
186.00	10.96	0.00	2.87	13.83	0.330
189.00	10.96	0.00	2.61	13.57	0.301
192.00	10.96	0.00	2.38	13.34	0.274
195.00	10.96	0.00	2.16	13.12	0.249
198.00	10.96	0.00	1.97	12.93	0.227
201.00	10.96	0.00	1.79	12.75	0.207
204.00	10.96	0.00	1.63	12.59	0.188
207.00	10.96	0.00	1.49	12.45	0.171
210.00	10.96	0.00	1.35	12.31	0.156
213.00	10.96	0.00	1.23	12.19	0.142
216.00	10.96	0.00	1.12	12.08	0.129
219.00	10.96	0.00	1.02	11.98	0.118
222.00	10.96	0.00	0.93	11.89	0.107
225.00	10.96	0.00	0.85	11.81	0.098
228.00	10.96	0.00	0.77	11.73	0.089
231.00	10.96	0.00	0.70	11.66	0.081
234.00	10.96	0.00	0.64	11.60	0.074
237.00	10.96	0.00	0.58	11.54	0.067
240.00	10.96	0.00	0.53	11.49	0.061
243.00	10.96	0.00	0.48	11.44	0.056
246.00	10.96	0.00	0.44	11.40	0.051
249.00	10.96	0.00	0.40	11.36	0.046
252.00	10.96	0.00	0.36	11.32	0.042
255.00	10.96	0.00	0.33	11.29	0.038
258.00	10.96	0.00	0.30	11.26	0.035
261.00	10.96	0.00	0.28	11.24	0.032
264.00	10.96	0.00	0.25	11.21	0.029
267.00	10.96	0.00	0.23	11.19	0.026
270.00	10.96	0.00	0.21	11.17	0.024
273.00	10.96	0.00	0.19	11.15	0.022
276.00	10.96	0.00	0.17	11.13	0.020

INFLOW PEAK 59.23 cumecs AT 71.7 hours
OUTFLOW PEAK 46.02 cumecs AT 92.4 hours

PEAK STORAGE 3.689 Mm3 AT 92.4 hours
ATTENUATION 22.3 %
PEAK-PEAK LAG 20.7 hours
STOP

25 Year Event

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SUBCATCHMENT

NET RAINS:	0.042	0.042	0.042	0.060	0.062	0.062	0.068	0.080
	0.111	0.130	0.153	0.235	0.268	0.292	0.326	0.346
	0.326	0.292	0.268	0.235	0.153	0.130	0.111	0.080
	0.068	0.062	0.062	0.060	0.042	0.042	0.042	
UH ORDS.	0.000	0.000	0.000	2.521	5.042	7.563	10.083	12.604
	15.125	17.646	20.167	18.514	16.861	15.208	13.556	11.903
	10.250	8.598	6.945	5.292	3.639	1.987	0.334	

SUBCATCHMENT

NET RAINS:	0.032	0.032	0.032	0.047	0.048	0.048	0.053	0.062
	0.086	0.101	0.118	0.182	0.208	0.226	0.252	0.268
	0.252	0.226	0.208	0.182	0.118	0.101	0.086	0.062
	0.053	0.048	0.048	0.047	0.032	0.032	0.032	
UH ORDS.	3.001	6.001	9.002	12.002	10.416	8.449	6.481	4.514
	2.547	0.580						

SUBCATCHMENT

NET RAINS:	0.030	0.030	0.030	0.044	0.046	0.046	0.050	0.058
	0.081	0.095	0.112	0.172	0.197	0.214	0.239	0.254
	0.239	0.214	0.197	0.172	0.112	0.095	0.081	0.058
	0.050	0.046	0.046	0.044	0.030	0.030	0.030	
UH ORDS.	4.617	9.235	9.698	6.671	3.644	0.617		

KENSIM FOR 92.2 mm, 93.0-hour STORM

TIME	RAIN	SUBCATCHMENT FLOWS			TOTAL
hr	mm/hr	cumecs	cumecs	cumecs	cumecs
0.0	0.032	9.75	0.96	0.49	11.20
3.0	0.032	9.75	1.15	0.77	11.67
6.0	0.032	9.75	1.44	1.07	12.26
9.0	0.047	9.85	1.87	1.33	13.06
12.0	0.048	10.06	2.29	1.58	13.94
15.0	0.048	10.38	2.71	1.74	14.83
18.0	0.053	10.84	3.12	1.87	15.83
21.0	0.062	11.47	3.48	2.01	16.95
24.0	0.086	12.25	3.87	2.24	18.36
27.0	0.101	13.20	4.32	2.63	20.15
30.0	0.119	14.35	4.91	3.13	22.39
33.0	0.183	15.60	5.81	3.89	25.30
36.0	0.209	17.02	6.97	4.91	28.90
39.0	0.227	18.64	8.41	5.97	33.02
42.0	0.253	20.61	10.11	6.96	37.67
45.0	0.269	22.99	11.83	7.81	42.64
48.0	0.253	25.85	13.39	8.36	47.60

