Institute of Hydrology

Natural Environment Research Council

RBB

# Hydrological and Hydrogeological Assessment

# Cransley Lodge, Kettering

# for

# Stock Land and Estates Ltd

# Volume 1

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# Glossary of Terms

| | |
|---|---|
| ADF | average daily flow in cumecs |
| AREA | catchment area in $km^2$ |
| BFI | base flow index |
| LAKE | proportion of the catchment covered by a lake |
| MSL | mainstream length |
| PR | percentage runoff |
| Q95(D) | flow exceeded 95% of the time, D is the duration over which the flow is averaged |
| S1085 | slope between points 10% and 85% up the main stream from the point of interest in m/km |
| SAAR | standard period (1941-1971) average annual rainfall in mm |
| SOIL | soil index, based on winter rainfall acceptance potential |
| SMD | soil moisture deficit in mm |
| SPR | standard percentage runoff |
| STMFRQ | stream frequency in junctions per $km^2$ |
| Tp | time to peak of T hour unit hydrograph |
| RSMD | one day rainfall of 5 year return period less effective mean soil moisture deficit |
| URBAN | proportion of catchment under urban development |

Within the context of this report "urbanisation" refers to the proposed village development.

# Summary

This report describes the results of studies being undertaken by the INSTITUTE OF HYDROLOGY to assess the hydrological impact of the proposed Cransley Lodge village development upon the Birch Spinney - Mawsley Marsh Site of Special Scientific Interest. Results to date suggest that the proposed village development will not have any significant hydrological impact upon the SSSI.

Following a preliminary hydrological assessment in December 1990, a monitoring network was designed and installed during March - April 1991. The network was designed to provide sufficient quantitative data to reliably characterise the major controls upon the existing surface and groundwater regimes. This network now comprises seven boreholes, five surface water flow gauges, eighteen piezometers, two soil moisture probe sites, and one rain gauge. Continuous reading chart or digital recorders were established on several sites, while monthly readings were collected at the other sites.

The hydrology of the wetland SSSI is dominated by the influence of perennial flow from springs at the western end of Birch Spinney and land drains near Mawsley Lodge. The springs have developed where the south westerly flow of groundwater within Jurassic sediments is restricted against an upfaulted block of impermeable Upper Lias clay. The land drains underlie extensive areas of reclaimed ironstone quarries to the north of the SSSI. The proposed village development will have no influence upon the quality or quantity of this perennial groundwater flow.

The primary impact of the proposed village development will be upon surface runoff from one of the four catchments supplying the SSSI. This change to surface runoff behaviour can be substantially ameliorated by established engineering practices. The volume of groundwater originating from the area of the proposed village and entering the SSSI is extremely small. The proposed development site is underlain by a considerable thickness of effectively impermeable Boulder Clay which is in turn underlain by Lias Clay, or unsaturated Pleistocene and Jurassic sands.

Infiltration from the site is therefore minimal, with most of the small amount of water which reaches the main Pleistocene/Jurassic aquifers being separated from the SSSI by a groundwater divide. The only groundwater which will reach the SSSI will be the minor amount of shallow subsurface water moving down slope through the Boulder Clay Soil horizon.

It is expected that the long term impact of the proposed development upon water quality will be minimal. The options available in the design of the drainage of runoff from roof and road surfaces and foul sewage allow for effective elimination of any impact of the proposed village upon water quality within the SSSI.

# 1. Introduction

The INSTITUTE OF HYDROLOGY has been commissioned by STOCK LAND & ESTATES LTD to undertake a hydrological and hydrogeological assessment of the impact of the development of a proposed 750 unit village at Cransley Lodge near Kettering, Northamptonshire.

This study has sought to fulfil two objectives. Firstly, to characterise the existing hydrological regime of the study area, and in particular the relationship between surface and groundwater flow in this area. Secondly, to quantify the hydrological effects of the proposed village development upon this existing regime and thereby assess the impact of the village upon the hydrology of the Birch Spinney - Mawsley Marsh wetland SSSI.

The results from this hydrological assessment will form part of a multi-disciplinary study of the wider implications of the proposed village development.

# 2. Site Description and Study Outline

## 2.1 LOCATION

The proposed Cransley Lodge village development site is situated approximately six (6) kilometres west-south-west of Kettering, Northamptonshire. The proposed village is planned to cover the area to the west of the present farm buildings at Cransley Lodge (SP812764). The northern boundary of the proposed village lies some 250 metres to the south of the Birch Spinney-Mawsley Marsh SSSI as shown on Figure 1.

## 2.2 ARTIFICIAL INFLUENCES

The hydrological regime which currently exists in the Cransley Lodge area is the result of the interaction of a number of man-made changes upon the "natural" system. The most significant of these man-made modifications have been the quarrying of the Northampton Sand for iron ore, augmenting of river flow and the clearing of land for agricultural purposes.

### 2.2.1 Ironstone Quarries

Ironstones within the Northampton Sand around Kettering have been quarried for iron ore since pre-historic times. Exploitation of these deposits increased substantially after the industrial revolution, reaching a peak in the early 1900's before ceasing in the 1960s.

Changes to the natural hydrological conditions that have been produced by these open cast quarrying operations include:

| Quarrying Operation | Hydrological Impact |
|---|---|
| Removal of Overburden | Removal of Boulder Clay, gravel and Lower Estuarine Series Sand changing infiltration and run-off. |
| Quarrying of iron ore | Physical removal of sand aquifer and replacement with less permeable material. Possible changes to groundwater chemistry. |

| | |
|---|---|
| Backfilling | Replacement of pre-existing stratified sequence of aquifers and aquicludes with a disordered mix of clays, sand and gravel. |
| Pit Development | Crossing of natural catchment divides as a quarry expands with capture of other drainages. |
| Quarrying de-watering | Laying of land drains which usually remained in place after restoration of quarry site back to agricultural use. |
| Ore transport | Construction of railway embankments and cuttings, either obstructing surface flow or truncating groundwater flow. |

These changes are most pronounced in the Cransley Lodge area to the north of the SSSI as shown on Figure 1. Smaller areas of local disturbance also occur in the vicinity of the Cransley Lodge farm buildings. In this latter area it is proposed to construct part of the village across a restored quarry site.

The main period of quarrying to the north of the SSSI took place during the early 1950s and was completed by 1958.

As part of the quarrying operations the excavations extended northwards in a continuous line to within 300 metres of Loddington Lodge. The headwaters of the stream draining into the northern arm of Cransley Reservoir were captured by these excavations and diverted southwards into the area now covered by the Mawsley Marsh SSSI. The capture of these headwaters has added 0.728 $km^2$ or 27.8% to the total catchment area of the SSSI measured at S4.

The installation of land drains, initially for quarry dewatering and then as part of site restoration, has altered the hydrological behaviour of the catchments affected by quarrying. Base flow has been eliminated from the surface channels and discharge has been focused at specific drain outfalls. Hydrological changes associated with this period of quarrying coincided with the classification of the area as a Site of Special Scientific Interest in the late 1950s.

A small site to the immediate south of the Cransley Lodge farm buildings was excavated on a trial basis during the late 1890's. Work was abandoned because of the poor quality of the ore and the excessive thickness of Boulder Clay over-burden. A poorly restored shallow depression has been left which local people report contains a body of standing water after periods of high rainfall. These particular quarrying activities have no impact upon the hydrology of the SSSI.

### 2.2.2 Augmented Spring Flow

The springs at the western end of Birch Spinney are fed by a system of trenches which augment the natural flow to this site. These trenches were installed during the drought of 1934 following the failure of a borehole (KDC 1) at this site to yield a sufficient supply. A record of both the borehole and the trenches is included in this report as Appendix VII. The borehole is thought to have been dug out as a well, and this lies beneath a steel cap to the south of the spring outfall.

The orientation, depth or extent of this trench system is unknown. Similarly the extent to which this trench system increases the spring flow is also unknown.

### 2.2.3 Agricultural Practices

The study area is predominantly cleared arable land with usage on rotation as either pasture or sown to cereal crops. The more elevated areas are underlain by Boulder Clay and appear to be more regularly cropped than the lower lying sandier areas. This cropping pattern results in a high sediment load in surface runoff from recently ploughed areas to the west of the SSSI.

The land to the north of the SSSI has in recent years been converted almost exclusively to use as pasture, and there are small areas to the south which have recently been "set aside" as part of EC quota schemes. Otherwise agricultural practices and their hydrological impact have changed very little over recent years.

There is a long established network of agricultural drains which serve to reduce the response time and increase run-off within the catchment. These features are likely to be lost during village development but as they represent such a small influence upon the hydrology their loss will not be significant. It is probable that the loss of these drainage channels will be compensated for by the village drains and balancing pond.

An hydraulic ram has operated from within Birch Spinney (827765) for several decades, abstracting up to 4000 l/d. This produces a very distinctive and regular cyclic variation in river flow rates. This hydraulic ram is also likely to be lost as a result of development of the proposed village. The slightly increased flow that will result will have a beneficial impact upon the SSSI, particularly during very dry summer periods.

## 2.3 MONITORING NETWORK

A monitoring network was established in order to characterise the local hydrological regime prior to assessing the possible impact of the proposed village development.

The network was designed to provide the necessary temporal and spatial data on rainfall, infiltration, groundwater flow, runoff and surface flows to characterise the key elements of the local regime. In particular, the network was to enable quantification of the volume and chemistry of any waters which may be affected by the proposed village and the relative importance of these waters to the maintenance of the Birch Spinney - Mawsley Marsh wetland SSSI.

To achieve this objective the network as described in Annex I and shown on Figure 2 was installed in March-April, 1991. Additional piezometers, auger holes and a soil moisture access tube were completed during the course of the study to provide data in areas where this was required. Due to difficulties calibrating surface flow at S1 and S4, temporary V-notch plates were installed at these sites. A tank weir with a 1/4 90° V-notch was also installed at the land drain outflow near Mawsley Lodge. The times over which the various components of the monitoring network have been operational are shown in Figure 3.

# 3. Geology

The Cransley Lodge area is underlain by a sequence of Pleistocene fluvio-glacial clays which partially cover Jurassic sandstones and Upper Lias clay. The stratigraphic sequence is summarised in Table 1.

*Table 1 Stratigraphic Sequence*

| | | Thickness (m) |
|---|---|---|
| RECENT | Alluvium Peat | 0-1 |
| PLEISTOCENE | Boulder Clay | 0-12 |
| | Gravel | 0-4? |
| JURASSIC | Lower Estuarine Series | 0-7 |
| | Northampton Sand | 0-7 |
| | Upper Lias Clay | >6 |

Areas of higher topographic relief are capped by Boulder Clay while valleys are incising through these sediments into the underlying Jurassic sequence (Figure 4).

On a regional scale the Jurassic sediments dip at a shallow angle (2-3°) to the south east, but are offset and rotated on a local scale by east-west oriented block faulting. The Pleistocene gravels and Boulder Clay were deposited upon an irregular weathering surface where deeper erosion occurred along friable fault zones.

## 3.1 JURASSIC SEQUENCE

The Jurassic sediments of the Northamptonshire region consist of the clay and mudstones of the Upper Lias and the more variable clays, silts, ferruginous sands and oolitic limestones of the Northampton Sand and Lower Estuarine Series. The Northampton Sand rests with varying angular unconformity upon the marine sediments of the Upper Lias. The shallow marine conditions in which the Northampton Sand was deposited were followed by the deltaic and estuarine environment in which the Lower Estuarine Series were deposited.

The Upper Lias forms the major basal aquiclude to the regionally extensive Jurassic sand aquifers. On a local scale it also acts as an important aquiclude where Pleistocene gravels rest directly upon the Lias clays.

On a local scale the dip of the Northampton Sand - Upper Lias contact, as shown in Figure 5, is quite irregular. This irregularity is thought to reflect a combination of local block faulting, and possible topographic relief on the pre-Northampton Sand erosion surface.

Variations in the distribution and geometry of the Jurassic sediments have a strong influence upon infiltration and groundwater flow and these are discussed in Chapter 4.

### 3.1.1 Upper Lias

The Upper Lias consists of bluish grey mudstones which become pale brownish grey when weathered. A deep borehole (SP77/10) at Harringdon Dale near Orton (794 791) intersected 11.6 m of Upper Lias clay above a 2.4 m thick oolite bed marking the top of the Middle Lias. Borehole BH6 finished in silty clay beneath 3.7 m of slightly weathered Upper Lias clay.

The up-thrown block of Lias clay to the south of KDC1 was a positive topographic feature during the Pleistocene. Both the Jurassic and Pleistocene gravel aquifers thin out against this ridge and hence this feature exercises an important control upon groundwater flow. Over much of this block Boulder Clay rests directly upon the Upper Lias. The relative elevations of the Boulder Clay - Upper Lias contact in P9 and BH6 suggest that this boundary dips to the south and away from the SSSI.

A similar structural relationship exists in the vicinity of the Cransley Lodge farm buildings where a southern block of Upper Lias is uplifted relative to a northern block of Jurassic sand.

Within the central portions of the SSSI the Cransley Brook cuts through a thin alluvial cover above the Upper Lias. Recent arching of the Upper Lias beneath the axis of incised valleys in response to load pressures has been reported from a number of localities in the Northamptonshire region. Some of the irregularities in the Upper Lias contact in the study area may be due to such up-warping beneath the Mawsley Marsh SSSI.

### 3.1.2 Northampton Sand

The Northampton Sand consists of orange brown, medium to coarse grained quartz sand with lesser sandy silts and clays. On a regional scale this formation can be up to 21 m thick, but within the study area the maximum thickness encountered is in the order of 7 m. Over much of the study area substantial parts of the Northampton Sand have been removed by Pleistocene and/or Recent erosion. The Northampton Sand is the major regional aquifer in the study area, and also the aquifer primarily responsible for supporting surface flow through the wetland SSSI.

Complete sections of Northampton Sand have been encountered in BH's 2-4 while reduced sections have been encountered in BH5, BH6, and KBC1. Changes in the thickness and lithology of the unit due to original depositional conditions are apparent in these boreholes, although there is insufficient data to show particular trends. Ironstone is developed in the basal portions of the unit and thin limestone bands occur throughout the section. Where the ironstone has been encountered at Cransley Lodge it is almost always oxidised and consists of irregular veins of iron oxides filling joints, fractures and bedding planes. In its unoxidised state the ironstone consists of chamositic, kaolinitic, sideritic and limonitic oolites.

The continuity of the Northampton Sand has been strongly disrupted by a series of northeast-southwest trending normal faults. These faults are part of a regional structural pattern which may be related to Cretaceous age tectonism. Two such faults have been identified within the study area and are shown on Figure 6. In the vicinity of KDC1 and P14 this faulting has involved downthrow of the northern blocks by several tens of metres, creating impermeable barriers to the southeasterly groundwater flow through the Northampton Sand.

To the north of the SSSI the Northampton Sand - Upper Lias contact has been rotated by faulting to dip in a south-easterly direction. Within the fault block to the immediate south of the SSSI the Northampton Sand dips gently to the north east, as shown in Figure 5, and thins rapidly to the southwest as a result of Pleistocene erosion.

### 3.1.2 Lower Estuarine Series

The Lower Estuarine Series in the Cransley Lodge area consists of intercalated fine yellowish white sands, silt and occasional clay lenses. The base of the Series is marked by a persistent 25-30 cm thick dense dark grey clay horizon. The outcrop trace of this basal clay is shown in Figure 7 as is the elevation to the top of this horizon. In the fault block to the south of the SSSI this unit dips at approximately 0.6 degrees to the north north east.

In the Kettering district the Lower Estuarine Series can be up to 7.6 m thick, however over most of the Cransley Lodge area this Series has been removed by Pleistocene erosion. In areas where it is preserved, such as between BH3 and BH4 the Series reaches a maximum thickness of approximately 6.0 m (Figure 8).

Regional data from BGS mapping suggests that the Lower Estuarine Series is absent beneath the Pleistocene unconformity in the area to the north of the SSSI. However, the clay horizon intersected between 2.6-3.0 m BGL in BH2 may be the basal portion of the Lower Estuarine Series.

## 3.2 PLEISTOCENE DEPOSITS

The Pleistocene sequence consists predominantly of dark grey to black, dense impermeable Boulder Clay with variable amounts of clastic material. These clastics are usually matrix supported and are more common towards the base of the section. Chert, chalk and limestone fragments predominate throughout the section, while the basal portions have a greater proportion of ironstone or Lias clay clasts derived from the underlying Jurassic sequence.

In some locations the clastics have sufficient continuity to be mapped as a separate basal gravel unit. In the study area this basal gravel plays a significant role in controlling the local hydrogeological regime.

The Pleistocene sediments were deposited on an irregular erosion surface as shown in Figure 9. During this time a valley existed approximately coincident with the location of the present valley. It is thought that this deeper erosion may have been as a result of fracturing of the Jurassic rocks along the faults which strike sub-parallel to this valley. The available data also suggests that there was a northeast trending Pleistocene age topographic high between BH6 and BH5. This ridge is believed to form an important groundwater divide separating much of the proposed village site from the SSSI to the north.

### 3.2.1 Pleistocene Gravel

Coarser fluvio-glacial clastic material of Pleistocene age occurs at the base of the Boulder Clay. British Geological Survey mapping of the Kettering Sheet area indicated that this gravel was absent between BH4 and BH5, however the present study has shown it extends southwest from auger hole A4 to P16, lensing out before P17.

This gravel unit is highly variable in geometry and lithology (Figure 10). Along the southern margins of the SSSI the "gravel" is represented by several tens of centimetres of uniform medium grained sand in P10, thickening eastwards to include coarse pebbles in P16 and further thickening and coarsening towards BH4 where it contains coarse gravel boulders. The 2 cm thick sand unit encountered immediately above the Lower Lias in BH6 is thought to be a fine grained lateral, but hydraulically separate, equivalent of this unit.

Clay horizons intercalated with the gravels have been found at several locations (BH4, BH5, P11, P12, P16, SM2). It is unlikely that these represent a single laterally continuous unit.

### 3.2.2 Boulder Clay

Boulder Clay underlies most of the proposed village site. As shown in Figure 11 this unit is thickest along ridge crests, being in excess of 12 m thick to the south and west of BH6. It is everywhere a very dense and impermeable material with only scattered matrix supported clasts.

Two thin sandy silt units were encountered within the Boulder Clay in BH6. Only the upper unit was sufficiently continuous to extend the 10 m to BH7. Data from BH6, BH7 and P8 indicates that the Boulder Clay in this area dips to the southwest.

## 3.3 RECENT DEPOSITS

The study area is covered by thin superficial deposits of Recent age. In elevated areas these consist of soils developed from the in-situ weathering of Boulder Clay, while detrital silts and sands are intermixed with peat along the valley bottoms. In areas where the Boulder Clay is absent coarser clastic material from either the Pleistocene gravel or the Jurassic sands have been reworked by Recent erosion.

# 4. Hydrogeology

The Jurassic Sand and Pleistocene gravels are the main aquifers in the Cransley Lodge area. The Lias Clay forms an extensive basal aquiclude across the whole area while the Boulder Clay forms an important upper aquiclude in the areas where it is preserved. A number of thin clay units of variable permeability subdivide the main sand and gravel aquifers.

Groundwater flow within the area is controlled by the local lateral discontinuities which occur within each of the aquifers. These discontinuities are the result of either erosion, structural breaks or quarrying.

Theoretical, field and laboratory values for bulk aquifer characteristics are shown in Table 2.

## 4.1 JURASSIC SEQUENCE

### 4.1.1 Upper Lias

The Upper Lias is the regional basal aquiclude to the Jurassic sand sequence. Where it is faulted against the Northampton Sand to the south of KDC1 and BH2 the Upper Lias forms a barrier to the southerly flow of groundwater. This barrier of up-thrown Lias has probably been instrumental in the focusing of spring flow towards the western edge of Birch Spinney.

Boulder Clay rests directly upon the Upper Lias over much of this southern up-thrown block and hence infiltration rates are extremely low. The Upper Lias is more extensively weathered beneath the Pleistocene erosion surface and although this may result in very slightly increased permeability the effect is unlikely to be significant. The shallow groundwater encountered in P8 and P9 only during the winter months is indicative of the small amount of water present within the weathered upper 1-2 m of Lias clay. Consequently there is very little groundwater flow from this area.

As the western parts of the proposed village will be built upon this impermeable Upper Lias block only a very small amount of groundwater will reach the SSSI from this area.

*Table 2 Bulk Hydraulic Properties for Principal Aquifers - Cransley Lodge*

| | Permeability m/day | Specific Yield % |
|---|---|---|
| PLEISTOCENE SEQUENCE | | |
| Boulder Clay | | |
| Theoretical [1] | 0.0002 | 3 |
| Regional [2] | 0.0007-0.038 | |
| Boulder Clay - Sandy Silt | | |
| Theoretical [1] | 0.08 | 15 |
| Regional [2] | 0.2-1.15 | |
| Falling Head Test | 0.0365 | |
| Gravel | | |
| Theoretical [1] | 270 | 24 |
| Grain Size Analysis | 201 | - |
| Gravel - Sand | | |
| Theoretical [1] | 20-45 | 28 |
| Grain Size Analysis | 63 | - |
| JURASSIC | | |
| Lower Estuarine Series | | |
| Theoretical [1] | 0.1-2.5 | 18-23 |
| Permeameter | ? | 14.6 |
| Grain Size Analysis[3] | 99 | |
| Northampton Sand | | |
| Theoretical [1] | 5-20 | 20-25 |
| Permeameter | | 15.8 |
| Grain Size Analysis[3] | 68 | |
| Falling Head Test | | 0.0155 |
| Upper Lias | | |
| Theoretical [1] | 0.00005 | 1-2 |

[1] From: Todd, D.K., 1980
[2] From: Bonell, M., 1978
[3] Biased by coarse cemented fragments

The relative elevations of the Boulder Clay - Upper Lias contact in P8 and BH6 suggest that this boundary dips to the south and away from the SSSI. In this situation groundwater penetrating the Boulder Clay and reaching any clastic material preserved along the Upper Lias contact is likely to flow to the south and away from the SSSI.