51.0	0.227	29.24	14.63	8.50	52.37
54.0	0.209	33.18	15.40	8.25	56.82
57.0	0.183	37.48	15.58	7.70	60.76
60.0	0.119	41.97	15.08	6.82	63.87
63.0	0.101	46.49	14.07	5.74	66.30
66.0	0.086	50.63	12.67	4.69	67.99
69.0	0.062	54.09	10.97	3.79	68.86
72.0	0.053	56.73	9.31	3.06	69.09
75.0	0.048	58.35	7.79	2.54	68.69
78.0	0.048	58.83	6.50	2.21	67.54
81.0	0.047	58.22	5.49	2.01	65.72
84.0	0.032	56.65	4.73	1.86	63.24
87.0	0.032	54.22	4.21	1.70	60.13
90.0	0.032	51.10	3.80	1.56	56.45
93.0		47.61	3.38	1.32	52.30
96.0		43.89	2.96	0.99	47.84
99.0		40.06	2.53	0.68	43.27
102.0		36.26	2.04	0.48	38.78
105.0		32.61	1.63	0.37	34.61
108.0		29.17	1.32	0.35	30.85
111.0		26.01	1.11	0.35	27.46
114.0		23.15	0.96	0.35	24.46
117.0		20.67	0.88	0.35	21.90
120.0		18.51	0.86	0.35	19.72
123.0		16.62	0.86	0.35	17.83
126.0		15.14	0.86	0.35	16.35
129.0		13.93	0.86	0.35	15.14
132.0		12.95	0.86	0.35	14.16
135.0		12.16	0.86	0.35	13.37
138.0		11.51	0.86	0.35	12.72
141.0		10.98	0.86	0.35	12.19
144.0		10.55	0.86	0.35	11.76
147.0		10.22	0.86	0.35	11.43
150.0		10.00	0.86	0.35	11.21
153.0		9.85	0.86	0.35	11.06
156.0		9.76	0.86	0.35	10.97
159.0		9.75	0.86	0.35	10.96
162.0		9.75	0.86	0.35	10.96
165.0		9.75	0.86	0.35	10.96
168.0		9.75	0.86	0.35	10.96
171.0		9.75	0.86	0.35	10.96
174.0		9.75	0.86	0.35	10.96
177.0		9.75	0.86	0.35	10.96
180.0		9.75	0.86	0.35	10.96
183.0		9.75	0.86	0.35	10.96
186.0		9.75	0.86	0.35	10.96
189.0		9.75	0.86	0.35	10.96
192.0		9.75	0.86	0.35	10.96
195.0		9.75	0.86	0.35	10.96
198.0		9.75	0.86	0.35	10.96
201.0		9.75	0.86	0.35	10.96
204.0		9.75	0.86	0.35	10.96
207.0		9.75	0.86	0.35	10.96
210.0		9.75	0.86	0.35	10.96
213.0		9.75	0.86	0.35	10.96
216.0		9.75	0.86	0.35	10.96
219.0		9.75	0.86	0.35	10.96
222.0		9.75	0.86	0.35	10.96
225.0		9.75	0.86	0.35	10.96
228.0		9.75	0.86	0.35	10.96
231.0		9.75	0.86	0.35	10.96
234.0		9.75	0.86	0.35	10.96
237.0		9.75	0.86	0.35	10.96
240.0		9.75	0.86	0.35	10.96
243.0		9.75	0.86	0.35	10.96
246.0		9.75	0.86	0.35	10.96

249.0		9.75	0.86	0.35	10.96
252.0		9.75	0.86	0.35	10.96
255.0		9.75	0.86	0.35	10.96
258.0		9.75	0.86	0.35	10.96
261.0		9.75	0.86	0.35	10.96
264.0		9.75	0.86	0.35	10.96
267.0		9.75	0.86	0.35	10.96
270.0		9.75	0.86	0.35	10.96
273.0		9.75	0.86	0.35	10.96
276.0		9.75	0.86	0.35	10.96

FLOOD ROUTING ASSUMING THROTTLE OF 14.00 cumecs
AND FLOOD PLAIN STORAGE LAG OF 32.00 hours

TIME hr	INFLOW cumecs	Q2 cumecs	Q3 cumecs	OUTFLOW cumecs	STORAGE Mm3
0.00	11.20	0.00	0.00	11.20	0.000
3.00	11.67	0.00	0.00	11.67	0.000
6.00	12.26	0.00	0.00	12.26	0.000
9.00	13.06	0.00	0.00	13.06	0.000
12.00	13.94	0.00	0.00	13.94	0.000
15.00	14.83	0.83	0.04	14.04	0.004
18.00	15.83	1.83	0.15	14.15	0.018
21.00	16.95	2.95	0.35	14.35	0.041
24.00	18.36	4.36	0.65	14.65	0.075
27.00	20.15	6.15	1.06	15.06	0.122
30.00	22.39	8.39	1.62	15.62	0.186
33.00	25.30	11.30	2.35	16.35	0.271
36.00	28.90	14.90	3.31	17.31	0.382
39.00	33.02	19.02	4.54	18.54	0.522
42.00	37.67	23.67	6.04	20.04	0.696
45.00	42.64	28.64	7.84	21.84	0.903
48.00	47.60	33.60	9.92	23.92	1.143
51.00	52.37	38.37	12.26	26.26	1.412
54.00	56.82	42.82	14.79	28.79	1.704
57.00	60.76	46.76	17.48	31.48	2.013
60.00	63.87	49.87	20.24	34.24	2.331
63.00	66.30	52.30	23.00	37.00	2.649
66.00	67.99	53.99	25.69	39.69	2.960
69.00	68.86	54.86	28.27	42.27	3.256
72.00	69.09	55.09	30.66	44.66	3.532
75.00	68.69	54.69	32.83	46.83	3.781
78.00	67.54	53.54	34.73	48.73	4.001
81.00	65.72	51.72	36.33	50.33	4.185
84.00	63.24	49.24	37.60	51.60	4.331
87.00	60.13	46.13	38.50	52.50	4.435
90.00	56.45	42.45	39.02	53.02	4.495
93.00	52.30	38.30	39.14	53.14	4.509
96.00	47.84	33.84	38.87	52.87	4.477
99.00	43.27	29.27	38.21	52.21	4.402
102.00	38.78	24.78	37.21	51.21	4.287
105.00	34.61	20.61	35.91	49.91	4.137
108.00	30.85	16.85	34.37	48.37	3.960
111.00	27.46	13.46	32.65	46.65	3.762
114.00	24.46	10.46	30.80	44.80	3.548
117.00	21.90	7.90	28.87	42.87	3.326
120.00	19.72	5.72	26.89	40.89	3.098
123.00	17.83	3.83	24.91	38.91	2.870
126.00	16.35	2.35	22.96	36.96	2.645