A similar structural and hydrogeological relationship exists in the vicinity of the Cransley Lodge farm buildings where a southern block of Upper Lias is uplifted relative to a northern block of Jurassic sand. There is a similar obstruction of groundwater flow against the impermeable fault block of Lias clay, similar springs develop along the fault line and there is a similar thinning of the Jurassic and Pleistocene aquifers on to this fault block.

Within the central portions of the SSSI the main stream cuts through a thin alluvial cover above the Upper Lias. In the area underlain by Lias clay between P4, P5 and P6 water levels in these piezometers are higher than in the adjacent stream. The stream is therefore influent, that is groundwater flows into the stream. This is particularly the case in the vicinity of the land drain outfalls at S5 and P7.

This contrasts with the reach underlain by Northampton Sand between P10, S2, P2 and P3 where, as water levels are lower in the piezometers to the north and the stream is effluent in this direction. It is also probably effluent into the Northampton Sand to the south of P2 and P3.

### 4.1.2 Northampton Sand

The Northampton Sand is the major regional aquifer in the study area, and also the aquifer primarily responsible for supporting surface flow through the wetland SSSI. The Northampton Sand will have considerable stratigraphic variability in aquifer properties, with the potential for multiple clay aquitards. Structural features result in large differences in saturated thickness of Northampton Sand (See Appendix III - Section 1)

The hydraulic gradient within the Northampton Sand between BH3 and BH4 is approximately 0.0045. The saturated thickness of the formation also increases rapidly in this direction. This geometry is consistent with recharge predominantly through the bed of Cransley Brook between P10 and P3, and to a lesser extent by infiltration through the Pleistocene gravels in the vicinity of SM2 between BH4 and BH5. The Northampton Sands are also recharged from springs at the base of the Lower Estuarine Series and from within the Pleistocene gravel which lies above the southern bank of Cransley Brook.

The narrow saturated thickness and slow rate at which water flowed into BH4 and BH5 indicates that there is very limited vertical recharge of the Northampton Sand through the Boulder Clay in the area to the immediate west of the Cransley Lodge farm buildings.

The Northampton Sand and Pleistocene Gravel are absent to the west of BH5 effectively eliminating any lateral recharge from this direction, while the clay aquitard at the base of the Lower Estuarine Series further reduces recharge by infiltration from above. Clay horizons within the Pleistocene Gravel also reduce recharge from infiltration.

Borehole BH1 is sited within a small remnant of Northampton Sand left after mining of the surrounding material to the north, east and west of Mawsley Lodge. The very narrow saturated thickness is thought to reflect the proximity to the valley, reduced recharge due to the effects of mining and dewatering by land drains.

Permeameter tests on a bulk sample of the Northampton Sand returned inconclusive results for permeability and a specific yield of 15.8%. An input test on the Northampton Sand in BH2 returned values for permeability of 0.016 m/d., details of which are presented in Appendix IV. this is thought to represent an anomalously low value.

Groundwaters from this unit typically have a high iron content and produce a distinctive orange colloidal precipitate upon exposure to air.

Groundwater within the Northampton Sand will be affected by the proposed village development in two areas. In the vicinity of the Cransley Lodge farm buildings very limited infiltration will occur through Pleistocene gravels and the Lower Estuarine Series sands. From this location groundwater flow is towards the northeast and hence will have no effect upon the SSSI.

In the other area, between S2, A5, P16, P17 & P10, surface flow and shallow subsurface flow will recharge the Northampton Sand via infiltrate through the thinner Boulder Clay cover. The hydraulic gradient in this area is towards the SSSI. Infiltration rates are low and there is only a thin wedge of aquifer preserved in this area. As a result the anticipated minor changes in surface flow conditions to be produced by the proposed village (see Chapter 5) will produce a proportionally smaller impact upon the groundwater flow regime.

### 4.1.3 Lower Estuarine Series

The Lower Estuarine Series is present in the study area to the south of the SSSI between BH3 and BH4. The stratigraphic intercalation of clays, silts and sands within the Lower Estuarine Series result in rapid variation in aquifer properties. The bulk hydraulic properties used for this Series during the current study are shown in Table 2. The high silt content of the bulk sample of Lower Estuarine Series resulted in permeameter tests giving inconclusive permeability readings. Similarly the fine grain size of the Series reduced the accuracy of the grain size technique for determining permeability.

The basal clay layer forms an aquitard between the Lower Estuarine Series and the underlying Northampton Sands. A perched water table occurs above this unit. The saturated thickness of the Lower Estuarine Series varies between 4.0 m of saturated sand in BH3 to only 20-30 cm of damp silt in BH4.

Recharge of the Lower Estuarine Series occurs via infiltration through the Pleistocene Gravels. There is no hydraulic connection between the Series and Cransley Brook. Runoff from the Boulder Clay will be focused at points where local drainage depressions cross the outcrop boundary of the Boulder Clay. Two such focal points of recharge are shown on Figure 13. In the area west of the Cransley Lodge farm buildings recharge will be enhanced by runoff from sub-catchment E ponding in the depressions left after quarrying. The very narrow saturated thickness of Lower

Estuarine Series encountered in BH4 suggests that even with this ponding there is only limited recharge in this area.

The hydraulic gradient and general direction of groundwater flow in the Lower Estuarine Series is towards the northeast (Figure 13). The limited data available from BH3A and P13 indicates that groundwater flow within the Lower Estuarine Series undergoes seasonal variations in direction. During the winter months flow directions are strongly controlled by the recharge mound that develops beneath the zone of high infiltration around the fringes of the Boulder Clay. There a steep gradient from the northern fringe of the Boulder Clay (RWL approx 116.4 m.O.D.) towards the SSSI (stream bed level 108.5-113.5 m.O.D.) and flow also occurs towards the southeast where rest water levels in P13 are approximately 116.2 m.O.D..

During the summer months the water table in the Lower Estuarine Series is rapidly drawn down by the steep gradient along the southern margins of the SSSI, while the drawdown is slower in the area of P13. As drawdown along the northern margins of the aquifer continues the recharge mound built up during the winter is eliminated until groundwater begins to flow from the area of P13 towards the north. The hydraulic gradient between P13 and BH3A during the summer months August - October 1991 was only 0.0009, and therefore flow within the approximately 4 m of saturated silts and fine sands (K= 0.1-2.5 m/d) will be very small (2 $m^3$/d).

Groundwater within the Lower Estuarine Series will be affected by the proposed village only in the vicinity of the Cransley Lodge farm buildings. As noted above the predominant direct of groundwater flow within the Lower Estuarine Series from this area is towards the northeast. However during the summer there may be a small component of groundwater flow towards the north and the most easterly portions of the SSSI. The volume of water involved is insignificant (2 $m^3$/d) when compared with the total volume of water flowing through this part of the SSSI.

## 4.2 PLEISTOCENE SEQUENCE

### 4.2.1 Pleistocene Gravel

The gravel unit at the base of the Pleistocene sequence is laterally and stratigraphically quite variable. This unit plays an important role in determining the infiltration rates around the margins of the Boulder Clay. The unit thin and fines towards the uplifted block of Lias between BH6 and KDC1. The gravel is water bearing where it contains thin intercalated clay aquitards, or where it rests upon impermeable material such as the Upper Lias.

Clay horizons are intercalated with the gravels at several locations (BH4, BH5, P11, P12, P16, SM2). These clay horizons are unlikely to be laterally continuous, and can be regarded as fairly leaky aquitards between the Boulder Clay and the Jurassic sands. The springs near BH3, in the higher parts of Ragsdale Spinney near P18 and along the stream banks to the north of SM2 probably emerge from the Pleistocene gravel above such clay aquitards.

The 2 cm thick sand unit encountered immediately above the Lower Lias in BH6 is thought to be a fine grained lateral, but hydraulically separate, equivalent of the Pleistocene gravel unit. These facies changes are thought to reflect the presence of the Pleistocene topographic high in the area between BH6 and KDC1. This topographic high forms an important groundwater divide which directs the limited amount of water which will infiltrate through the Boulder Clay beneath most of the village away to the south.

One of the current options is for the balancing pond for road surface water drainage to be constructed at a site between P16 and P17. This pond will discharge to the steam through a channel of pre-set dimensions to a point below the SSSI. At this site the pond will be excavated through thin Boulder Clay into moderate to highly permeable sands of the Pleistocene gravel unit. The hydraulic gradient at this point is towards the SSSI and hence there would be a need to seal the base of the pond in order to prevent leakage towards the SSSI.

### 4.2.2 Boulder Clay

Regional and local data indicate that infiltration rates through the Boulder Clay are very low and therefore the clay forms a highly impermeable seal between the village and the underlying Jurassic aquifers. The virtual absence of groundwater in either the Northampton Sand and the Lower Estuarine Series in BH's 4 & 5 are indicative of the very low infiltration rates of the Boulder Clay.

Two thin confined aquifers were encountered within the Boulder Clay during the drilling of BH6. Their lithology, the absence of the lower aquifer and the thickening of the upper silty aquifer at the BH7 site would suggest that these units may be small, discontinuous channel fill deposits. The relative elevation of the upper clayey siltstone aquifer in boreholes BH6 and BH7, and the relative elevations of the basal contact in P8 and BH6, indicates an apparent dip to the southwest and away from the SSSI. The inferred outcrop trace and probable source of recharge to these two aquifers is shown in Figure 11.

There is insufficient water level data to determine the hydraulic gradient or direction of groundwater flow within the two silt aquifers within the Boulder Clay. Based upon the general configuration of the Boulder Clay as a whole it is probable that groundwater flow within these aquifers is towards the southwest.

A falling head test on the upper silty aquifer encountered in BH7 indicated a permeability of 0.037 m/d. This value is consistent with the lithology of the material recovered from the borehole (Table 2).

## 4.3 RECENT DEPOSITS

These deposits of Recent age affect local infiltration rates and the characteristics of the shallow sub-surface flow regime.

The soil moisture site SM1 is located within soils derived from in-situ weathering of Boulder Clay. There is very little seasonal change in water content below 1.2 m as seen in Figure 14. The monthly changes in soil moisture reveal a typical pattern of summer drying followed by wetting up with the onset of winter. Minor variations to this pattern can be closely correlated to the timing and magnitude of local rainfall events relative to the time of monitoring. This pattern is consistent with that seen in other studies such as McGowan, *et al.* (1980).

The small fluctuations observed over the lower 20 cm of the SM1 profile are probably related to the filling of void space created during attempts to penetrate a clast within the Boulder Clay.

In winter conditions, when fully saturated and with an inferred gradient of 0.02, this shallow subsurface flow within the upper 2 m of Boulder Clay/Upper Lias within subcatchment C is likely to contribute in the order of 0.04 $m^3/d$ at S2. During summer evapotranspiration losses effectively eliminate this shallow subsurface down slope flow.

The soils of Recent age which have developed over the Pleistocene "gravels" or Jurassic sands are typically quite sandy, although often enriched in clay washed down slope from the overlying Boulder Clay. An additional soil moisture access tube (SM2) was installed in August 1991, in order to assess infiltration characteristics in this soil type. Profiles show a typical increase in soil moisture over the autumn - winter period in the upper portions of the section (Figure 15). A zone of minimal change between 1.40 - 1.60 m is coincident with a clay horizon with higher water contents reflecting a perched water table above this layer.

The water table at the SM2 site is in the order of 1.0 m below the bottom of the access tube. The slight variations in water content below 1.8 m may therefore be in response to changes in groundwater levels.

*Table 3 Soil Moisture Water Balance - SM1*

| Period | Rainfall | Potential Evaporation | Soil Moisture Change | Runoff/ Infiltration |
|---|---|---|---|---|
| 21/08/91-19/09/91 | 6 | 81.2 | -69.6 | -0.8 |
| 19/09/91-28/10/91 | 63 | 43.1 | 42.2 | -22.3 |
| 28/10/91-21/11/91 | 80 | 18.4 | 77.4 | -15.4 |
| 21/11/91-17/12/91 | 11.5 | 4.9 | -10.2 | 16.8 |

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Using the simple water balance equation

$$P = E + U + \Delta\theta$$

where P is the precipitation: E is the evaporation; and $\Delta\theta$ is the change of soil moisture storage, it is possible to compute a runoff/infiltration factor U. The short record at Cransley Lodge prevents calculation of a comprehensive soil moisture based water balance.

An indication of seasonal trends is apparent from the data included in Table 3.

The six piezometers P1 to P6 within the SSSI sited within recent alluvium. While the monthly water level readings from these reveal only broad trends, it is apparent that the water table in this material is influenced by changes in stream levels.

# 5. Surface Hydrology

## 5.1 INTRODUCTION

The aim of the hydrological analyses outlined in this chapter, is to assess the impact of the proposed development on the hydrology of the catchment and in particular to predict any influence it might have on the surface water regime of the Birch Spinney-Mawsley Marsh SSSI. The study has included the determination of the impact of sub-catchment urbanisation on the total catchment response.

It is necessary to ascertain what affect, if any, the proposed new town will have on both high and low flows on the un-named stream (referred to hereafter as Cransley Brook) passing through the SSSI. The study undertaken includes evaluation of catchment characteristics, flood estimates (both by statistical and rainfall-runoff methods) and flow duration curves at different locations within the catchment.

## 5.2 CATCHMENT DESCRIPTION

The Birch Spinney-Mawsley Marsh SSSI is situated in the headwaters of the Cransley Brook catchment. The stream flows roughly north east through the middle of the SSSI. At the downstream end of the SSSI (S4, see Figure 2) Cransley Brook drains a rural 2.62 $km^2$ catchment of low relief. Land use in the area is predominantly cereal crops with cattle and sheep pasture. Trees are restricted to a few hedgerows and three small areas of woodland of which Mawsley Wood (5.7 ha in extent) is the largest.

Sharp crested V-notch weirs and stage recorders were installed at S4 and on the stream confluences S1,S2 and S3 within the catchment. The whole catchment was thus effectively divided into four subcatchments (A,B,C and D - see Figure 1). Estimates of the physical characteristics of each subcatchment and the catchment as a whole were made using the maps in the Floods Studies Report (NERC, 1975). Wherever possible, for example in soil classification, information gained during installation of the monitoring network and subsequent site visits was used to give a better estimate of the characteristics than could be gained from the FSR maps alone. Values for these characteristics are given in Table 4, together with those for Egleton Brook and West Glen, two nearby catchments which have long term records of river flow. The location of the Egleton Brook and West Glen catchments as shown in Figure 16.

The raingauge and stage recorders at sites S1 to S4 were installed at the end of April 1991, although not all the V-notch weirs required to obtain rating equations to convert stage to flow were in place until July 1991. The data used in this study is that collected between April 22 1991 and February 18 1991 (see Figure 3).

## *Table 4 Catchment Characteristics*

| | A | B | C | Whole | West Glen | Egleton Brook |
|---|---|---|---|---|---|---|
| Area (km²) | 0.842 | 0.686 | 0.643 | 2.621 | 4.4 | 2.5 |
| MSL (km) | 1.0 | 0.9 | 0.45 | 1.7 | 2.8 | 2.6 |
| S1085 (m/km) | 16.0 | 14.8 | 14.81 | 15.7 | 14.6 | 14.9 |
| STMFRQ (Junctions/km) | 1.19 | 1.46 | 1.56 | 1.14 | 3.18 | 1.2 |
| Soil | 0.42 | 0.44 | 0.45 | 0.43 | 0.45 | 0.45 |
| Lake | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Urban Pre | 0.0 | 0.0 | 0.0 | 0.0 | 0 | 0 |
| Urban Post | 0.0 | 0.0 | 0.34 | 0.084 | - | - |
| SAAR (mm) | 625 | 625 | 625 | 625 | 647 | 653 |
| RSMD | 24.9 | 24.9 | 24.9 | 24.9 | 27.7 | 27.3 |
| Grid Reference | (SP)808767 | (SP)807764 | (SP)807764 | (SP)813769 | (SK)9652 58 | (SK)878073 |

The short duration over which site records are available restricts comparisons with other sites with longer term records. From regional data 1991 was the second driest year this century, with rainfall approximately 78% below the 1940-1971 average. This followed 1990 which was in this region, the fourth driest year this century.

The flows monitored indicate that the response in each of the subcatchments A to C and indeed over the whole catchment to S4 are extremely flashy (see Figures 17-20). In other words, flows are generally low, or even, in the cases of subcatchments A and C non-existent for long periods of time, but all the subcatchments respond rapidly during periods of high rainfall. For example, the storms of 29-30 April 1991, 17-21 November 1991 and 8-9 January 1992 (see Figure 19) resulted in a rapid response on each of the subcatchments, producing hydrographs with very steep rising and falling limbs. A similar response occurred as a consequence of the relatively low, but intense rainfall on 12 February 1992. However, periods of high rainfall, notably in the middle and at the end of June and particularly at the end of September (see Figure 19) generated little or no runoff.

These results indicate the importance of antecedent soil moisture conditions in determining catchment response. Figure 22 shows the soil moisture monitored at the site SM1 using a neutron probe. Stage measurements at S2 (subcatchment C) indicate the times when there was water in this channel, but it was not flowing over the weir crest (see Figure 18). This is an indication of the level of the water table immediately adjacent to the stream. Both figures show that prior to the rainfall in June and September the catchment soils were dry. Consequently, most of the rainfall went to reducing the soil moisture deficit (SMD) and there was little or no increase in surface flow. However, prior to the April, November, January and February events, soil moisture was higher, the soil became saturated much more rapidly and consequently large increases in flow were generated.

For the period April to December there was for most of the time no surface flow from subcatchments A and C. There was a small but continuous discharge from subcatchment A into the main stream channel from a land drain (S5) which emerged a few metres downstream of S3 but the mainstay of flow at S4, during this period was the flow from subcatchment B.

Records from the National Borehole Archive show that flow into the channel from subcatchment B is augmented by a subsurface trench network. This was installed by Kettering District Council in 1936 to ensure that the flow in Cransley Brook to Cransley Reservoir (2 km downstream of the SSSI) was maintained. This drainage network, the extent of which is unknown, discharges to the channel about 150 m upstream of the S1 gauging site.

Throughout December,January and February flows were sustained for the majority of the time from subcatchment C, but even in these winter months flow only occurred at S3, surface flow from subcatchment A, during and for a few days after heavy rainfall events.

## 5.3 FLOOD FREQUENCY ANALYSIS

Flood frequency analysis was used to determine the impact of the development upon high flows within the Birch Spinney-Mawsley Marsh catchment. Analysis was conducted on each of the subcatchments A to C and also on the whole catchment to S4, treating it as a single lumped system.

The flood regime of a stream is generally described in terms of a flood frequency curve which is a graphical representation of the relationship between a maximum flow (Q, cumecs) and the period of time (T, years) during which it is likely to be equalled or exceeded only once on average. A given peak flow, Q(T), is thus said to have a return period or recurrence interval of T years. The return period, T years, is the long term average of the intervals between successive exceedances of a flood of magnitude, Q(T), but it should be remembered that those intervals may vary considerably around the average value T.

The Flood Studies Report (NERC, 1975) and Flood Studies Supplementary Reports (Institute of Hydrology, 1976-1986) provide methods of estimating the flooding behaviour of a stream either :

- from past records of river flows or
- from the physical characteristics of the catchment.

The latter methods are used when flow data is unavailable or records are not of sufficient duration, that is less than 10 years as is the case at Cransley Lodge. In this case two methods are available:

- the instantaneous peak discharge of a given design flood can be estimated directly by the "statistical" method.
- the entire flood hydrograph resulting from a design rainfall can be derived by the "rainfall-runoff" method.

### 5.3.1 Statistical Method

In this method an index of the typical size of the annual maximum flood is estimated, in this case the mean annual flood, $\bar{Q}$ (return period, 2.33 years). $Q_{obs}$ is calculated from the set of observed flood peaks. When adequate flow records are not available $Q_{cc}$ may be estimated from the physical characteristics of the catchment. $\bar{Q}$ is then scaled by appropriate growth factors to estimate floods of less frequent occurrence. These factors are available for all regions of the U.K.

#### 5.3.1.1 $\bar{Q}$ adjustment

Values of $\bar{Q}_{cc}$ and $\bar{Q}_{obs}$ for the Egleton Brook and West Glen catchments are given below, together with the discrepancy between the two methods expressed as a proportion of $Q_{cc}$.

***Table 5 Comparison of $\bar{Q}_{obs}$ and $\bar{Q}_{cc}$ for the two catchments with long flow records.***

| Catchment | $\bar{Q}_{cc}$ ($m^3/s$) | $\bar{Q}_{obs}$ ($m^3/s$) | $\bar{Q}_{obs}/\bar{Q}_{cc}$ |
|---|---|---|---|
| Egleton Brook | 0.66 | 0.85 | 1.29 |
| West Glen | 1.48 | 2.50 | 1.69 |

These results indicate that in this area, the observed $\bar{Q}$ is somewhere between 1.29 and 1.69 times that estimated from catchment characteristics. Both catchments have very similar physical characteristics with the principle difference being the catchment area. The smaller Egleton Brook catchment has a similar area to that of the whole Cransley Lodge catchment (see Table 4). Estimates of $\bar{Q}$ for the Cransley Lodge catchment and subcatchments were therefore scaled by 1.34, a weighted average (weighted by catchment area), of these two. There was no justification for using a different scaling factor between subcatchments. This yielded preferred pre-development estimates of $\bar{Q}$, listed in Table 6.