129.00	15.14	1.14	21.06	35.06	2.426
132.00	14.16	0.16	19.24	33.24	2.216
135.00	13.37	0.00	17.52	30.89	2.019
138.00	12.72	0.00	15.95	28.68	1.838
141.00	12.19	0.00	14.53	26.71	1.673
144.00	11.76	0.00	13.23	24.99	1.524
147.00	11.43	0.00	12.04	23.48	1.387
150.00	11.21	0.00	10.96	22.17	1.263
153.00	11.06	0.00	9.98	21.04	1.150
156.00	10.97	0.00	9.09	20.06	1.047
159.00	10.96	0.00	8.28	19.24	0.953
162.00	10.96	0.00	7.54	18.50	0.868
165.00	10.96	0.00	6.86	17.82	0.790
168.00	10.96	0.00	6.25	17.21	0.720
171.00	10.96	0.00	5.69	16.65	0.655
174.00	10.96	0.00	5.18	16.14	0.597
177.00	10.96	0.00	4.72	15.68	0.543
180.00	10.96	0.00	4.29	15.25	0.495
183.00	10.96	0.00	3.91	14.87	0.450
186.00	10.96	0.00	3.56	14.52	0.410
189.00	10.96	0.00	3.24	14.20	0.373
192.00	10.96	0.00	2.95	13.91	0.340
195.00	10.96	0.00	2.69	13.65	0.310
198.00	10.96	0.00	2.45	13.41	0.282
201.00	10.96	0.00	2.23	13.19	0.257
204.00	10.96	0.00	2.03	12.99	0.234
207.00	10.96	0.00	1.85	12.81	0.213
210.00	10.96	0.00	1.68	12.64	0.194
213.00	10.96	0.00	1.53	12.49	0.176
216.00	10.96	0.00	1.39	12.35	0.161
219.00	10.96	0.00	1.27	12.23	0.146
222.00	10.96	0.00	1.16	12.12	0.133
225.00	10.96	0.00	1.05	12.01	0.121
228.00	10.96	0.00	0.96	11.92	0.110
231.00	10.96	0.00	0.87	11.83	0.100
234.00	10.96	0.00	0.79	11.75	0.092
237.00	10.96	0.00	0.72	11.68	0.083
240.00	10.96	0.00	0.66	11.62	0.076
243.00	10.96	0.00	0.60	11.56	0.069
246.00	10.96	0.00	0.55	11.51	0.063
249.00	10.96	0.00	0.50	11.46	0.057
252.00	10.96	0.00	0.45	11.41	0.052
255.00	10.96	0.00	0.41	11.37	0.047
258.00	10.96	0.00	0.38	11.34	0.043
261.00	10.96	0.00	0.34	11.30	0.039
264.00	10.96	0.00	0.31	11.27	0.036
267.00	10.96	0.00	0.28	11.24	0.033
270.00	10.96	0.00	0.26	11.22	0.030
273.00	10.96	0.00	0.23	11.19	0.027
276.00	10.96	0.00	0.21	11.17	0.025

INFLOW PEAK 69.10 cumecs AT 71.6 hours
OUTFLOW PEAK 53.15 cumecs AT 92.4 hours

PEAK STORAGE 4.510 Mm3 AT 92.4 hours
ATTENUATION 23.1 %
PEAK-PEAK LAG 20.8 hours
STOP

100 Year Event

C:\DWR\JOB\KENNET>kensim

0 1

SUBCATCHMENT

NET RAINS:	0.054	0.054	0.054	0.078	0.080	0.080	0.088	0.103
	0.143	0.168	0.197	0.304	0.347	0.377	0.420	0.447
	0.420	0.377	0.347	0.304	0.197	0.168	0.143	0.103
	0.088	0.080	0.080	0.078	0.054	0.054	0.054	
UH ORDS.	0.000	0.000	0.000	2.521	5.042	7.563	10.083	12.604
	15.125	17.646	20.167	18.514	16.861	15.208	13.556	11.903
	10.250	8.598	6.945	5.292	3.639	1.987	0.334	