*Table 6 $\bar{Q}_{rural}$ for Cransley Lodge catchments.*

| Catchment | $\bar{Q}_{ss}$ (m$^3$/s) | scaling factor | $\bar{Q}_{rural}$ (m$^3$/s) |
|---|---|---|---|
| A | 0.198 | 1.34 | 0.27 |
| B | 0.165 | 1.34 | 0.22 |
| C | 0.180 | 1.34 | 0.24 |
| whole | 0.592 | 1.34 | 0.79 |

### 5.3.1.2 Urban adjustment

The Flood Studies Supplementary Report 6 (FSSR-6) provides a further correction factor to estimate $\bar{Q}$ for the period after urban development. This factor depends upon the extent of urbanisation and the characteristics of the rural catchment, but assumes that the introduction of impermeable surfaces and an effective drainage system results in increased volumes of runoff and faster flow times. As a result flood hydrographs are faster to peak, faster to recede and of increased peak discharge. Floods of all return periods are (in general) increased, and consequently the flood frequency distribution is affected. Urban catchments are more responsive to short intensive storms, which tend to occur in summer. This coupled with their reduced sensitivity to soil conditions, means high flows become more common in summer.

The only subcatchment impacting on the SSSI, that would be affected by the proposed urbanisation is subcatchment C. Within subcatchment C the development would cover some 0.220 km$^2$ which represents urbanisation of 34% of subcatchment C and 8.4% of the lumped catchment to S4. The rest of the development area lies within subcatchment E and so does not contribute surface water to the catchment of the SSSI. Within the urbanised area of subcatchment C, the total area covered by roads and car parking space is about 2.76 ha (0.0276 km$^2$). This represents 4.3% of the area of subcatchment C. The rest of the urbanised area (0.192 km$^2$) would be covered by low density houses and gardens, the total impermeable cover amounting to some 40% of the development area.

In the Cransley Lodge development it is planned to direct runoff from building roofs to soakaways. The objective of the soakaways is to attenuate the increased and accelerated runoff from the development so that high flows produced by the urbanised catchment are as similar as possible to that of the rural catchment prior to development. Runoff from roads and car parking areas will enter a balancing pond in order to attenuate flows from these areas. From the balancing pond runoff will then be piped to a point downstream of the SSSI in order to ensure that water quality is not adversely affected by pollutants picked up from road surfaces.

$\bar{Q}$ was recalculated for both subcatchment C and the lumped catchment to S4, following UK standard practice and correcting by an urban factor determined from FSSR-6. The catchment areas were reduced to allow for the rainfall falling on roads and parking spaces and lost from the catchment, but no allowance was made for the fact that runoff from rooftops will be directed to soakaways. The resultant $Q_{urban}$ values obtained were 0.43 $m^3/s$ and 0.92 $m^3/s$ for subcatchment C and the whole catchment respectively.

#### 5.3.1.3 Flood Quantiles

The estimates of $\bar{Q}$ are scaled to derive the specified design flood discharge using growth factors appropriate to the region for the rural and urbanised cases. The results, with all flows in cumecs, are shown in Table 7.

*Table 7 Q(T) estimates for each Cransley Lodge Subcatchment, pre and post development, derived by the statistical method.*

| Return Period (yrs) | Catchment A | | Catchment B | | Catchment C | | Whole catchment | |
|---|---|---|---|---|---|---|---|---|
| | $Q(T)_{pre}$ | $Q(T)_{post}$ | $Q(T)_{pre}$ | $Q(T)_{post}$ | $Q(T)_{pre}$ | $Q(T)_{post}$ | $Q(T)_{pre}$ | $Q(T)_{post}$ |
| 2 | 0.25 | 0.25 | 0.19 | 0.19 | 0.22 | 0.41 | 0.70 | 0.84 |
| 5 | 0.36 | 0.36 | 0.28 | 0.28 | 0.32 | 0.57 | 1.02 | 1.20 |
| 10 | 0.46 | 0.46 | 0.35 | 0.35 | 0.40 | 0.70 | 1.31 | 1.52 |
| 20 | 0.58 | 0.58 | 0.45 | 0.45 | 0.52 | 0.84 | 1.67 | 1.91 |
| 30 | 0.66 | 0.66 | 0.52 | 0.52 | 0.59 | 0.90 | 1.90 | 2.15 |
| 50 | 0.78 | 0.78 | 0.61 | 0.61 | 0.69 | 0.99 | 2.24 | 2.51 |
| 100 | 0.98 | 0.98 | 0.77 | 0.77 | 0.87 | 1.18 | 2.82 | 3.12 |

### 5.3.2 Rainfall-Runoff Method

Application of this method requires the estimation of two parameters. Firstly the response of the catchment to a unit amount of rainfall, where a single parameter time-to-peak (Tp), is sufficient to describe all aspects of this response. A second parameter, percentage runoff (PR), defines the percentage of the design storm depth which contributes to the flood hydrograph. This is the most influential factor in determining the flood response since the resulting unit hydrograph is scaled directly by PR.

### 5.3.2.1 Tp Adjustment

Tp may be expressed in various forms according to the standard duration of rainfall considered; thus Tp(0) defines the response to unit rainfall falling instantaneously over the catchment. Tp may be derived by using observed rainfall sequences together with the resulting catchment response. A value of Tp(0) has been defined in this manner for the West Glen catchment. Tp(0) can also be estimated using the catchment lag between rainfall centroid and peak river level. From the water level records collected at Cransley Lodge an average Tp(0) was estimated in this manner, for sites S1,S3 and S4, using the rainfall events of April and November 1991 and January and February 1992. Unfortunately, because of problems with the clock of the stage chart recorder, insufficient data was obtained at S2 to estimate Tp(0) for subcatchment C in a similar manner. Tp(0) can also be estimated from the physical catchment characteristics. Estimates of Tp(0) from hydrometric data and catchment characteristics for all the Cransley Lodge catchments and West Glen catchment are listed in Table 8.

***Table 8 Comparison of $Tp(0)_{obs}$ and $Tp(0)_{cc}$.***

| Catchment | $Tp(0)_{obs}$ | $Tp(0)_{cc}$ | $Tp(0)_{obs}/Tp(0)_{cc}$ |
|---|---|---|---|
| A | 3.60 | 3.50 | 1.03 |
| B | 3.4 | 3.51 | 0.97 |
| C | - | 2.99 | - |
| whole | 6.0 | 3.98 | 1.51 |
| West Glen | 4.30 | 4.99 | 0.96 |

The relationship between $Tp(0)_{obs}$ and $Tp(0)_{cc}$ is not consistent between catchments. However, data from each of the subcatchments and from West Glen, suggest that the catchment characteristic equation closely approximates $Tp(0)_{obs}$, the mean adjustment being 0.99. However the data for the whole Birch Spinney-Mawsley Marsh catchment indicate that for this catchment, the catchment characteristic equation significantly under estimates Tp(0). This occurs as a consequence of the fact that during periods of high flow, water overtops the stream bank and spreads out across the flood plain - the area enclosed within the SSSI. The dispersal of water to flood plain storage and the modification of the flow velocity arising as a consequence of the presence of bushes and tall grasses on the flood plain, results in increased attenuation downstream of S1,S2 and S3 and produces an increased lag at S4. Attenuation of peak flow as a consequence of flooding is not taken into account in the catchment characteristic equation and consequently a much larger correction factor is required for the whole catchment.

The mean value of 0.99 was chosen to adjust $Tp(0)_{cc}$ for each of the subcatchments. No justification could be seen for applying a different correction to the different subcatchments and so this value was used for all. The correction of 1.51 was applied to the whole catchment to S4. The corrected pre-urbanisation Tp values are given in Table 9.

***Table 9 Corrected Tp(0) values for all Cransley Lodge Subcatchments.***

| Catchment | $Tp(0)_{cc,rural}$ (hr) | scaling factor | $Tp(0)_{rural}$ (hr) |
|---|---|---|---|
| A | 3.50 | 0.99 | 3.47 |
| B | 3.51 | 0.99 | 3.47 |
| C | 2.99 | 0.99 | 2.96 |
| whole | 3.98 | 1.51 | 6.0 |

### 5.3.2.2 PR Adjustment

The percentage runoff, PR, is closely related to the type of soil in the catchment. The soils underlying the West Glen catchment have a similar classification to those at Cransley Lodge (see Table 4). Analysis of flood events in this catchment suggests that the standard percentage runoff, SPR, is around 33%. The relevant catchment characteristics equation implies an SPR of 47%. The ratio of $Tp(0)_{obs}$ to $Tp(0)_{cc}$ is therefore 0.70 and consequently this correction factor was applied to the SPR calculated from catchment characteristics for each of the Cransley Lodge subcatchments (see Table 10).

***Table 10 Corrected SPR values for all Cransley Lodge catchments.***

| Catchment | $SPR_{cc}$ | scaling factor | SPR |
|---|---|---|---|
| A | 41.81 | 0.70 | 29.27 |
| B | 45.39 | 0.70 | 31.77 |
| C | 46.93 | 0.70 | 32.85 |
| whole | 43.33 | 0.70 | 30.33 |

### 5.3.2.3 Urban Adjustment

As in the statistical method FSSR-6 allows corrections to be made to Tp and PR for the post urbanisation situation assuming that increased volumes of runoff from the man-made impervious areas reach the stream rapidly. Once again the area of subcatchment C and the whole catchment to S4 were reduced to reflect water lost as a consequence of the removal of road runoff from the catchment, but no allowance was made for the presence of soakaways.

#### 5.3.2.4 Flood Quantiles

To estimate the flood frequency relationship for sites S1 to S4 a series of design rainfalls each corresponding to a flow of a given return period, were transformed into runoff hydrographs using the unit hydrograph model. Two sets of flood estimates resulted corresponding to the pre and post development cases (see Table 11).

***Table 11 Q(T) estimates for each Cransley Lodge catchment, pre and post urbanisation, derived by the rainfall-runoff method.***

| Return Period (yrs) | Catchment A | | Catchment B | | Catchment C | | Whole catchment | |
|---|---|---|---|---|---|---|---|---|
| | $Q(T)_{pre}$ | $Q(T)_{post}$ | $Q(T)_{pre}$ | $Q(T)_{post}$ | $Q(T)_{pre}$ | $Q(T)_{post}$ | $Q(T)_{pre}$ | $Q(T)_{post}$ |
| 2 | 0.17 | 0.17 | 0.15 | 0.15 | 0.17 | 0.33 | 0.39 | 0.45 |
| 5 | 0.28 | 0.28 | 0.25 | 0.25 | 0.28 | 0.46 | 0.62 | 0.73 |
| 10 | 0.34 | 0.34 | 0.31 | 0.31 | 0.33 | 0.55 | 0.78 | 0.90 |
| 20 | 0.42 | 0.42 | 0.38 | 0.38 | 0.41 | 0.65 | 0.94 | 1.09 |
| 30 | 0.46 | 0.46 | 0.41 | 0.41 | 0.45 | 0.71 | 1.03 | 1.19 |
| 50 | 0.53 | 0.53 | 0.47 | 0.47 | 0.51 | 0.80 | 1.18 | 1.36 |
| 100 | 0.62 | 0.62 | 0.55 | 0.55 | 0.60 | 0.97 | 1.37 | 1.58 |

### 5.3.3 Flood Frequency Curves

Flood frequency relationships derived using both the statistical and rainfall-runoff methods are shown for each of the sub catchments and the lumped whole catchment in Figures 23 to 26. It is clear that the two methods produce somewhat different results. For example, for the whole catchment pre-urbanisation a flood with a return period of 50 years is estimated to have a peak flow of 2.24 $m^3/s$ from the statistical method but only 1.18 $m^3/s$, from the rainfall-runoff method. The estimates are closer for short as opposed to long return periods.

It should be noted that post urbanisation, for both subcatchment C and the whole catchment, both methods predict a similar relative difference between pre and post development frequency curves. Since the frequency curves derived from the rainfall-runoff method are in part derived from flow data collected at the site and are not dependent just on catchment characteristics and regional equations, it is felt that they are more likely to be a better representation of true catchment response than those produced by the statistical method. It is the results produced by the rainfall-runoff method which are discussed below.

### 5.3.4 Results

Without the presence of soakaways, urbanisation of area C would significantly increase high flows from this subcatchment (see Figure 25). The peak flows would be increased by between 57% and 66%. Thus pre development flood peaks are in the range 0.17 $m^3/s$ to 0.60 $m^3/s$ and post development peaks are in the range 0.33 $m^3/s$ to 0.97 $m^3/s$ for return periods of 2 to 100 years. An alternative interpretation of this result is that the pre-development 30 year flood (0.45 $m^3/s$) would occur once on average, every 4 years after development and the present 50 year flood (0.51 $m^3/s$) would become the new 8 year flood.

The impact on the whole catchment to S4, the downstream end of the SSSI would be less than that for subcatchment C (see Figure 26). At this point the effect of the proposed development, again not allowing for the presence of soakaways, would be to increase peak flows by about 15% for all return periods. Thus pre development flood peaks are in the range 0.39 $m^3/s$ to 1.37 $m^3/s$ and post development peaks are in the range 0.45 $m^3/s$ to 1.58 $m^3/s$ for return periods of 2 to 100 years. The pre-development 30 year flood (1.03 $m^3/s$) would occur once, on average, every 15 years after development and the present 50 year flood (1.18 $m^3/s$) would become the new 29 year flood.

It is believed that these results represent a worse case scenario in the impact of the development on the flow regime of the SSSI. The dispersal of roof runoff to soakaways may significantly mitigate the impact of the development on the catchment and ensure that the response of sub catchment C more closely resembles that of the present rural catchment.

## 5.4 LOW FLOW ANALYSIS

As well as impacting on high flows the proposed urbanisation will change the low flow regime of the catchment. Since the increase in impermeable catchment cover reduces the contribution of rainfall to soil moisture storage, urbanisation normally leads to a reduction in dry weather flows. However at Cransley Lodge the plan is to divert runoff to soakaways and remove road runoff from the catchment. Consequently, the impact on low flows is different to what might be expected under normal urbanisation conditions.

## 5.4.1 Flow Duration Curves

A flow duration curve shows graphically the relationship between any given discharge and the percentage of time that the discharge is exceeded. It is a useful tool for assessing how changes within a catchment will affect low flows.

The procedure for estimating flow duration curves is outlined in the Low Flows Report (IH, 1980). The method used depends on the availability of flow data at the site of interest. With only a short period of flow data available it was necessary to use a technique based primarily on catchment characteristics. The methodology applied is standard UK practice for such situations.

Estimating a flow duration curve at a site with less than one years flow data is based on estimating the 95 percentile 10 day flow Q95(10). This is the average 10 day flow that will be exceeded by 95% of 10 day average discharges. This index flow is converted to Q95(1), the average daily flow that will be exceeded 95% of the time. Appropriate multipliers are then used to determine other one day percentile flows.

Determination of Q95(10) requires the estimation of two parameters. Firstly, the average daily flow (ADF) is needed. This is calculated by estimating the average annual evaporation and subtracting from the standard average annual rainfall (SAAR) for the catchment. The evaporation is most easily estimated by comparison with an analogous catchment for which a long term flow record exists. In this study the several years of record for the Egleton Brook catchment, which is also a small catchment located on Boulder Clay, were used to estimate the evaporation. The Egleton Brook catchment was used in preference to the West Glen catchment, because it is closer to Cransley Lodge and is more similar in area. Allowance was made for the fact that flow was maintained from subcatchment B, by the subsurface drainage network, by adding 0.0025 $m^3/s$ to the ADF determined from evaporation and SAAR. The ADF of the whole catchment is slightly greater than the sum of ADF from subcatchments A, B and C, because during periods of high flow there is also a contribution from subcatchment D.

The second parameter required is catchment base flow index (BFI). BFI can be thought of as measuring the proportion of stream runoff that is derived from stored sources. If a year or more flow data exists it can be calculated from these data but with less than a year of data it must be estimated from catchment characteristics. Rules for BFI calculation from catchment characteristics cannot be given entirely objectively. The principle control on BFI is catchment geology but other factors such as catchment area, the proportion of the catchment urbanised, the area covered by lakes, vegetation type, catchment topography and the presence of springs will all affect BFI.

BFI estimates for the Cransley Lodge catchments were estimated using local knowledge of catchment geology, soil classifications, topography and the location of springs and subsurface drainage networks. Comparisons were also made with nearby catchments with similar geology and soils for which BFI was calculated from long term flow records. Estimates of ADF, BFI and the calculated Q95(10) are given in Table 12.

***Table 12 Estimates from catchment characteristics of ADF, BFI and Q95(10) for each of the Cransley Lodge catchments.***

| | Catchment A | Catchment B | Catchment C | Whole Catchment |
|---|---|---|---|---|
| ADF ($m^3/s$) | $5x10^{-3}$ | $6.5x10^{-3}$ | $6.5x10^{-3}$ | $18x10^{-3}$ |
| BFI | 0.52 | 0.55 | 0.35 | 0.55 |
| Q95(10) (%ADF) | 11.74 | 13.47 | 3.55 | 13.47 |

## 5.4.2 Urban Adjustment

The impact of urbanisation on BFI has not been fully resolved and to date there is no standard procedure for correcting BFI for an increase in the proportion of a catchment under urban development. For the development as proposed it is likely that the removal of water from the area covered by roads will very slightly reduce winter and summer low flows from subcatchment C. In the winter when the soils are wet this loss will make very little difference to what occurs at present, but in the summer it may extend slightly the period for which there is no flow from this subcatchment. Soakaways will slightly increase the baseflow component both in the summer and winter months. Overall the impact of the soakaways is likely to be greater than that of the water lost from the road surfaces and the net affect of the proposed urbanisation would probably be a small increase in the BFI of subcatchment C.

Flow duration curves for the subcatchments as they exist at present are shown in Figure 27. The steepness of the curves and the long periods of time over which flows are very low, is an indication of the variability in discharge from the catchments. These are small catchments with limited storage and consequently streamflow reflects to a large extent the variability in the rainfall pattern. The lines for subcatchment B and the whole catchment are slightly less steep as a consequence of the flow maintained by the subsurface drainage network discharging into subcatchment B. It can be seen that the flow duration curve for subcatchment C intersects that of subcatchments A and B at higher (less frequent flows). Thus approximately 6% of flows from subcatchment C exceed flows from subcatchment A and approximately 4% of flows from subcatchment C exceed flows from subcatchment B. This occurs, despite the drainage network discharging into subcatchment B, because of the small differences in geology and soils of the subcatchments.

It appears that if the curve for subcatchment C was extrapolated further it would eventually intersect the curve for the whole catchment, indicating higher flows from a subcatchment than from the whole catchment. However, extrapolation to extremes of flow duration is uncertain because of the approximations inherent in estimating ADF and BFI. For this reason the curves drawn stop for flows greater than 2% of time of discharge exceeded.

It is probable that the post urbanisation flow duration curve in subcatchment C would not be not very dissimilar to that of the rural catchment. A small increase in BFI would decrease the gradient of the flow duration curves. This would reduce slightly the period of time for which flows from subcatchment C exceed those from subcatchment B and increase slightly the period of time for which flows are greater than zero. However, the volumes of water affected on by the proposed urbanisation are very small and it is believed that the overall impact on the whole catchment would be very small.

As subcatchment C has a very small area, low flows could be significantly increased by leakage from mains water supply to the development. Nationally such leakage is estimated to average 25% of supply. Care should be taken to ensure that this additional supplement to flows is reduced to a minimum.

## 5.5 RESULTS

To reduce the impact of New Town developments on existing flow regimes, NRA's often stipulate the construction of balancing ponds. These ensure that the post development flow regime closely resembles that prior to development. At Cransley Lodge it may be possible to direct runoff from rooftops to soakaways, although given the heavy soils underlying the site this may not be successful. An alternative solution is to direct the runoff from roofs directly to the Northampton Sand and hence to the SSSI. The detailed design of appropriate soakaway facilities is beyond the scope of the present studies and the effects cannot be quantified or commented on in depth. Given suitably designed drainage works for roof runoff it is possible that the runoff regime from the village development will not be markedly dissimilar to the existing situation.

Standard UK procedure for assessing the impact of urbanisation on a rural catchment, assumes that runoff from all man-made impermeable surfaces is directed to a pipe drainage network and then flows rapidly to the nearest river. Application of this procedure to the proposed development at Cransley Lodge, represents a worse case scenario in terms of the impact of the development on the existing rural catchment. The analysis conducted indicates that in this case the development would have a significant affect on the high flow regime of Cransley Brook as it passes through the SSSI. Peak flows entering at the upstream end of the SSSI, that is the combined flow from subcatchments C and B, would increase by about a third (33%), see Figure 28, for floods of all return periods. Attenuation of flows as they pass through the SSSI means that the impact of urbanisation on the downstream end of the SSSI (S4) is less significant than at the upstream end and at this location all high flows would be increased by about 15% (see Figure 28). The net impact of higher flows would be increased flooding (more frequently and to a greater depth than at present) over the area of the SSSI.

Figure 33 shows an estimate of the annual catchment water balance for subcatchment C before and after urbanisation.

The urban development as proposed, with soakaways taking roof runoff, will slightly augment baseflow from subcatchment C. With the data available at present it is impossible to quantify this slight change, but with the small volumes of water involved it is believed that the impact on Cransley Brook as it passes through the SSSI would be almost negligible.

# 6. Water Quality

To assess the potential impact of the proposed development upon water quality it is necessary to consider the chemistry of both the existing regime and the likely chemical input of the village.

The design of the drainage scheme for the proposed village will be the major determining factor in controlling the volume and quality of water coming from the development site. For the purposes of this report it has been assumed that all run-off from roof areas will be to soakaways, while run-off from road and parking areas will be to a balancing pond. This balancing pond will be sufficient to receive a 50 year return period rainfall event (1800 $m^3$), falling upon 4.58 Ha of 100% impermeable road surface. The pond will have a maximum outflow of 139 l/s, and be situated near gauging station S2 as shown on Figure 2. Discharge from the balancing pond will be via a pipeline to a point below the SSSI.

It is anticipated that the drainage layout may be significantly refined during the later planning stages. Using the above assumptions will provide an indication of conditions in a worst case scenario.

## 6.1 BASE LEVEL WATER CHEMISTRY

Hydrogeochemical data on the area was collated from the historical records of the National Borehole Archive. These analyses are shown in Table 13. The range of values is that to be expected from ferruginous quartz sands with moderate carbonate content, or from a calcareous Boulder Clay - Gravel.

As part of the current study a set of water samples were collected from in and around the Birch Spinney - Mawsley Marsh SSSI. These samples will provide a base level against which possible future changes in water chemistry could be assessed. The samples were collected at sites chosen to provide a indication of the compositional variation between waters derived from different surface and groundwater sources. Samples were also collected at different times of the year in order to quantify the seasonal variations in water chemistry. Analytical results for these samples are included as Appendix IX and shown in Figures 31 and 32.

### 6.1.1 Source Related Variations

It is evident that the water from the BH6 has distinctly different chemical characteristics from that at the other sites. The higher sulphate, chloride and magnesium, and lower bicarbonate would support the geological interpretation that this aquifer is a hydraulically distinct Pleistocene sand unit.

There is a consistent change in stream hydrochemistry from Northampton Sand type water in Birch Spinney to more aerated surface water leaving the site at the eastern end of the SSSI. In general terms these changes involve a decrease in bicarbonate relative to sulphate and an increase in magnesium relative to calcium due to precipitation of caliche.

As would be expected the samples from the spring at the western end of Birch Spinney and from BH2 have similar chemical characteristics, both being derived from the Northampton Sand. The land drain outfall near Mawsley Lodge has some of the characteristics of water from the Northampton Sand, indicating some contribution from this source. This would be consistent with its origin from the backfilled area where portions of the Northampton Sand has been removed or heavily disturbed by quarrying activities.

### 6.1.2 Seasonal Variations

The groundwater fed spring flow at the head of Birch Spinney shows very minor seasonal variation in hydrochemistry. The primary seasonal variation in chemistry being due to varying contributions from surface runoff. The minor seasonal variation in hydrochemistry of the outfalls near KDC1 and S5 fall within the range of sampling and analytical variance.

## 6.2 CHEMISTRY OF WATER FROM CRANSLEY LODGE VILLAGE

As has been discussed in earlier chapters of this report the volume of water entering the SSSI from the development site will be small in relation to the total volume of water derived from other areas. The small amount of water that does reach the SSSI will therefore be subject to extensive dilution.

The chemistry of the water from roof surfaces is likely to be very close to that of the existing rainfall-runoff. This water will also be subject to considerable buffering within the clay rich soils. Water from roof surfaces disposed to soakaways will therefore produce no significant change in water quality within the SSSI. Foul sewage is to exported from the catchment and therefore will have no impact upon the SSSI.

### 6.2.1 Chemistry of Road/Standing Area Runoff

Runoff from roads and vehicle standing areas derives material from a variety of sources including:

road surface degradation;
vehicle lubrication system losses;
vehicle exhaust emissions;
load losses from vehicles;
degradation of vehicle tyres;
road surface cleaning;
de-icing compounds;
roadside pesticides;
atmospheric deposition/precipitation.

Data is available from the literature for a number of studies, undertaken at various sites throughout the world, into the chemistry of roadway runoff. The majority of these studies have involved heavily utilised motorways with flows in excess of 20,000 vehicles per 24 hour period. The concentration of pollutants indicated in this literature is therefore far in excess of that to be expected from a lightly used village roadway network. More than forty different determinands have been analysed as part of roadway runoff studies, but usually only the major pollutants are examined in detail.

In addition, the concentration levels of different roadway pollutants vary considerably from season to season, and under different short term hydrometeorological conditions.

It should be noted that "treatment" of roadway runoff, such as collection in a balancing pond, will reduce levels of pollutants associated with suspended solids (such as lead) by over 90%. Some soluble materials such as cadmium are removed by adsorption or transformation during transport through the drainage system. Structures like balancing ponds generally have very little effect upon concentration levels of oils and polynuclear aromatic hydrocarbons (PAH) in roadway runoff.

New guidelines for water quality of urban runoff are currently being prepared by CIRIA (Ellis, in prep.). Typical values for pollutant discharges from surface water systems in the UK are given in that report and are included here as Table 14.

### 6.2.2 Dilution Effects

Runoff passing through the balancing pond will enter Cransley Brook below the SSSI. Here it will be mixed and diluted by the flow from the catchment above station S4. The extent of this dilution will depend upon seasonally conditioned flow rates and will continue only until the balancing pond is fully discharged. At its maximum discharge rate of 139 l/s the balancing pond will empty from full in 3.6 hours.

Small rainfall events during summer periods are likely to result in some roadway runoff to the balancing pond, and to the stream below the S4 gauging site. Elsewhere in the catchment this precipitation would be taken up by the soils and produce no surface flow.

***Table 14 Event Mean Concentrations and Unit Loads for Stormwater Runoff.***

| | Event mean concentrations (mg/l or g/m$^3$) | Load per unit area (kg/imp.ha/yr) |
|---|---|---|
| Suspended Solids (SS) | 21-582<br>(187) | 347-2340<br>(487) |
| Total Volatile Solids (TVS) | 26-149<br>(73) | 90-127<br>(98) |
| BOD | 7-22<br>(11) | 35-172<br>(59) |
| COD | 33-365<br>(85) | 22-703<br>(358) |
| Ammoniacal nitrogen | 0.2-4.6<br>(0.45) | 1.2-25.1<br>(1.76) |
| Total inorganic nitrogen | 0.5-8.8<br>(2.1) | N/A |
| Total phosphorus ($P^{tot}$) | 0.04-0.76<br>(0.34) | 0.5-4.9<br>(1.8) |
| Total lead ($Pb^{tot}$) | 0.03-3.1<br>(0.21) | 0.09-1.91<br>(0.83) |
| Total zinc ($Zn^{tot}$) | 0.05-3.68<br>(0.30) | 0.21-2.68<br>(1.15) |
| Total copper ($Cu^{tot}$) | 0.02-0.35<br>(0.11) | 0.06-1.05<br>(0.46) |
| Oil | 0.09-2.8<br>(0.4) | N/A |
| Faecal coliforms | 1200-11200<br>(6430) | 0.9-3.8<br>(2.1) |
| (E.coli) | (MPN/ml) | x10$^9$ count/ha) |

## 6.3 OTHER FACTORS

The change from agricultural to urban use will result in a reduction in the amount of nitrates, herbicides and pesticides entering the SSSI.

During the construction phase there will be an increase in silt and clay washed from the irregularly disturbed land surface of the development site. Adequate settling ponds will be required to reduce the inflow to such sediment laden flow into the SSSI.

# 7. Conclusions

The results of the hydrological study of the Cransley Lodge area indicate the following:

1. The important perennial springs at the western edge of Birch Spinney occur in an area where the regional southeastward groundwater flow through the Jurassic sands meets an impermeable fault barrier. Land drains underlying large areas to the north of the SSSI and emerging near Mawsley Lodge make the major contribution to the maintenance of the Mawsley Marsh wetland. The quantity and quality of the groundwater emerging from these springs and land drains will not be affected by the proposed Cransley Lodge village development.

2. The primary hydrological impact of the proposed village development will be upon the volume of surface flow from one particular subcatchment (C). The development will result in an 18% increase in the period of time for which flows will exceed 0.001 $m^3/s$, and a 10% increase in the period of time for which they will exceed 0.005 $m^3/s$ in subcatchment C. High flows from subcatchment C will be significantly increased, but only for flows with return periods greater than 30 years.

   The installation of a balancing pond and the present design of the drainage scheme will reduce this impact still further.

3. There are unlikely to be detectable impact of the proposed village upon long term water quality within the SSSI. During the construction phase adequate provision will need to be made to restrict silt laden surface flow entering the SSSI.

4. As the bulk of the proposed village will be underlain by highly impermeable Boulder Clay the development is unlikely to have any significant impact upon the quantity or quality groundwater flow. The Pleistocene and Jurassic aquifers underlying the area around the present Cransley Lodge farm buildings (subcatchment E) will be recharged by water derived from the proposed development. There is the potential for a very small proportion of this groundwater to reach the most easterly margins of the SSSI.

# References


Bonell, M., 1978. An Evaluation of Shallow Groundwater Movement in a Small Boulder Clay Catchment in Holderness. Dept of Geography, University of Hull.

Ellis, , (in prep). Storage Ponds. CIRIA Book 13.

Hains, B.A. and Horton, A., 1969. British Regional Geology - Central England (3rd Edition). Inst. Geol. Sci.. 142p.

Hollingworth, S.E. and Taylor, J.H., 1951. The Northampton Sand Ironstone - Stratigraphy, Structure and Reserves. Mem. of Brit. Geol. Surv.. 198p.

Institute of Hydrology (1976-1986) Flood Studies Supplementary Reports, IH Wallingford, Oxfordshire

Institute of Hydrology (1980) Low Flows Studies, IH Wallingford, Oxfordshire

McGowan, M. Williams, J.B. and Monteith, J.L., 1980. The Water Balance of an Agricultural Catchment. III The Water Balance. Jour. Soil Sci., 31, 245-262.

Natural Environment Research Council (1975) Flood Studies Report, NERC London. 5 vols.

Perry, R. and McIntyre, A.E., 1986. Impact of Motorway Runoff Upon Surface Water Quality. in Effects of Land Use on Fresh Water. (Ed J.F.de L.G. Solbe). Water Research Centre.

Taylor, J.H., 1963. The Geology of the Country around Kettering, Corby and Oundle. (Explanation of Sheet 171). Mem. Of Brit. Geol. Surv.. 148p.

# Annex I

## MONITORING NETWORK

RAINFALL: A 0.5 mm tipping bucket raingauge linked to an digital datalogger recording the number of tips per minute was set up at coordinate 810762. The lip of the raingauge is approximately 30 cm above ground level which is at an elevation of 126.5 m.O.D.. The site is central to the area of the proposed village on relatively level, exposed ground close to the crest of a hill several hundred metres to the west of the nearest buildings at Cransley Lodge.

SOIL MOISTURE: A neutron probe access tube (SM1) was installed approximately 8 m north of BH6 at 808760. The tube was sunk to 1.95 m below ground level in Boulder Clay. The hole was terminated at this depth due to obstruction by a Chalk boulder. It is possible that the attempts to penetrate this boulder may have created some void space around the bottom 20 cm of the tube.

A further soil moisture monitoring site was installed at 808764 in sandy soil above Pleistocene Sand and Northampton Sand. The tube was sunk to 2.18 cm.

GROUNDWATER: Six boreholes were drilled through the Jurassic sands and into the underlying Lias clay. The holes were geologically logged during drilling and screened HPVC tubing installed. In all cases larger diameter UPVC tubing ("A") was placed in the aquifer immediately above the Lower Lias contact. Where perched water tables were encountered above the Northampton Sand an additional narrow diameter UPVC piezometer tube ("B") was installed.

Bentonite seals were used to isolate different aquifers where necessary.

A seventh borehole (BH7) was drilled to monitor water levels within the Boulder Clay.

Borehole (KDC 1) was completed by the Kettering District Council in 1934 to supplement water supplies to the Cransley Reservoir. Geological logs for this holes were retrieved from the National Borehole Archive and integrated into the database for the site. It is thought that this holes lies beneath the cast iron capping at 804763. It has not been possible monitor water levels in this hole.

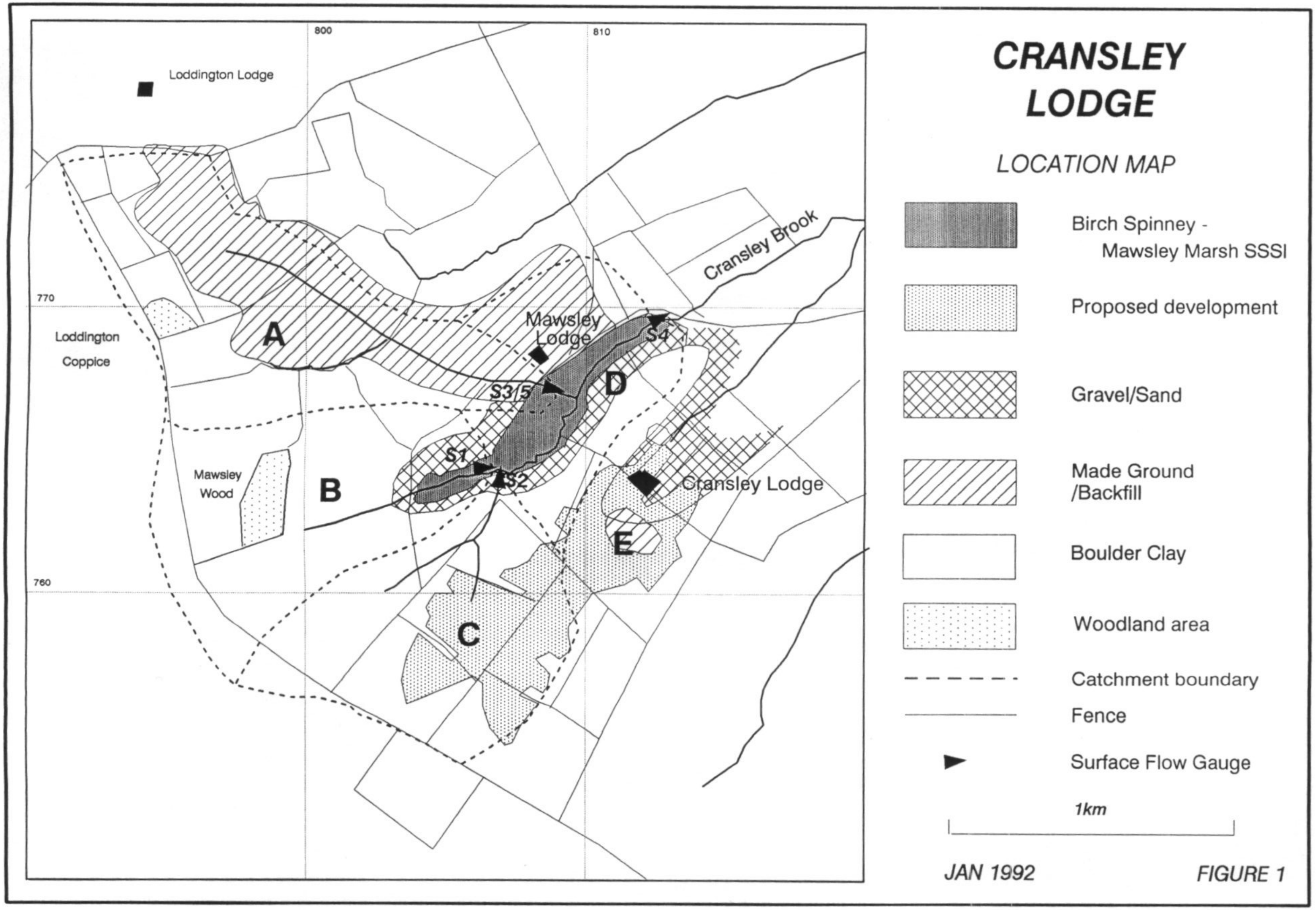
Seventeen narrow diameter (1" O.D. galvanised iron piping) piezometers were installed using a hand auger. Geological logs have been prepared for these and other hand auger holes drilled at various sites around the study area.

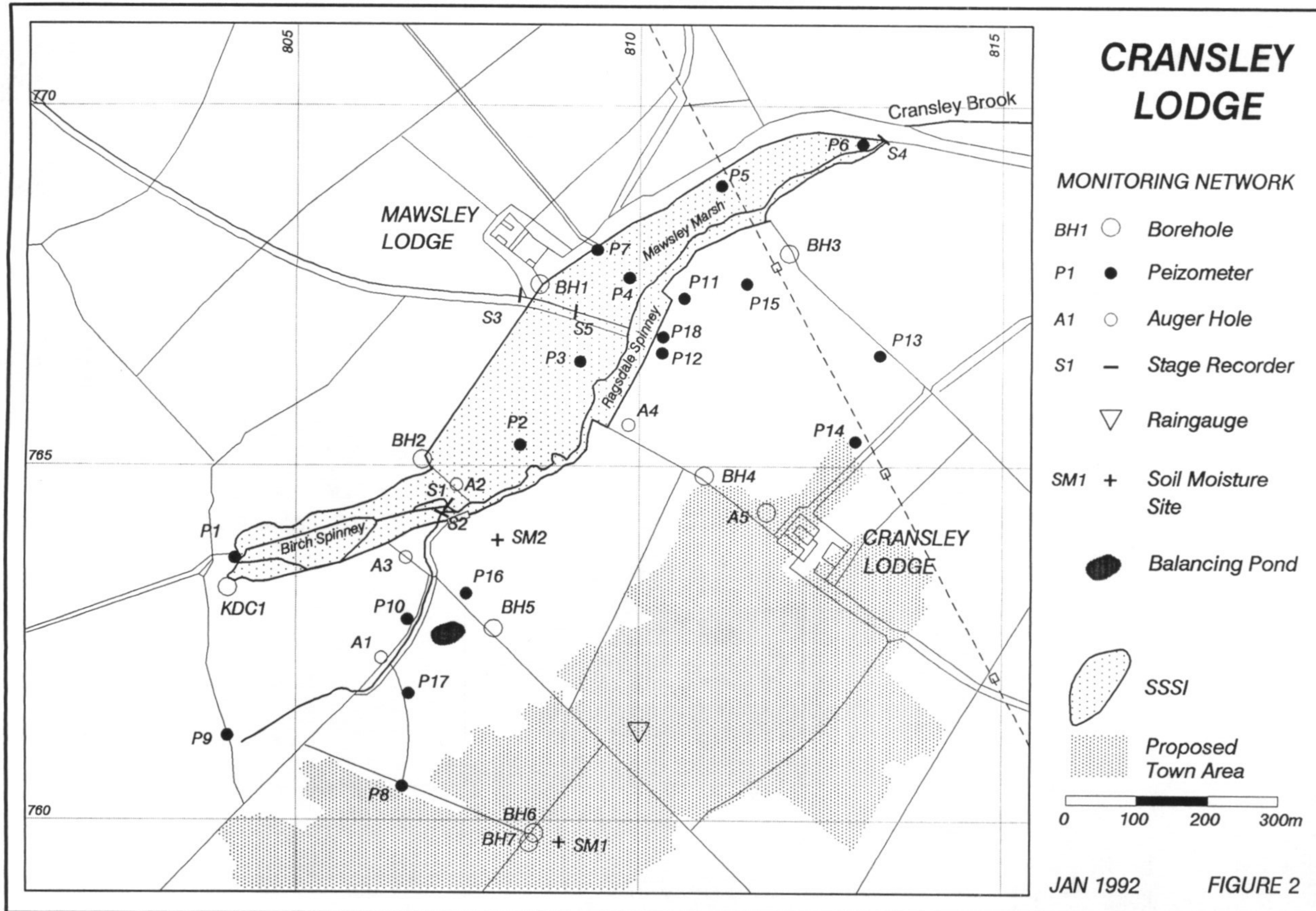
Boreholes and piezometers have been manually dipped on a monthly basis, while a multi-channel datalogger recording water levels at 6 hourly intervals has been installed at BH6 and BH7.

SURFACE FLOW: Two fully developed 90° V-notch gauges with chart recorders were initially installed on two intermittent streams at sites S1 and S3. A third chart recorder was set up to monitor stage levels through the railway tunnel (S4) at the eastern edge of the SSSI. A pressure transducer and datalogger reading initially at 15 minute intervals was established to monitor stage levels over the hydraulic ram weir (S1).

Due to problems associated with calibrating low flows at S1 and S4 temporary V-notch gauges (90° fully developed) were installed at these two sites during July 1991.

A fourth chart recorder was installed in July 1991 to monitor outflow from the land drain to the immediate west of Mawsley Lodge. This recorder was set up on a tank weir with a 1/4 90° V-notch gauge.