SUBCATCHMENT 2

NET RAINS:	0.042	0.042	0.042	0.061	0.063	0.063	0.069	0.080
	0.112	0.132	0.155	0.238	0.271	0.295	0.329	0.350
	0.329	0.295	0.271	0.238	0.155	0.132	0.112	0.080
	0.069	0.063	0.063	0.061	0.042	0.042	0.042	
UH ORDS.	3.001	6.001	9.002	12.002	10.416	8.449	6.481	4.514
	2.547	0.580						

SUBCATCHMENT 3

NET RAINS:	0.040	0.040	0.040	0.058	0.060	0.060	0.065	0.076
	0.106	0.125	0.146	0.225	0.257	0.280	0.312	0.331
	0.312	0.280	0.257	0.225	0.146	0.125	0.106	0.076
	0.065	0.060	0.060	0.058	0.040	0.040	0.040	
UH ORDS.	4.617	9.235	9.698	6.671	3.644	0.617		

KENSIM FOR 114.2 mm, 93.0-hour STORM

TIME	RAIN	SUBCATCHMENT FLOWS			TOTAL
hr	mm/hr	cumecs	cumecs	cumecs	cumecs
0.0	0.032	9.75	0.99	0.53	11.27
3.0	0.032	9.75	1.24	0.90	11.89
6.0	0.032	9.75	1.62	1.29	12.65
9.0	0.047	9.89	2.18	1.63	13.69
12.0	0.048	10.16	2.73	1.95	14.84
15.0	0.048	10.56	3.27	2.17	16.00
18.0	0.053	11.16	3.81	2.33	17.30
21.0	0.062	11.97	4.29	2.51	18.76
24.0	0.086	12.97	4.79	2.82	20.58
27.0	0.101	14.20	5.38	3.33	22.91
30.0	0.119	15.69	6.15	3.98	25.82
33.0	0.183	17.31	7.32	4.97	29.60
36.0	0.209	19.13	8.84	6.30	34.27
39.0	0.227	21.23	10.72	7.69	39.64
42.0	0.253	23.76	12.94	8.98	45.68
45.0	0.269	26.84	15.19	10.10	52.13
48.0	0.253	30.53	17.22	10.81	58.57

51.0	0.227	34.92	18.84	10.99	64.74
54.0	0.209	40.00	19.84	10.66	70.50
57.0	0.183	45.54	20.08	9.95	75.58
60.0	0.119	51.34	19.42	8.80	79.57
63.0	0.101	57.19	18.11	7.39	82.68
66.0	0.086	62.53	16.28	6.02	84.83
69.0	0.062	66.99	14.07	4.84	85.91
72.0	0.053	70.40	11.89	3.88	86.17
75.0	0.048	72.50	9.92	3.21	85.62
78.0	0.048	73.11	8.23	2.78	84.11
81.0	0.047	72.32	6.91	2.52	81.75
84.0	0.032	70.29	5.92	2.32	78.53
87.0	0.032	67.16	5.23	2.11	74.50
90.0	0.032	63.13	4.70	1.92	69.75
93.0		58.62	4.15	1.61	64.38
96.0		53.82	3.61	1.18	58.61
99.0		48.88	3.03	0.78	52.70
102.0		43.97	2.40	0.52	46.89
105.0		39.26	1.87	0.37	41.50
108.0		34.83	1.46	0.35	36.64
111.0		30.74	1.18	0.35	32.27
114.0		27.05	0.99	0.35	28.39
117.0		23.85	0.88	0.35	25.08
120.0		21.05	0.86	0.35	22.26
123.0		18.62	0.86	0.35	19.83
126.0		16.71	0.86	0.35	17.92
129.0		15.15	0.86	0.35	16.36
132.0		13.89	0.86	0.35	15.10
135.0		12.86	0.86	0.35	14.07
138.0		12.02	0.86	0.35	13.23
141.0		11.34	0.86	0.35	12.55
144.0		10.78	0.86	0.35	11.99
147.0		10.36	0.86	0.35	11.57
150.0		10.07	0.86	0.35	11.28
153.0		9.87	0.86	0.35	11.08
156.0		9.77	0.86	0.35	10.98
159.0		9.75	0.86	0.35	10.96
162.0		9.75	0.86	0.35	10.96
165.0		9.75	0.86	0.35	10.96
168.0		9.75	0.86	0.35	10.96
171.0		9.75	0.86	0.35	10.96
174.0		9.75	0.86	0.35	10.96
177.0		9.75	0.86	0.35	10.96
180.0		9.75	0.86	0.35	10.96
183.0		9.75	0.86	0.35	10.96
186.0		9.75	0.86	0.35	10.96
189.0		9.75	0.86	0.35	10.96
192.0		9.75	0.86	0.35	10.96
195.0		9.75	0.86	0.35	10.96
198.0		9.75	0.86	0.35	10.96
201.0		9.75	0.86	0.35	10.96
204.0		9.75	0.86	0.35	10.96
207.0		9.75	0.86	0.35	10.96
210.0		9.75	0.86	0.35	10.96
213.0		9.75	0.86	0.35	10.96
216.0		9.75	0.86	0.35	10.96
219.0		9.75	0.86	0.35	10.96
222.0		9.75	0.86	0.35	10.96
225.0		9.75	0.86	0.35	10.96
228.0		9.75	0.86	0.35	10.96
231.0		9.75	0.86	0.35	10.96
234.0		9.75	0.86	0.35	10.96
237.0		9.75	0.86	0.35	10.96
240.0		9.75	0.86	0.35	10.96
243.0		9.75	0.86	0.35	10.96
246.0		9.75	0.86	0.35	10.96