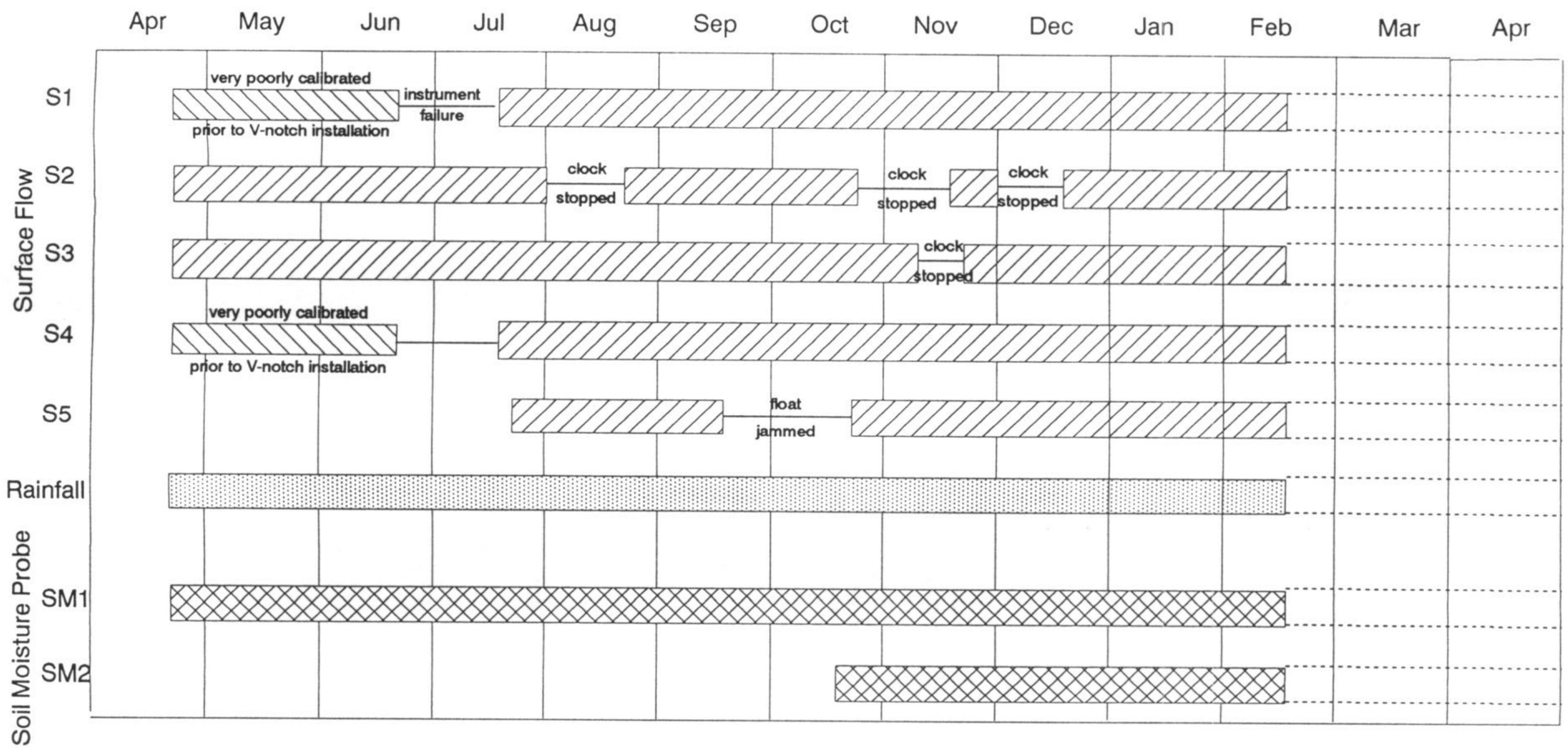

CRANSLEY
LODGE
LOCATION MAP
Birch Spinney -
Mawsley Marsh SSSI
Proposed development
Gravel/Sand
Made Ground
/Backfill
Boulder Clay
Woodland area
Catchment boundary
Fence
Surface Flow Gauge
1km
JAN 1992
FIGURE 1
Loddington Lodge
Loddington
Coppice
Mawsley
Wood
Mawsley
Lodge
Cransley Brook
Cransley Lodge
A
B
C
D
E
S1
S2
S3/5
S4
800
810
770
760



CRANSLEY LODGE
MONITORING NETWORK
BH1 Borehole
P1 Peizometer
A1 Auger Hole
S1 Stage Recorder
Raingauge
SM1 Soil Moisture Site
Balancing Pond
SSSI
Proposed Town Area
0 100 200 300m
JAN 1992
Cransley Brook
MAWSLEY LODGE
CRANSLEY LODGE
Mawsley Marsh
Ragsdale Spinney
Birch Spinney
KDC1
805
810
815
770
765
760

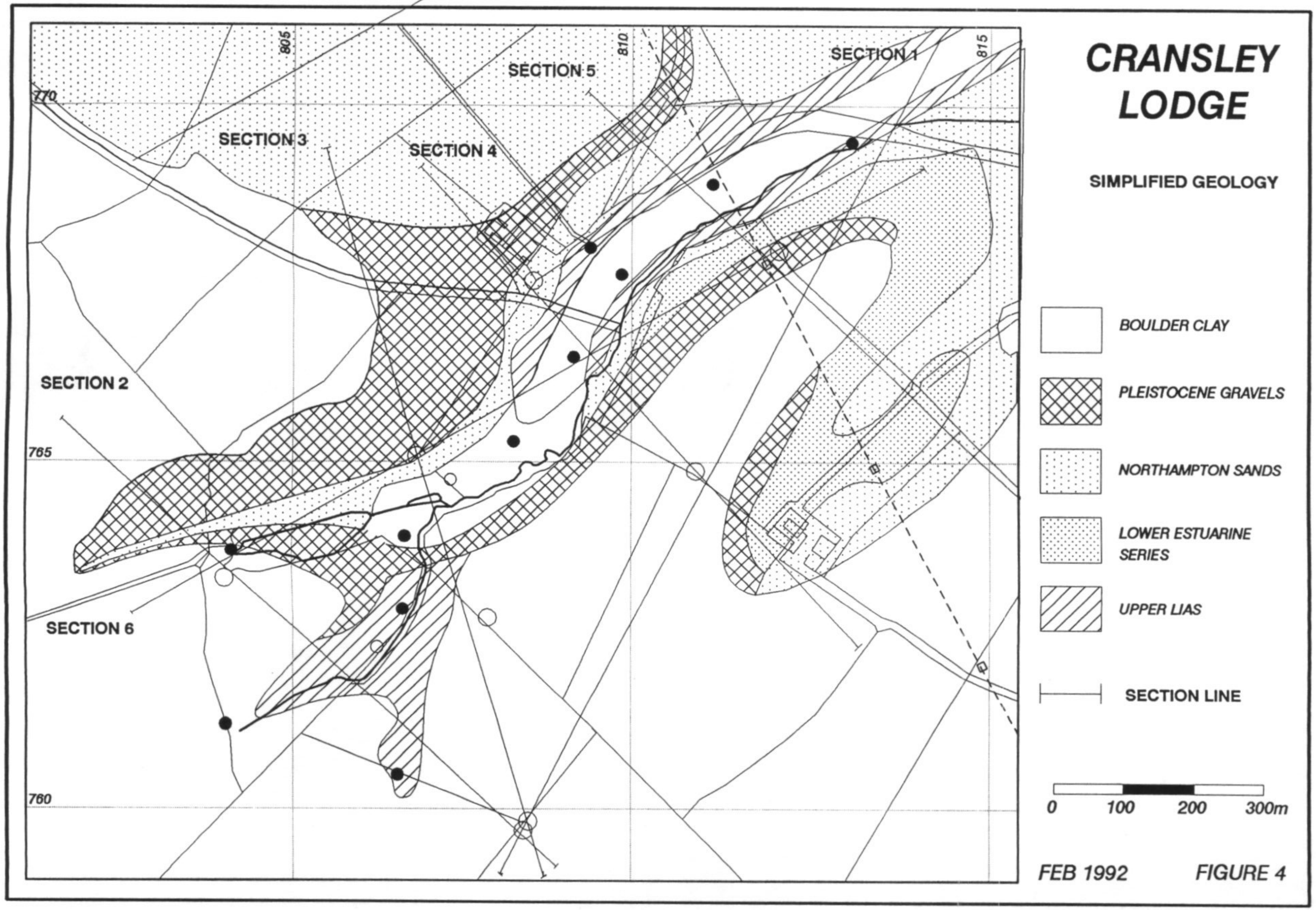

FIGURE 2

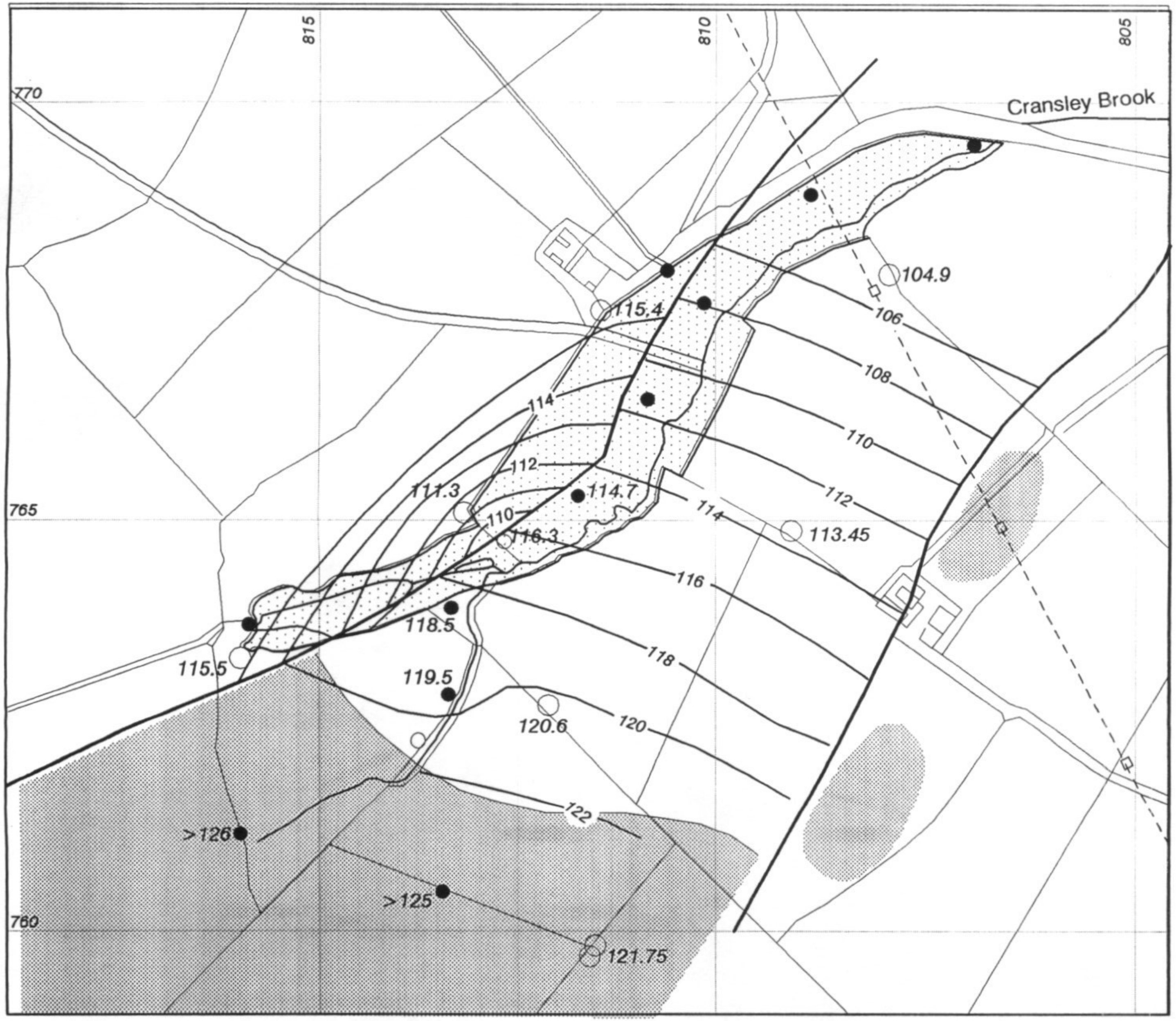
## Hydrological Data Availability at Cransley Lodge - 1991-1992




JAN 1992

FIGURE 3


CRANSLEY LODGE
SIMPLIFIED GEOLOGY
BOULDER CLAY
PLEISTOCENE GRAVELS
NORTHAMPTON SANDS
LOWER ESTUARINE SERIES
UPPER LIAS
SECTION LINE
0
100
200
300m
SECTION 1
SECTION 2
SECTION 3
SECTION 4
SECTION 5
SECTION 6
805
810
815
770
765
760
FEB 1992
FIGURE 4




# CRANSLEY LODGE

## ELEVATION OF BASE OF THE NORTHAMPTON SAND (m.O.D)

Northampton Sand absent due to:

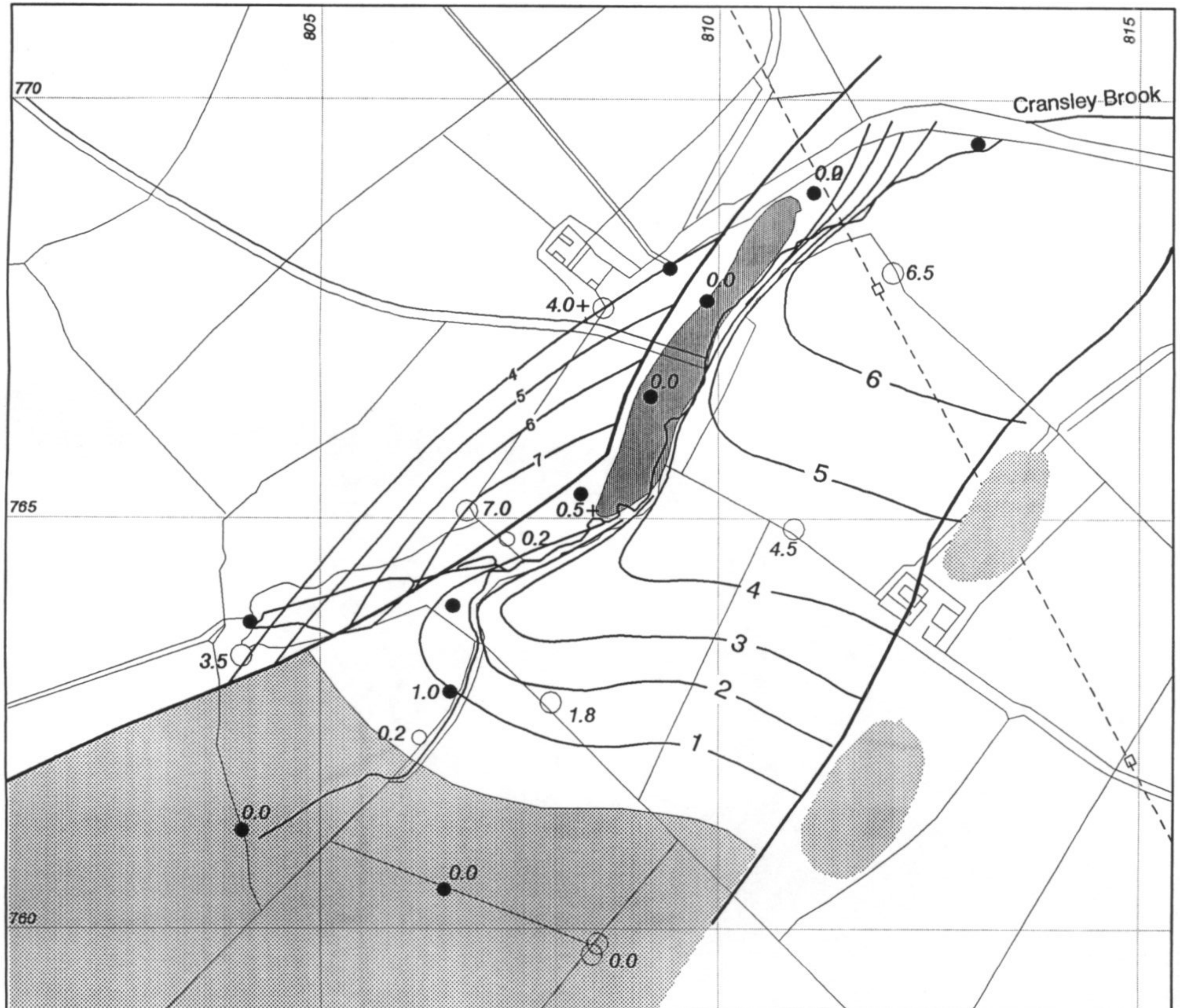
Pleistocene Erosion

SSSI

0 100 200 300m

JAN 1992

FIGURE 5




# CRANSLEY LODGE

ISOPACH OF NORTHAMPTON SAND

(m)

Northampton Sand
Absence due to:

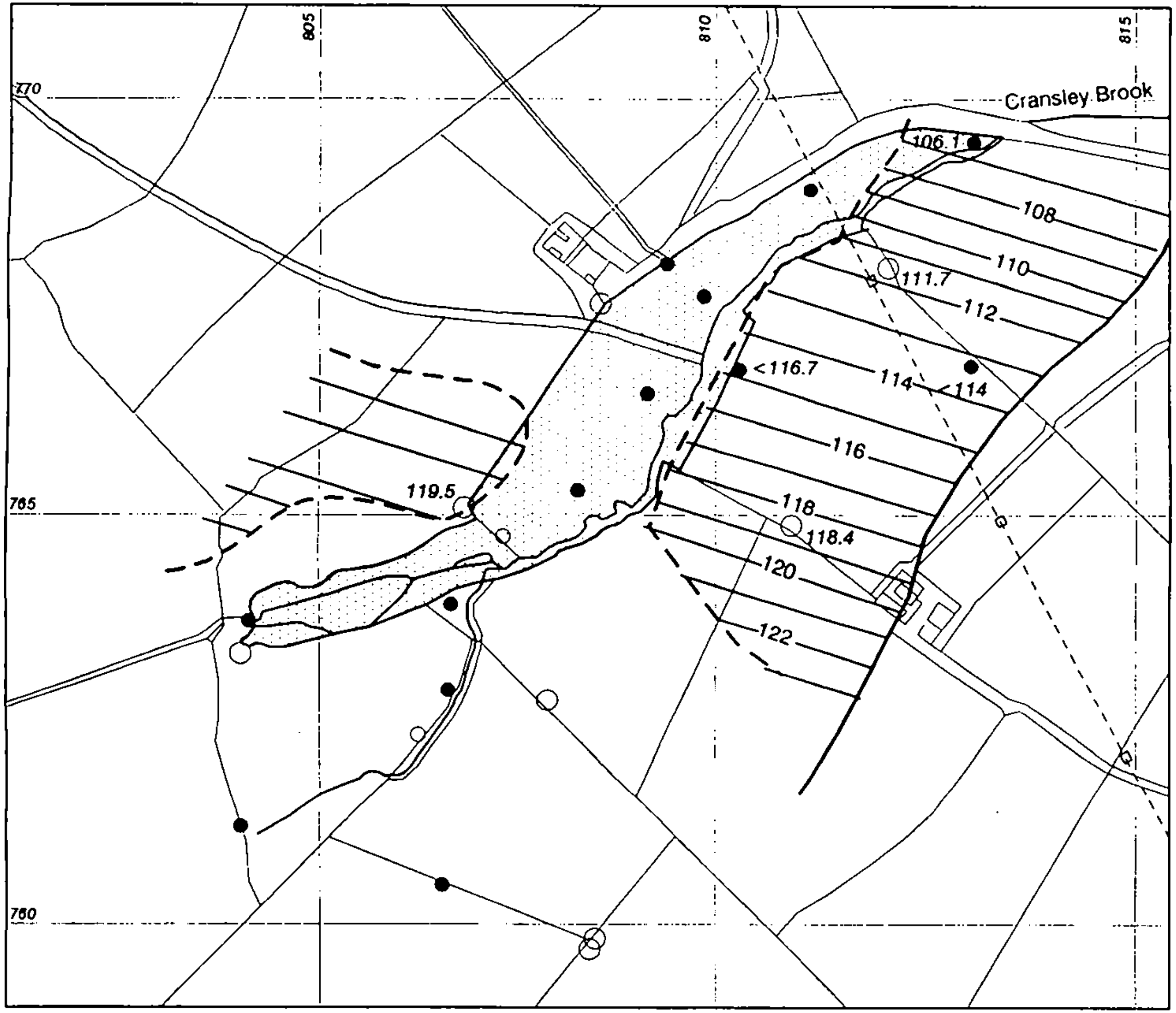
Recent Erosion

Pleistocene Erosion

0 100 200 300m

JAN 1992

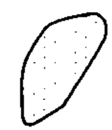
FIGURE 6




# CRANSLEY LODGE

*ELEVATION OF BASE OF THE LOWER ESTUARINE SERIES m.O.D*

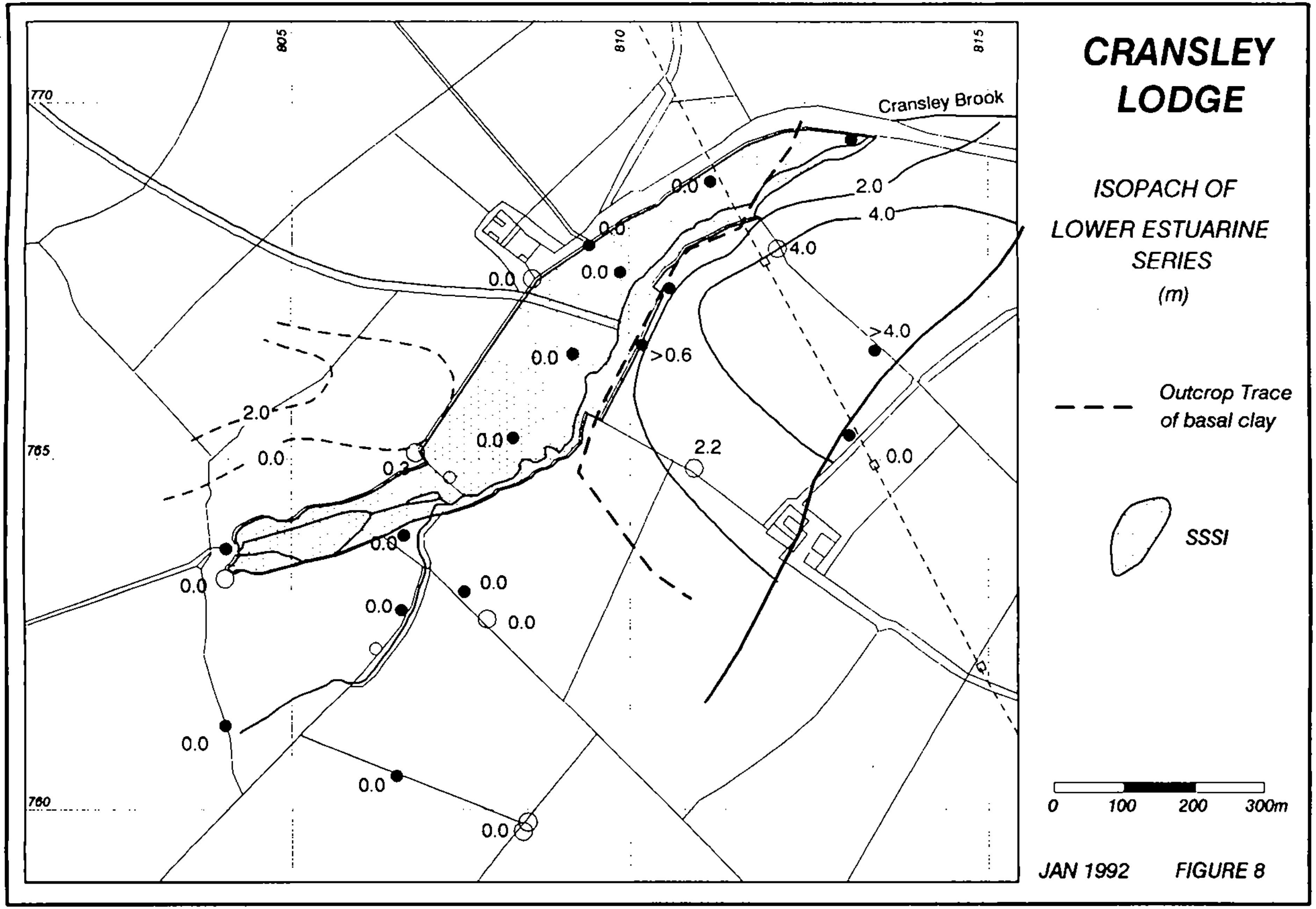
*(TOP OF CLAY AQUICLUDE)*

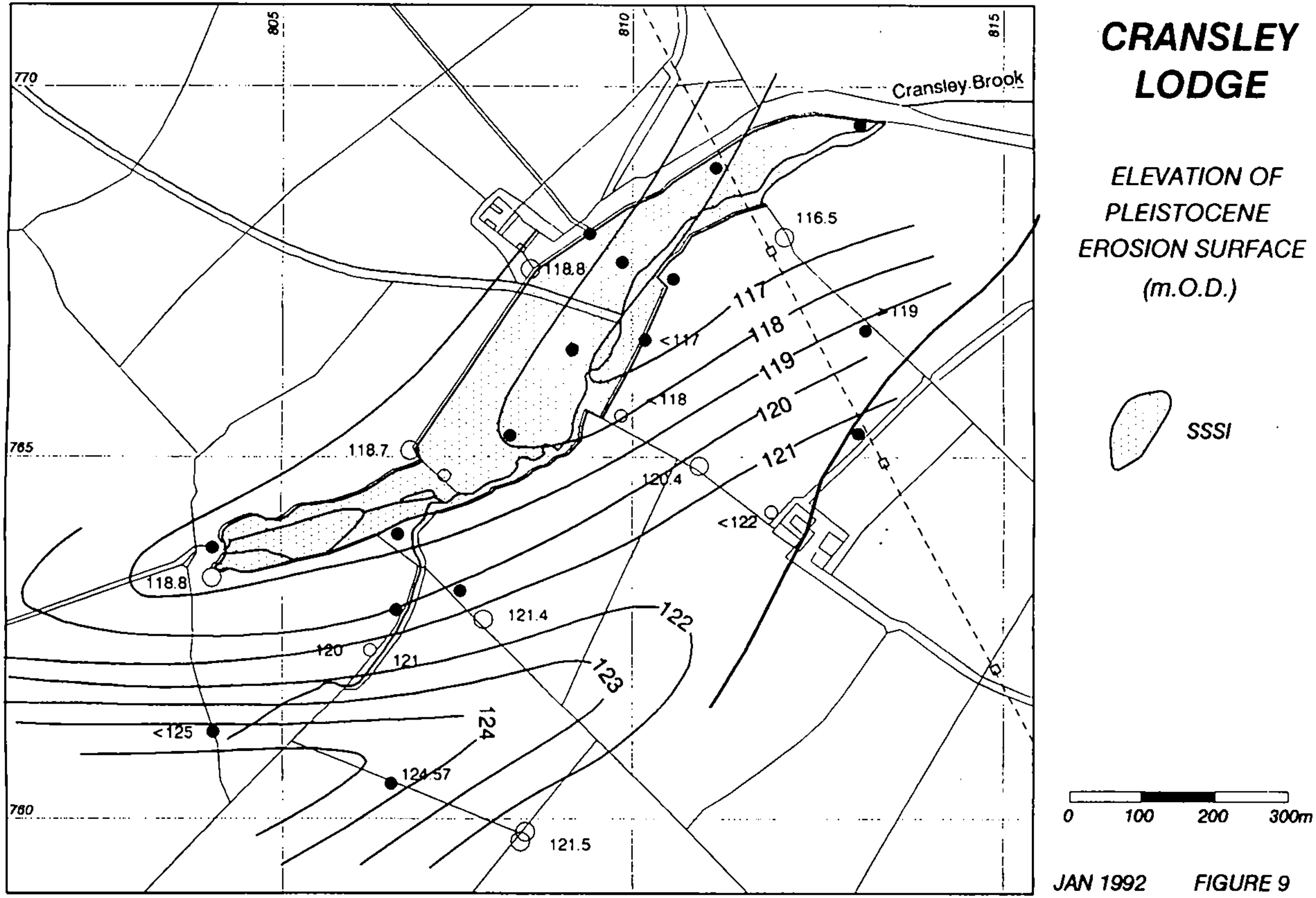


*SSSI*

*0 100 200 300m*

*JAN 1992* *FIGURE 7*


CRANSLEY
LODGE
ISOPACH OF
LOWER ESTUARINE
SERIES
(m)
Outcrop Trace
of basal clay
SSSI
0
100
200
300m
JAN 1992
FIGURE 8
Cransley Brook
805
810
815
770
765
760
2.0
4.0
4.0
>4.0
>0.6
2.2
0.3
0.0

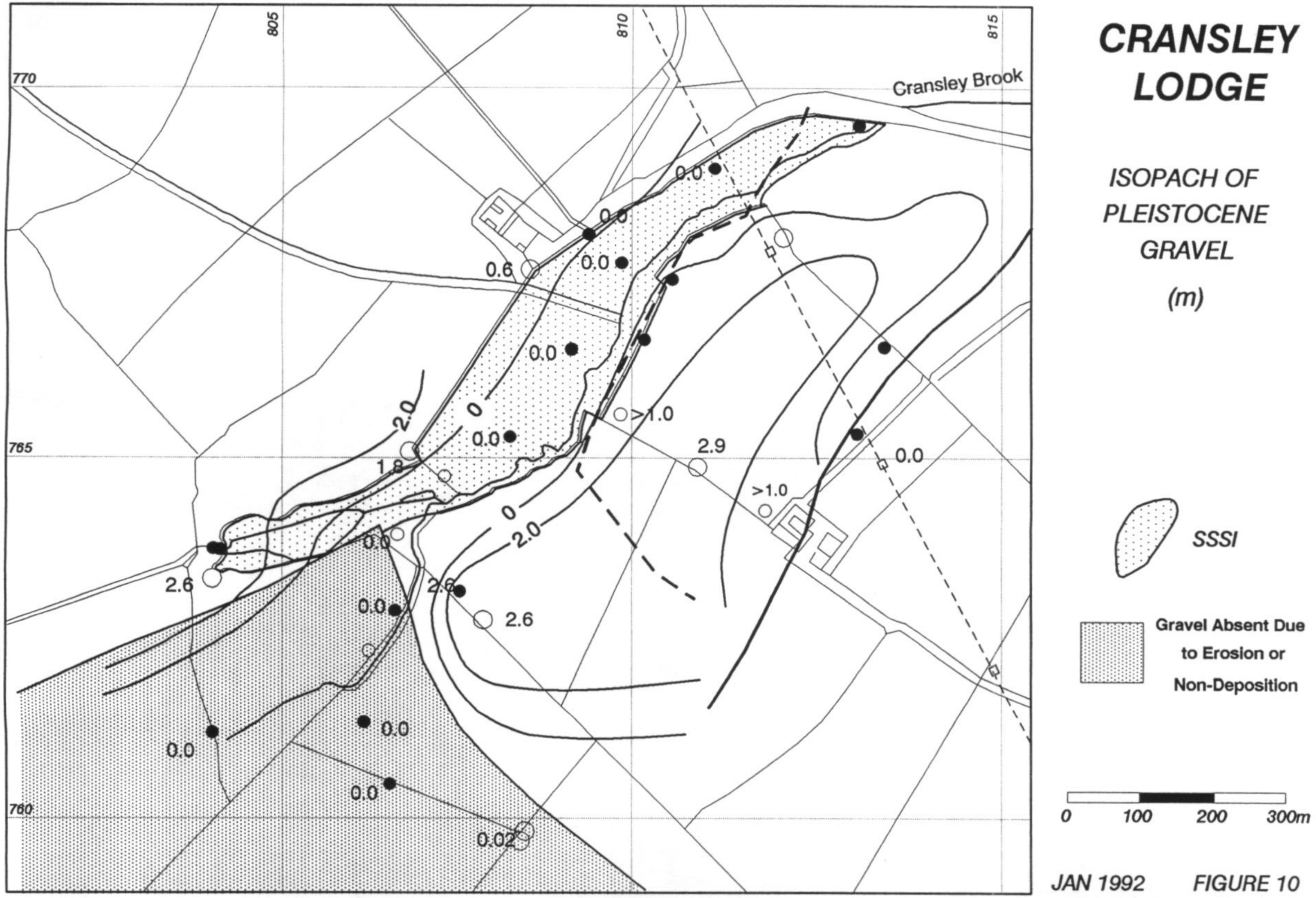



# CRANSLEY LODGE

*ELEVATION OF PLEISTOCENE EROSION SURFACE (m.O.D.)*

0 100 200 300m

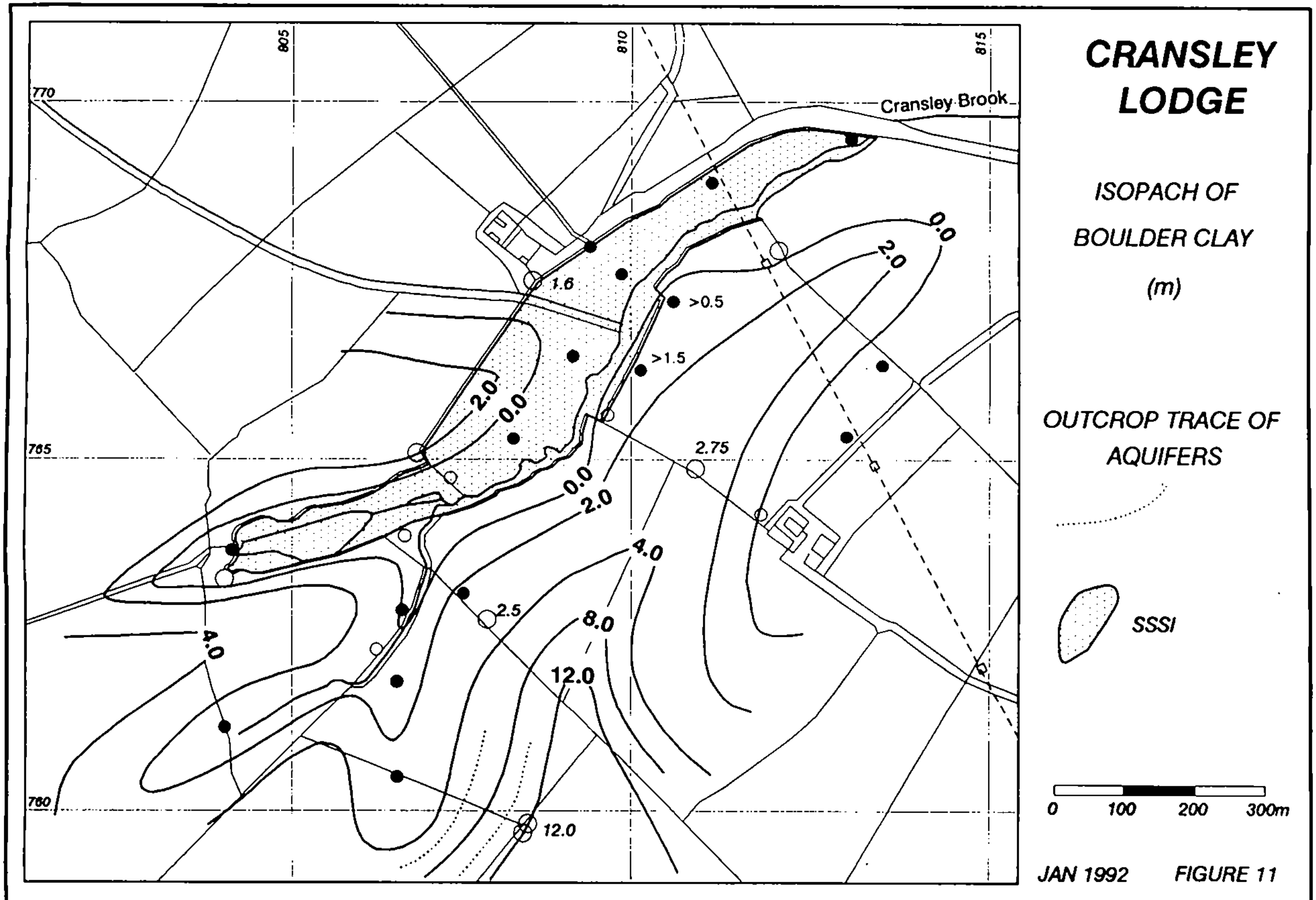
*JAN 1992* *FIGURE 9*

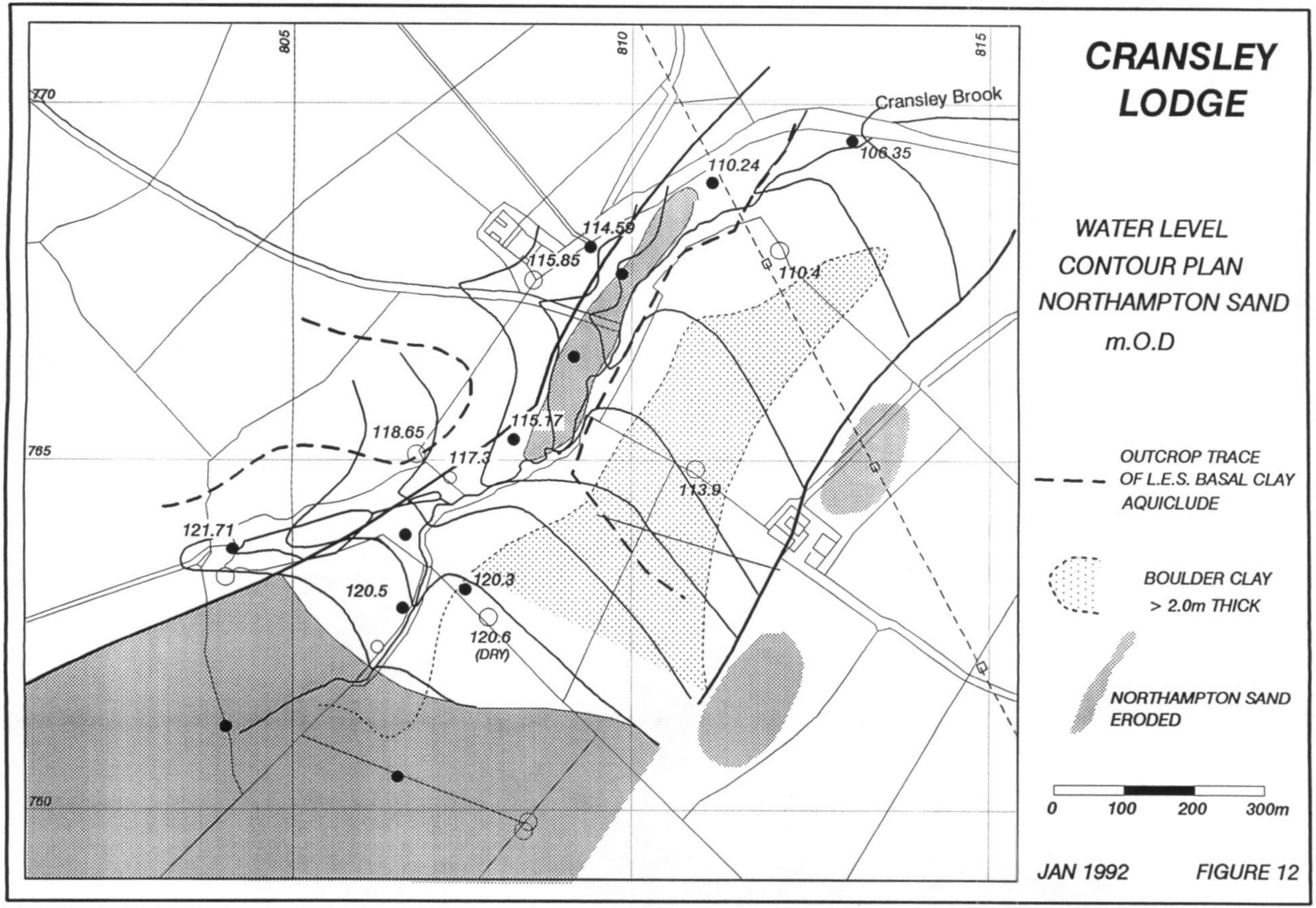


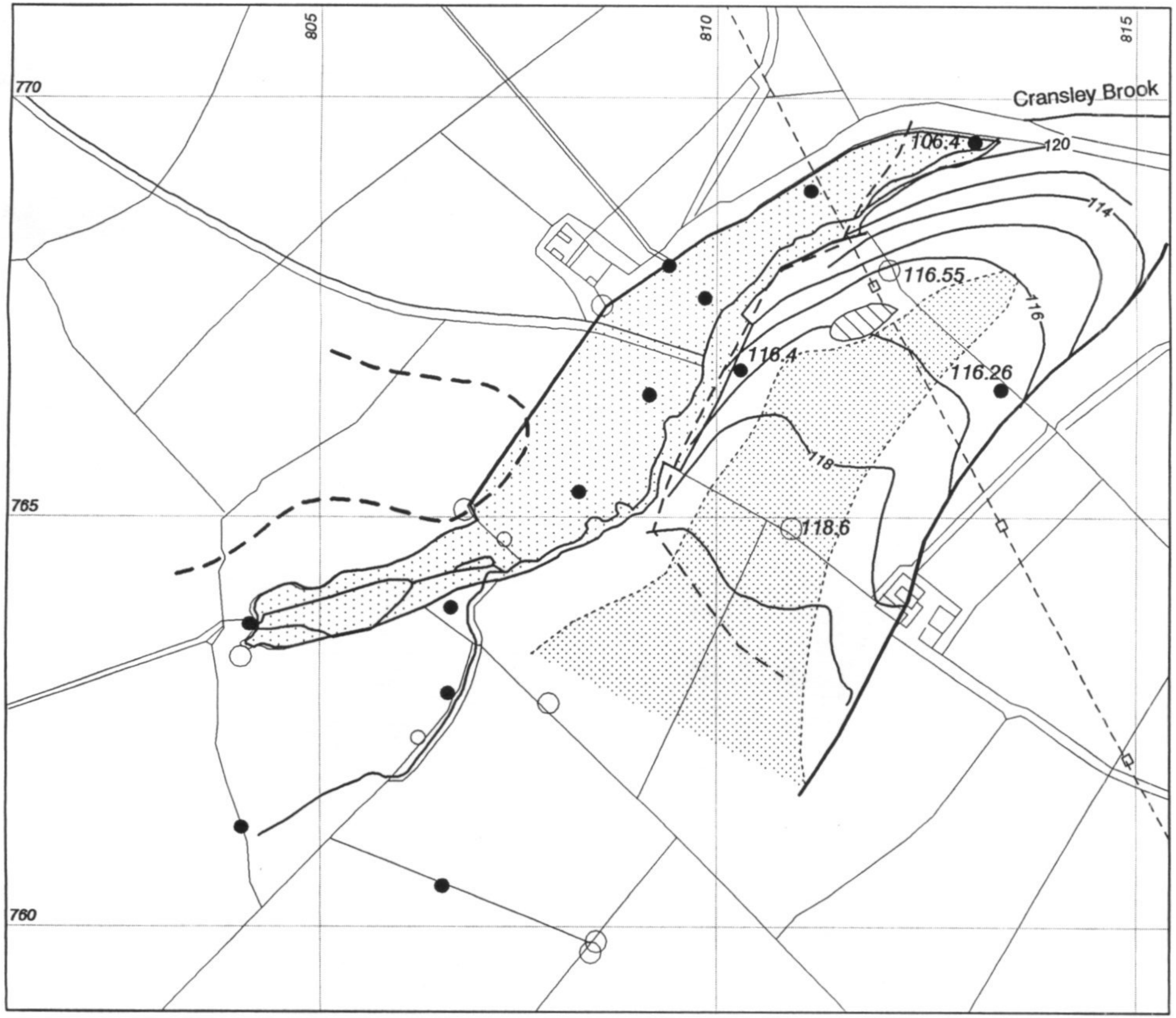

# CRANSLEY LODGE

*ISOPACH OF PLEISTOCENE GRAVEL (m)*

*JAN 1992* *FIGURE 10*


CRANSLEY
LODGE
ISOPACH OF
BOULDER CLAY
(m)
OUTCROP TRACE OF
AQUIFERS
SSSI
0
100
200
300m
JAN 1992
Cransley Brook
770
765
760
805
810
815
0.0
2.0
4.0
8.0
12.0
1.6
>0.5
>1.5
2.75
2.5
12.0
FIGURE 11


CRANSLEY LODGE
WATER LEVEL CONTOUR PLAN NORTHAMPTON SAND m.O.D
OUTCROP TRACE OF L.E.S. BASAL CLAY AQUICLUDE
BOULDER CLAY > 2.0m THICK
NORTHAMPTON SAND ERODED
0
100
200
300m
JAN 1992
Cransley Brook
106.35
110.24
110.4
114.59
115.85
115.17
113.9
118.65
117.3
121.71
120.3
120.5
120.6
(DRY)
805
810
815
770
765
760
FIGURE 12