249.0		9.75	0.86	0.35	10.96
252.0		9.75	0.86	0.35	10.96
255.0		9.75	0.86	0.35	10.96
258.0		9.75	0.86	0.35	10.96
261.0		9.75	0.86	0.35	10.96
264.0		9.75	0.86	0.35	10.96
267.0		9.75	0.86	0.35	10.96
270.0		9.75	0.86	0.35	10.96
273.0		9.75	0.86	0.35	10.96
276.0		9.75	0.86	0.35	10.96

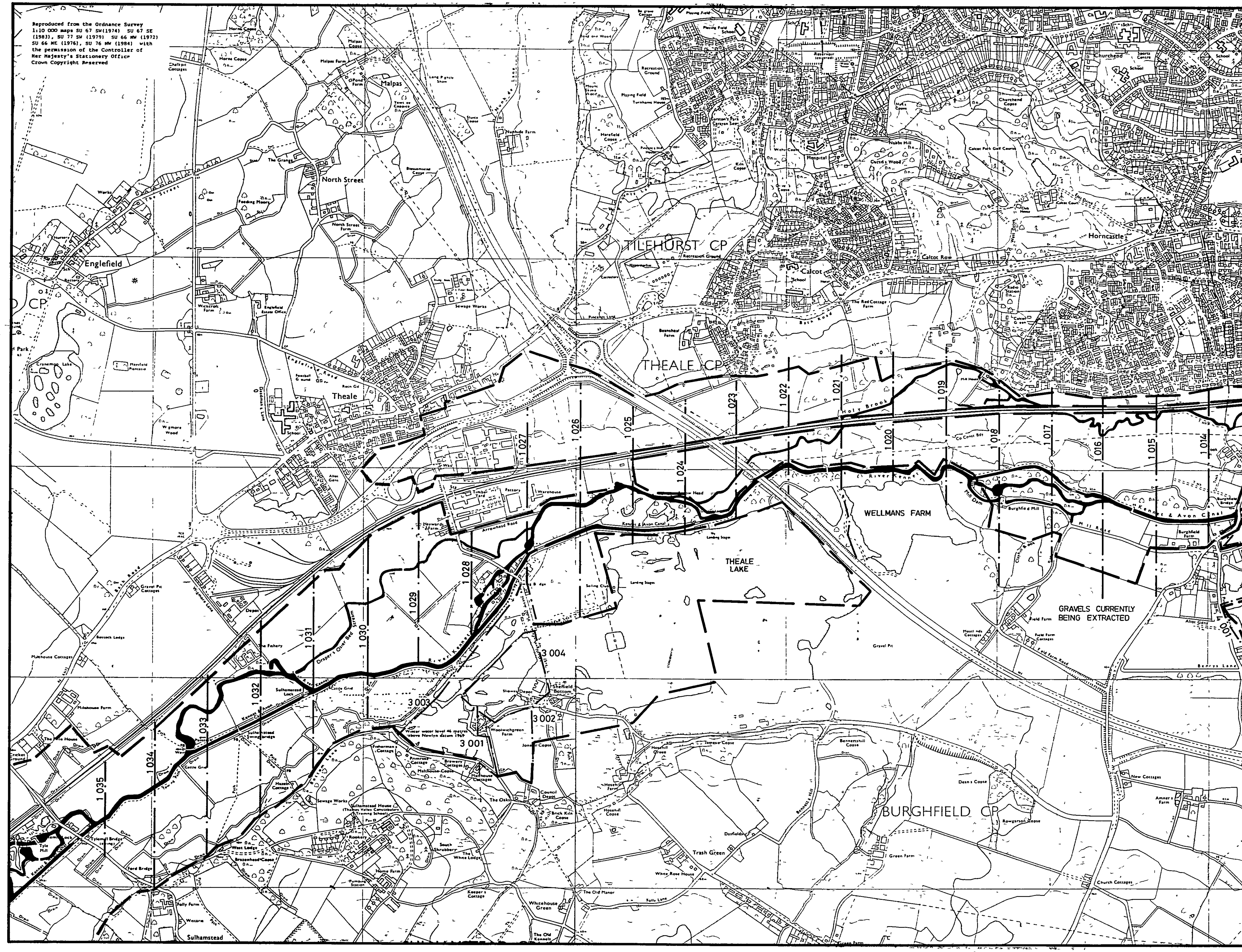
FLOOD ROUTING ASSUMING THROTTLE OF 14.00 cumecs
AND FLOOD PLAIN STORAGE LAG OF 32.00 hours

TIME hr	INFLOW cumecs	Q2 cumecs	Q3 cumecs	OUTFLOW cumecs	STORAGE Mm3
0.00	11.27	0.00	0.00	11.27	0.000
3.00	11.89	0.00	0.00	11.89	0.000
6.00	12.65	0.00	0.00	12.65	0.000
9.00	13.69	0.00	0.00	13.69	0.000
12.00	14.84	0.84	0.04	14.04	0.004
15.00	16.00	2.00	0.16	14.16	0.019
18.00	17.30	3.30	0.38	14.38	0.044
21.00	18.76	4.76	0.71	14.71	0.082
24.00	20.58	6.58	1.15	15.15	0.133
27.00	22.91	8.91	1.74	15.74	0.201
30.00	25.82	11.82	2.52	16.52	0.290
33.00	29.60	15.60	3.52	17.52	0.405
36.00	34.27	20.27	4.81	18.81	0.554
39.00	39.64	25.64	6.43	20.43	0.741
42.00	45.68	31.68	8.42	22.42	0.970
45.00	52.13	38.13	10.79	24.79	1.243
48.00	58.57	44.57	13.53	27.53	1.558
51.00	64.74	50.74	16.58	30.58	1.910
54.00	70.50	56.50	19.89	33.89	2.292
57.00	75.58	61.58	23.40	37.40	2.695
60.00	79.57	65.57	26.99	40.99	3.109
63.00	82.68	68.68	30.58	44.58	3.523
66.00	84.83	70.83	34.09	48.09	3.927
69.00	85.91	71.91	37.42	51.42	4.311
72.00	86.17	72.17	40.52	54.52	4.668
75.00	85.62	71.62	43.33	57.33	4.992
78.00	84.11	70.11	45.79	59.79	5.276
81.00	81.75	67.75	47.86	61.86	5.514
84.00	78.53	64.53	49.50	63.50	5.702
87.00	74.50	60.50	50.67	64.67	5.837
90.00	69.75	55.75	51.33	65.33	5.914
93.00	64.38	50.38	51.49	65.49	5.931
96.00	58.61	44.61	51.13	65.13	5.890
99.00	52.70	38.70	50.28	64.28	5.793
102.00	46.89	32.89	48.99	62.99	5.643
105.00	41.50	27.50	47.31	61.31	5.450
108.00	36.64	22.64	45.32	59.32	5.220
111.00	32.27	18.27	43.09	57.09	4.964
114.00	28.39	14.39	40.70	54.70	4.688
117.00	25.08	11.08	38.19	52.19	4.400
120.00	22.26	8.26	35.64	49.64	4.106
123.00	19.83	5.83	33.08	47.08	3.811
126.00	17.92	3.92	30.56	44.56	3.520

129.00	16.36	2.36	28.10	42.10	3.238
132.00	15.10	1.10	25.74	39.74	2.966
135.00	14.07	0.07	23.49	37.49	2.706
138.00	13.23	0.00	21.39	34.63	2.465
141.00	12.55	0.00	19.48	32.02	2.244
144.00	11.99	0.00	17.74	29.73	2.043
147.00	11.57	0.00	16.15	27.72	1.860
150.00	11.28	0.00	14.70	25.98	1.694
153.00	11.08	0.00	13.39	24.47	1.542
156.00	10.98	0.00	12.19	23.17	1.404
159.00	10.96	0.00	11.10	22.06	1.279
162.00	10.96	0.00	10.11	21.07	1.164
165.00	10.96	0.00	9.20	20.16	1.060
168.00	10.96	0.00	8.38	19.34	0.965
171.00	10.96	0.00	7.63	18.59	0.879
174.00	10.96	0.00	6.95	17.91	0.800
177.00	10.96	0.00	6.32	17.28	0.729
180.00	10.96	0.00	5.76	16.72	0.663
183.00	10.96	0.00	5.24	16.20	0.604
186.00	10.96	0.00	4.77	15.73	0.550
189.00	10.96	0.00	4.35	15.31	0.501
192.00	10.96	0.00	3.96	14.92	0.456
195.00	10.96	0.00	3.60	14.56	0.415
198.00	10.96	0.00	3.28	14.24	0.378
201.00	10.96	0.00	2.99	13.95	0.344
204.00	10.96	0.00	2.72	13.68	0.313
207.00	10.96	0.00	2.48	13.44	0.285
210.00	10.96	0.00	2.25	13.21	0.260
213.00	10.96	0.00	2.05	13.01	0.237
216.00	10.96	0.00	1.87	12.83	0.215
219.00	10.96	0.00	1.70	12.66	0.196
222.00	10.96	0.00	1.55	12.51	0.179
225.00	10.96	0.00	1.41	12.37	0.163
228.00	10.96	0.00	1.28	12.24	0.148
231.00	10.96	0.00	1.17	12.13	0.135
234.00	10.96	0.00	1.07	12.03	0.123
237.00	10.96	0.00	0.97	11.93	0.112
240.00	10.96	0.00	0.88	11.84	0.102
243.00	10.96	0.00	0.80	11.76	0.093
246.00	10.96	0.00	0.73	11.69	0.084
249.00	10.96	0.00	0.67	11.63	0.077
252.00	10.96	0.00	0.61	11.57	0.070
255.00	10.96	0.00	0.55	11.51	0.064
258.00	10.96	0.00	0.50	11.46	0.058
261.00	10.96	0.00	0.46	11.42	0.053
264.00	10.96	0.00	0.42	11.38	0.048
267.00	10.96	0.00	0.38	11.34	0.044
270.00	10.96	0.00	0.35	11.31	0.040
273.00	10.96	0.00	0.31	11.27	0.036
276.00	10.96	0.00	0.29	11.25	0.033

INFLOW PEAK 86.18 cumecs AT 71.5 hours
OUTFLOW PEAK 65.50 cumecs AT 92.4 hours

PEAK STORAGE 5.933 Mm3 AT 92.4 hours
ATTENUATION 24.0 %
PEAK-PEAK LAG 20.9 hours
STOP



LEGEND

LIMIT OF 1971 FLOOD

SURVEY CROSS SECTIONS WITH LEVELS EVERY 100 m AND AT CHANGES OF SLOPE

0 500 m

SCALE 1 10 000

THAMES WATER

KENNET VALLEY STUDY

AREA OF SURVEY AND CROSS SECTIONS

SIR ALEXANDER GIBB & PARTNERS

APRIL 1987

FIG 2.2

THAMES WATER
KENNET VALLEY STUDY

PLAN OF STRUCTURES

SIR ALEXANDER GIBB & PARTNERS
APRIL 1987 FIG 2.1

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LEGEND.