# CRANSLEY LODGE

WATER LEVEL CONTOUR PLAN

THE LOWER ESTUARINE SERIES

m.O.D

SSSI

OUTCROP TRACE OF BASAL CLAY AQUICLUDE

BOULDER CLAY > 2.0m THICK

AREAS OF FOCUSSED RECHARGE

0 100 200 300m

JAN 1992

FIGURE 13

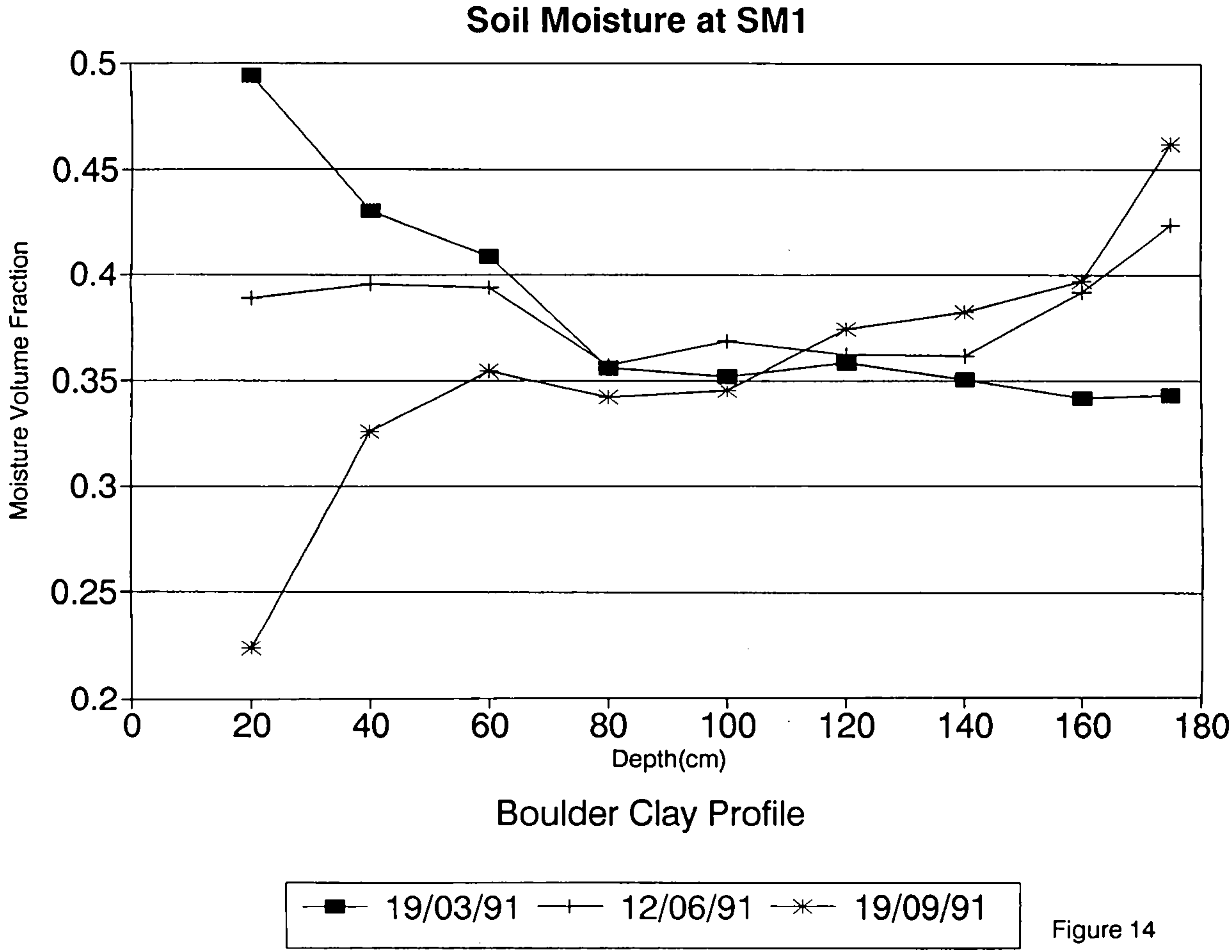

Soil Moisture at SM1
Moisture Volume Fraction
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0
20
40
60
80
100
120
140
160
180
Depth(cm)
Boulder Clay Profile
19/03/91
12/06/91
19/09/91

Figure 14

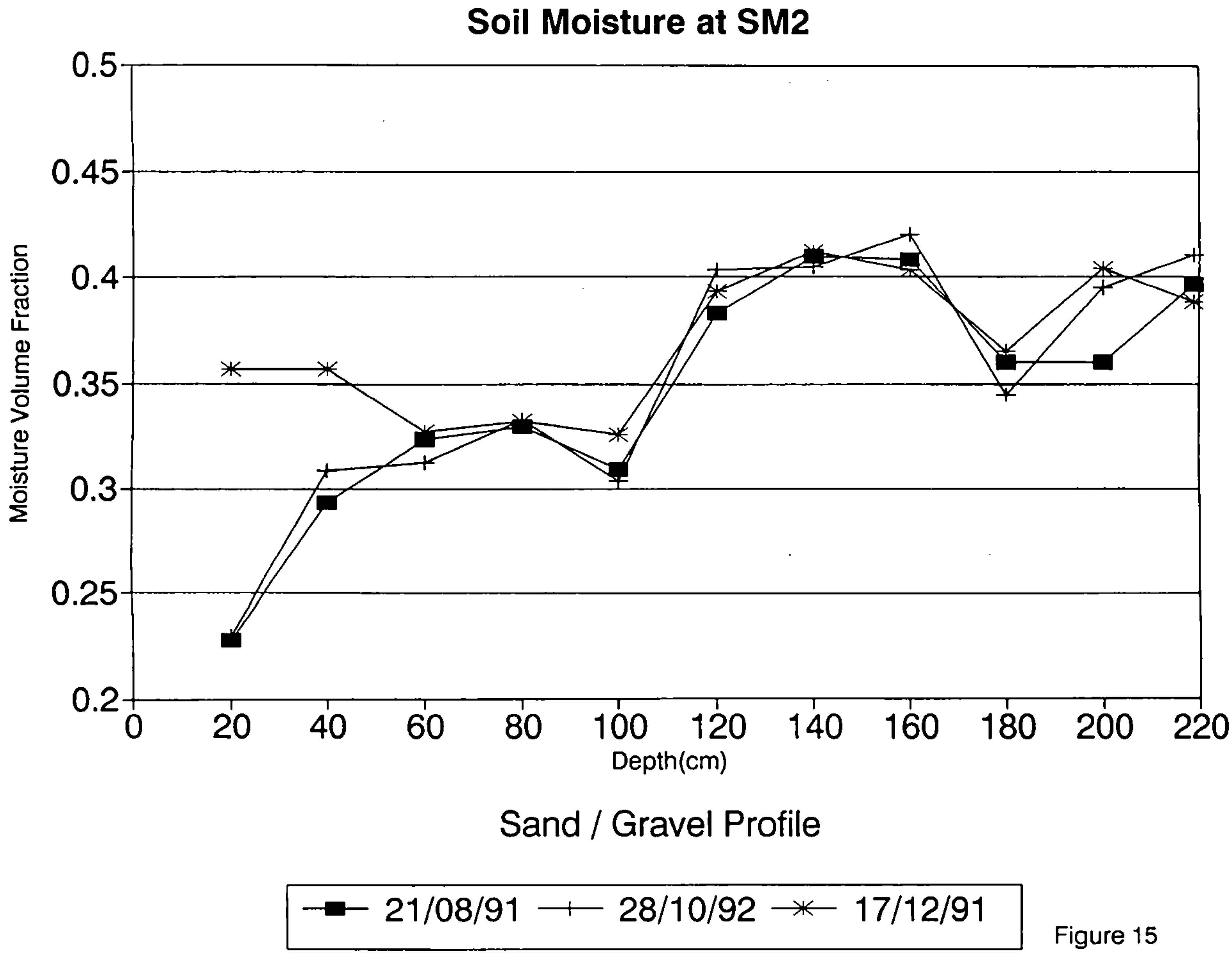
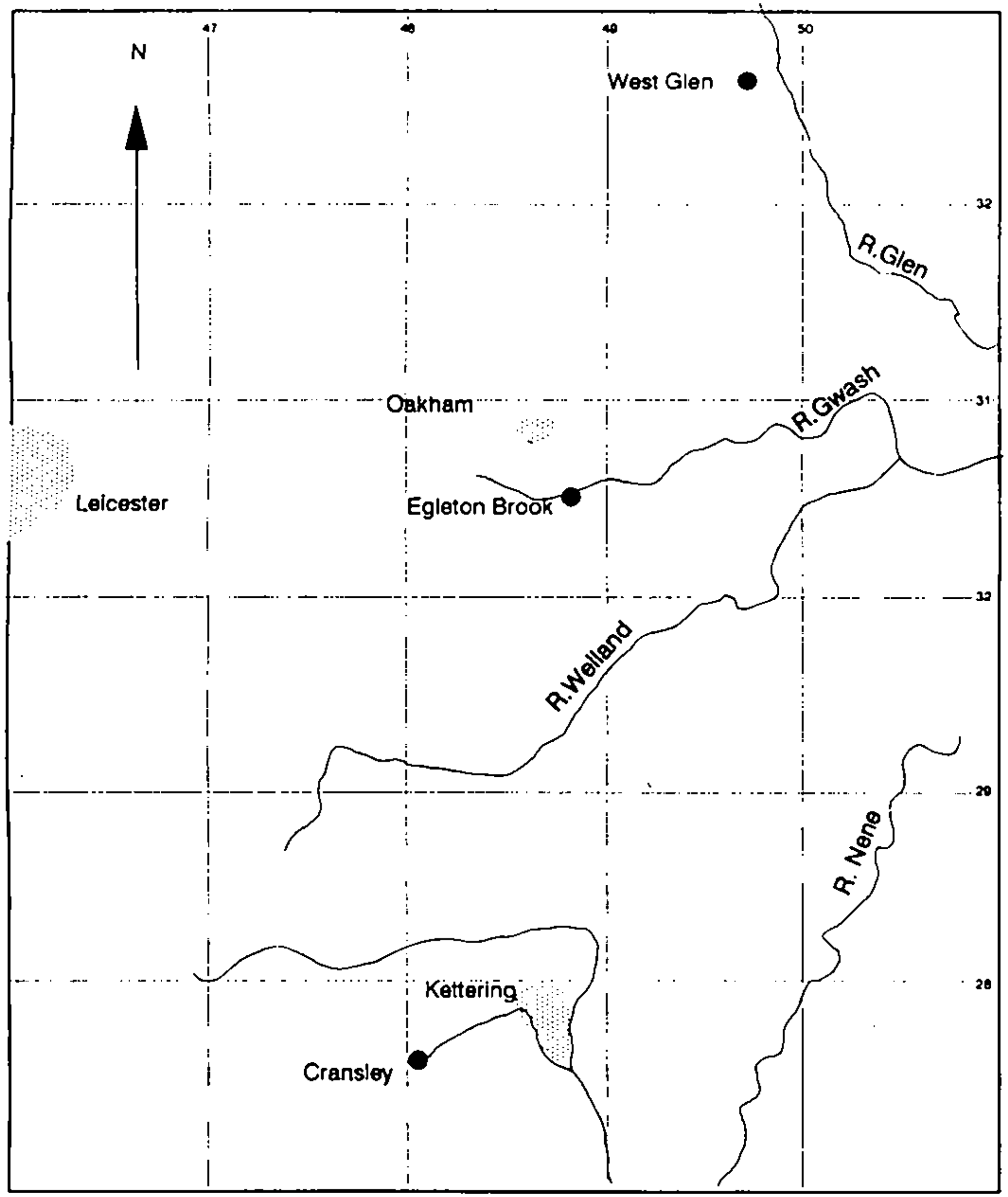

Soil Moisture at SM2
Moisture Volume Fraction
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0
20
40
60
80
100
120
140
160
180
200
220
Depth(cm)
Sand / Gravel Profile
21/08/91
28/10/92
17/12/91

Figure 15

# CRANSLEY LODGE

COMPARATIVE CATCHMENTS

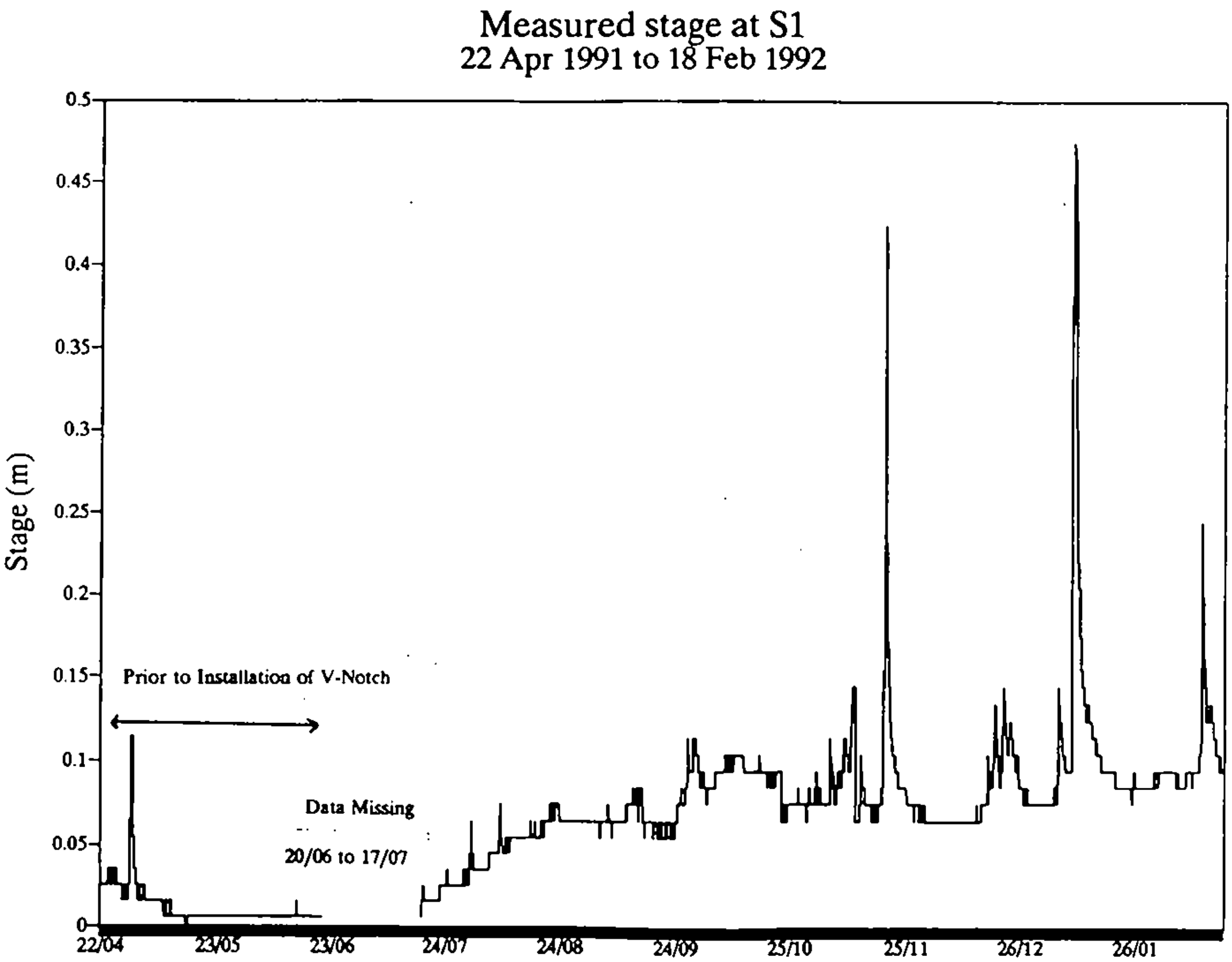



● GAUGING STATION

0 10 20 km

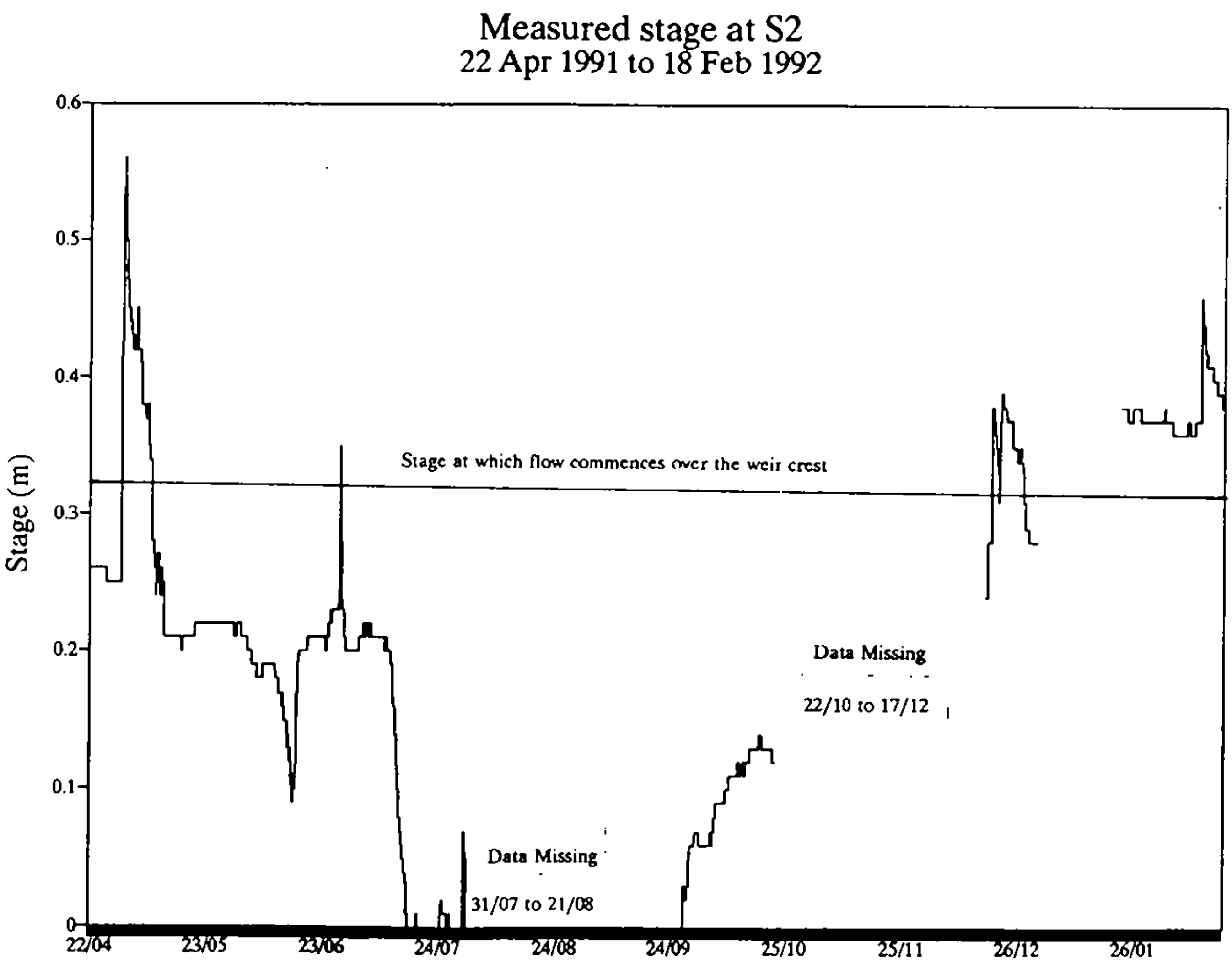
JAN 1992

FIGURE 16



Measured stage at S1
22 Apr 1991 to 18 Feb 1992
Stage (m)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Prior to Installation of V-Notch
Data Missing
20/06 to 17/07
22/04
23/05
23/06
24/07
24/08
24/09
25/10
25/11
26/12
26/01


FIGURE 17



Measured stage at S2
22 Apr 1991 to 18 Feb 1992
Stage (m)
0.6
0.5
0.4
0.3
0.2
0.1
0
Stage at which flow commences over the weir crest
Data Missing
22/10 to 17/12
Data Missing
31/07 to 21/08
22/04
23/05
23/06
24/07
24/08
24/09
25/10
25/11
26/12
26/01