- Flood information from aerial and ground inspection
- Gravel pits - Indicative only
- Bank overtopped
- 44.44 Flood level (m o d)

THAMES WATER

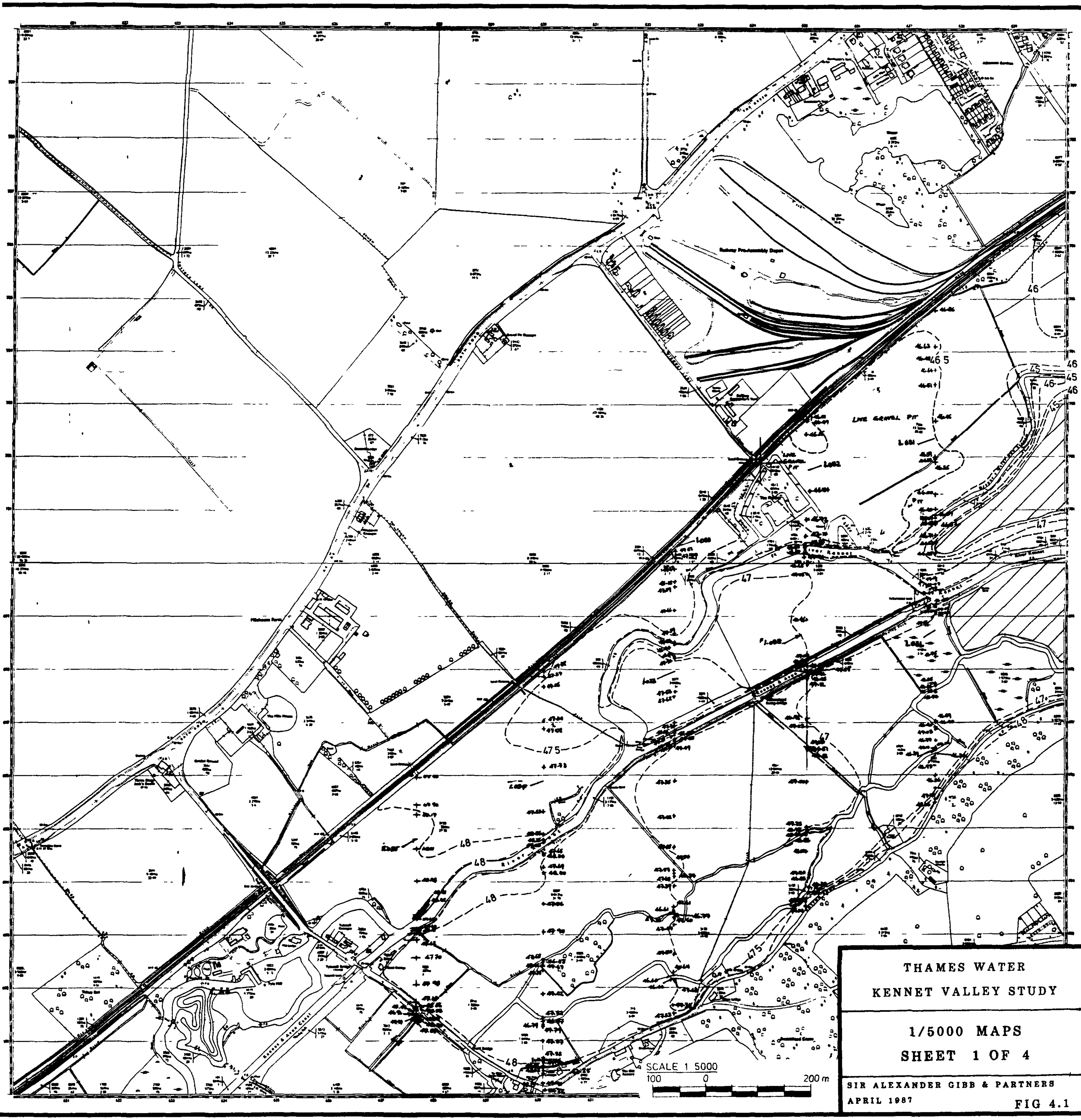
KENNET VALLEY STUDY

EXTENT OF 1971 FLOOD AND RECORDED LEVELS

SIR ALEXANDER GIBB & PARTNERS

APRIL 1987

FIG 2.3



THAMES WATER

KENNET VALLEY STUDY

1/5000 MAPS

SHEET 1 OF 4

SIR ALEXANDER GIBB & PARTNERS

APRIL 1987

FIG 4.1

THAMES WATER
KENNET VALLEY STUDY

1/5000 MAPS
SHEET 2 OF 4

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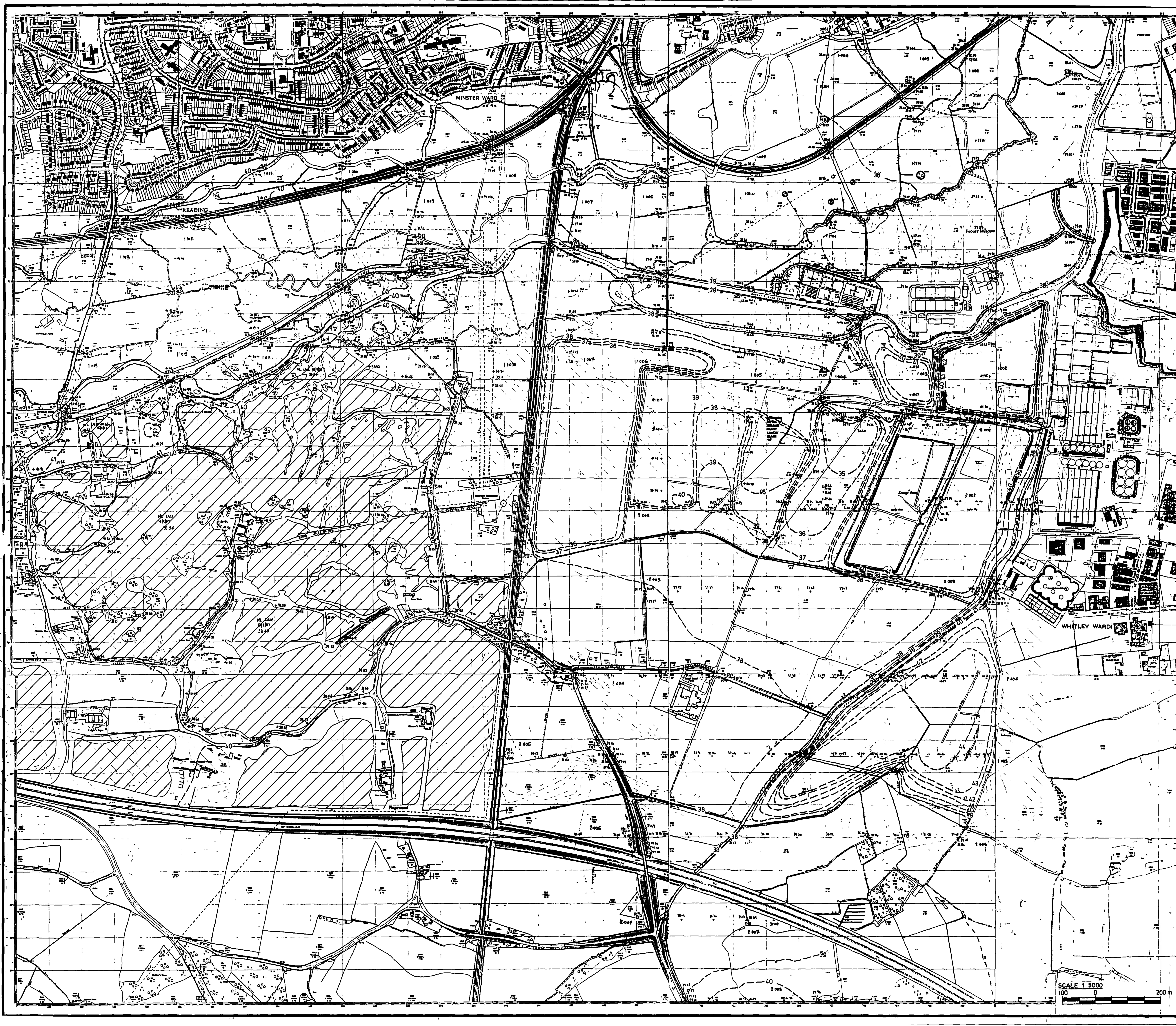
FIG 4.2



THAMES WATER

KENNET VALLEY STUDY

1/5000 MAPS

SHEET 3 OF 4

SIR ALEXANDER GIBB & PARTNERS

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FIG 4.3

THAMES WATER
KENNET VALLEY STUDY

1/5000 MAPS
SHEET 4 OF 4

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FIG 4.4

LEGEND

- Flood information from aerial and ground inspection in 1971.
- Gravel pits. Indicative only
- Bank overtopped. Indicative only
- (44.44) Flood level. (m a.o.d.) in 1971.

Flood envelopes
- 1 in 10 year
- 1971
- 1 in 100 year

THAMES WATER

KENNET VALLEY STUDY

FLOOD ENVELOPES

SIR ALEXANDER GIBB & PARTNERS

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FIG 4.5

LEGEND

- LAND WITH PLANNING PERMISSION FOR GRAVEL EXTRACTION
- AREAS NOT YET APPLIED FOR
- PLANNING APPLICATION MADE FOR GRAVEL EXTRACTION
- AREA TO REMAIN AS LAKE
- AREA TO BE RESTORED TO LAKE
- EXISTING GRAVEL PIT

NOTE:
ALL LAKES IN THIS AREA HAVE BEEN CREATED ARTIFICIALLY FROM GRAVEL PITS SINCE 1947

THAMES WATER

KENNET VALLEY STUDY

GRAVEL EXTRACTION AND OPEN WATER AREAS

SIR ALEXANDER GIBB & PARTNERS

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FIG 5 1

THAMES WATER

KENNET VALLEY STUDY

INFILLING AFTER GRAVEL EXTRACTION

SIR ALEXANDER GIBB & PARTNERS

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FIG 5.2