FIGURE 18

Measured stage at S3
22 Apr 1991 to 18 Feb 1992

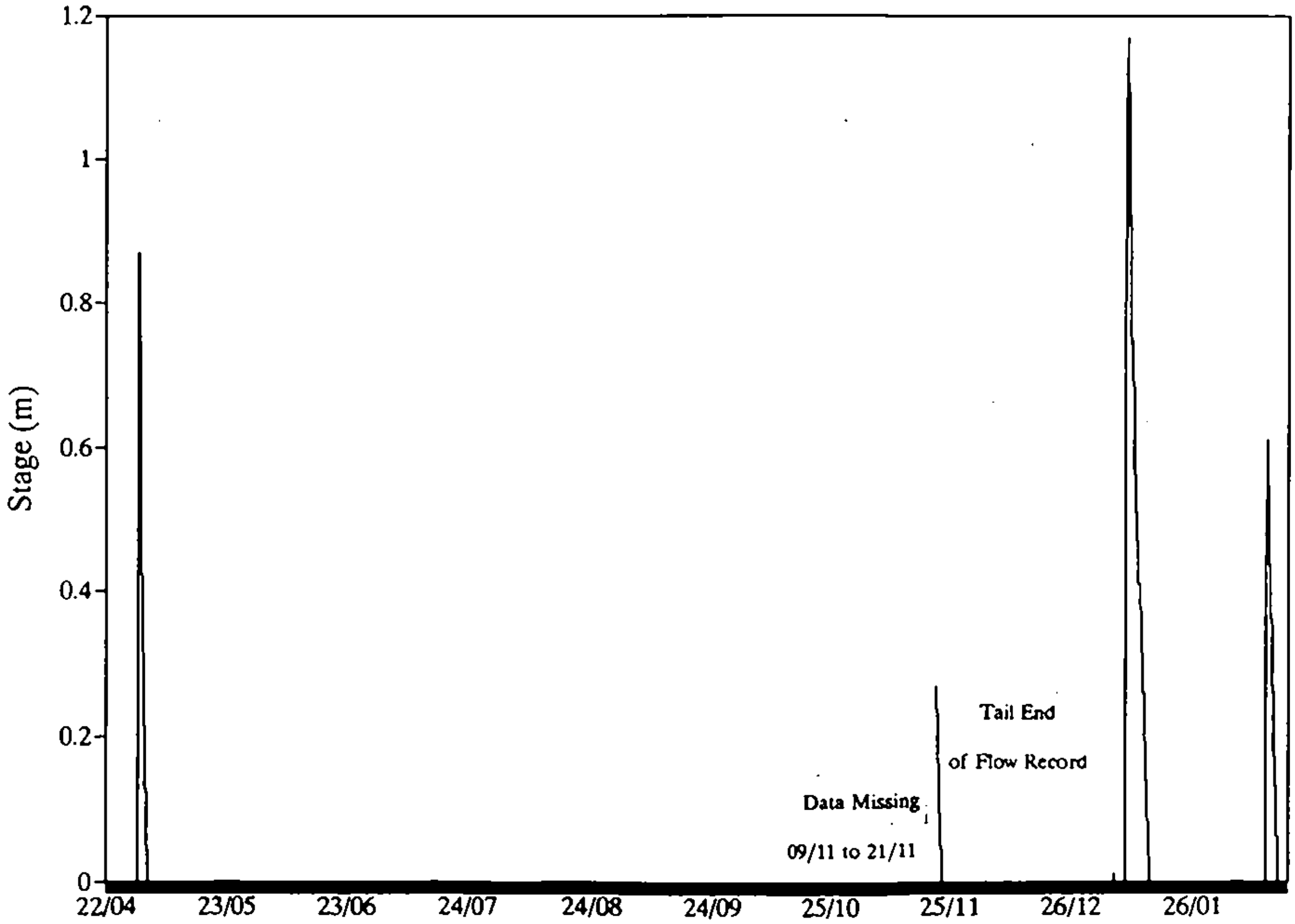



FIGURE 19

Measured stage at S4
22 Apr 1991 to 18 Feb 1992

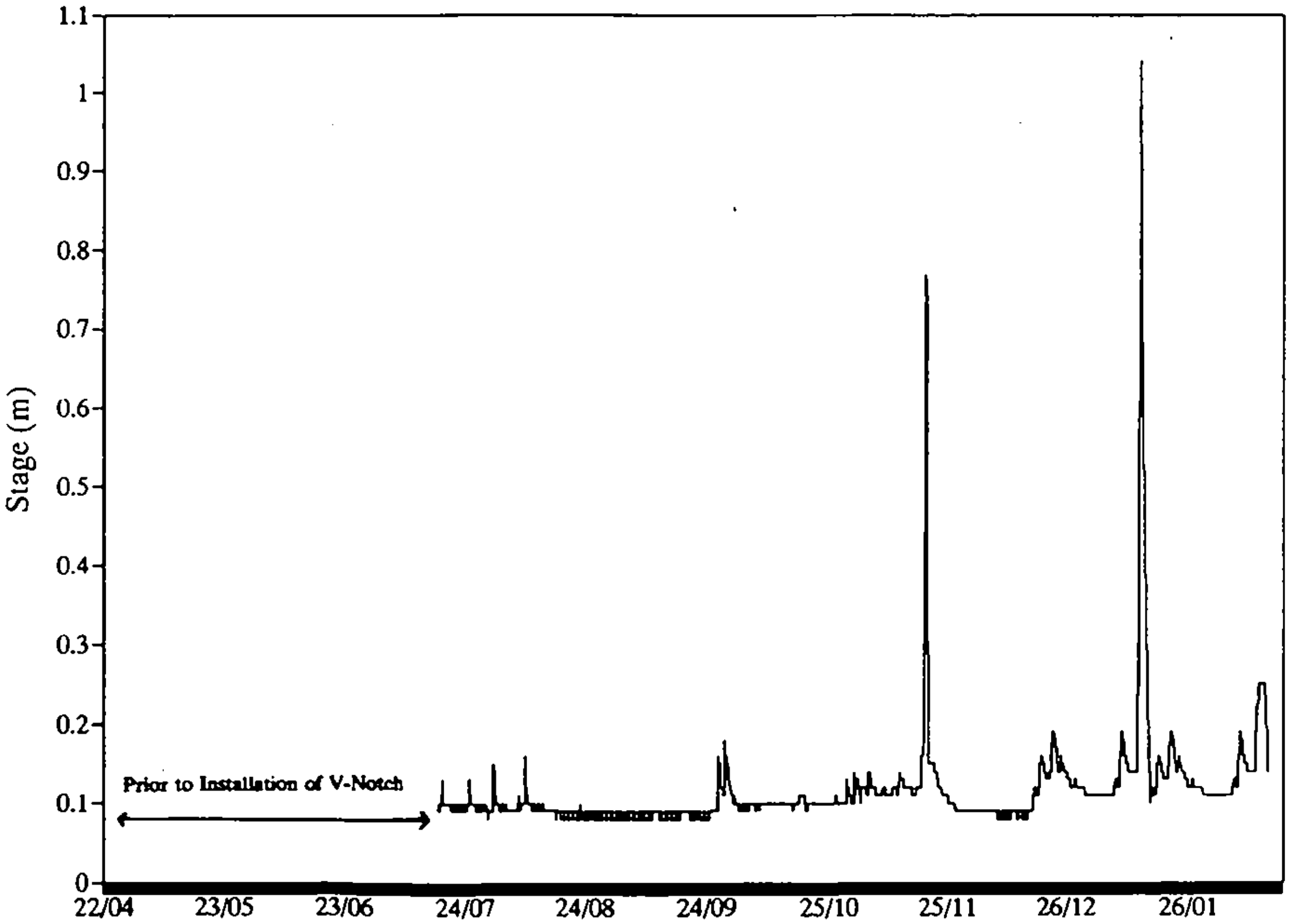



FIGURE 20

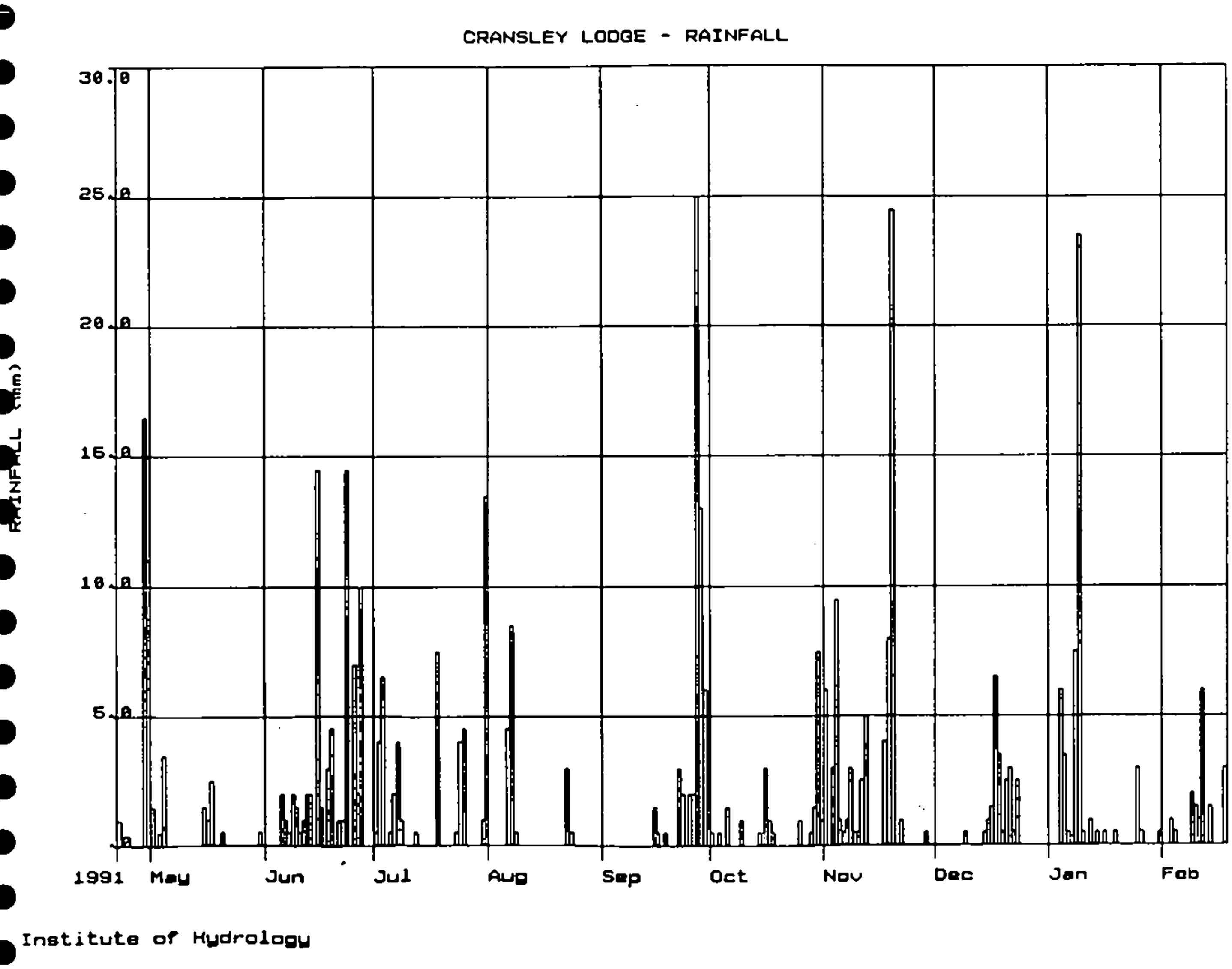
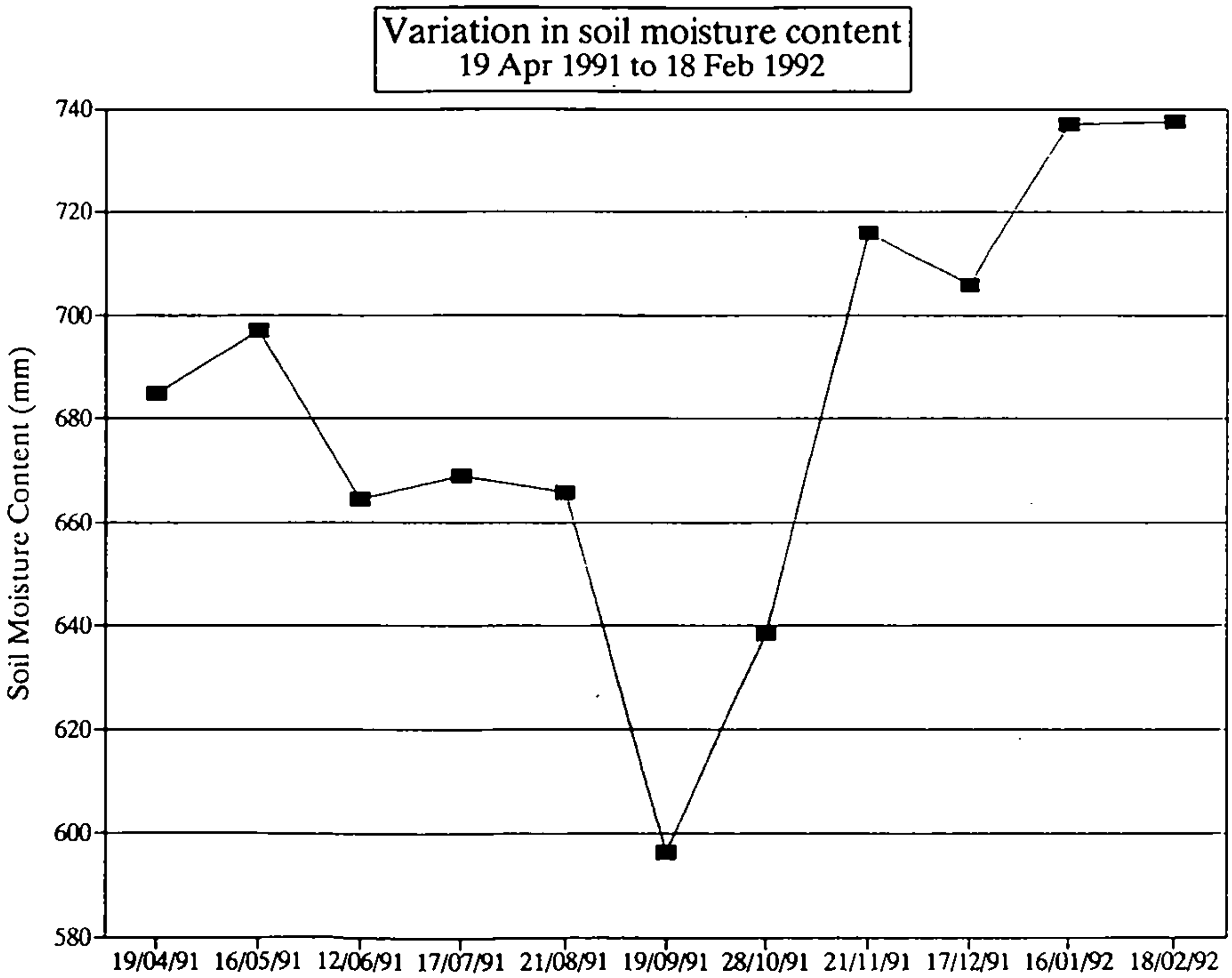

CRANSLEY LODGE - RAINFALL
RAINFALL (mm)
30.0
25.0
20.0
15.0
10.0
5.0
1991
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Institute of Hydrology

FIGURE 21



Variation in soil moisture content
19 Apr 1991 to 18 Feb 1992
Soil Moisture Content (mm)
740
720
700
680
660
640
620
600
580
19/04/91
16/05/91
12/06/91
17/07/91
21/08/91
19/09/91
28/10/91
21/11/91
17/12/91
16/01/92
18/02/92


FIGURE 22

Flood Frequency Curves at S3, Sub-catchment A

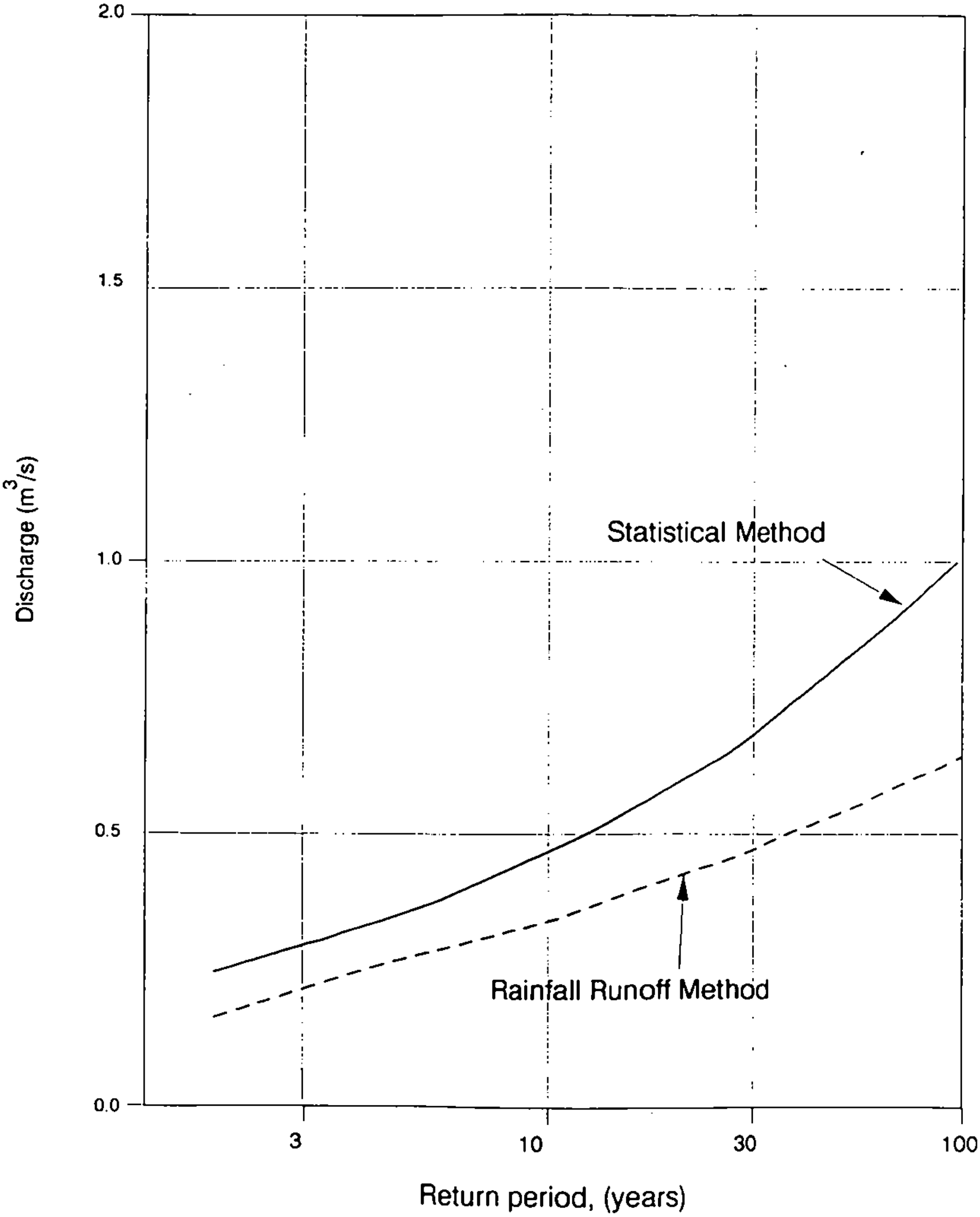



*FIGURE 23*

Flood Frequency Curves at S1, Sub-catchment B

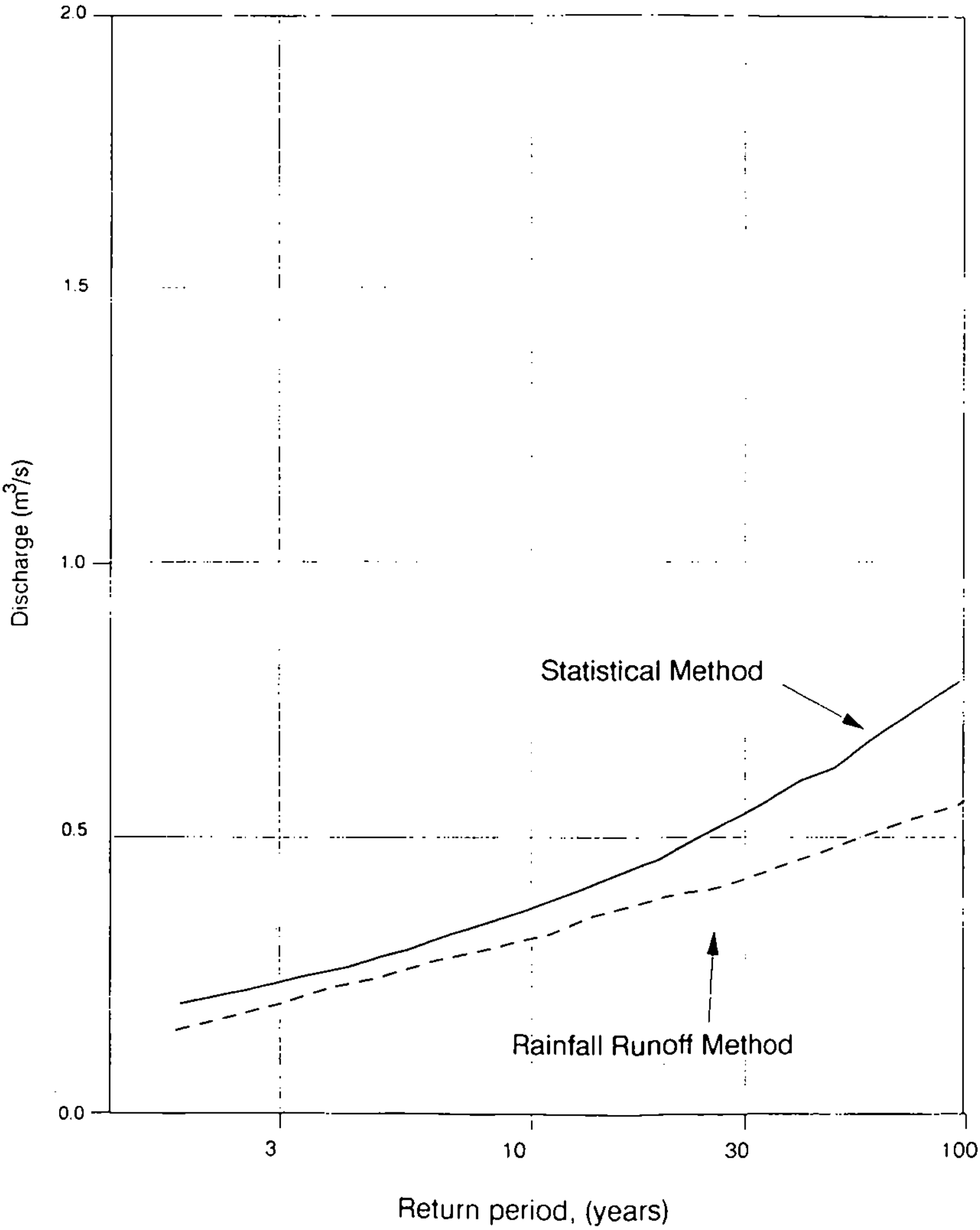



FIGURE 24

Flood Frequency Curves at S2, Sub-catchment C

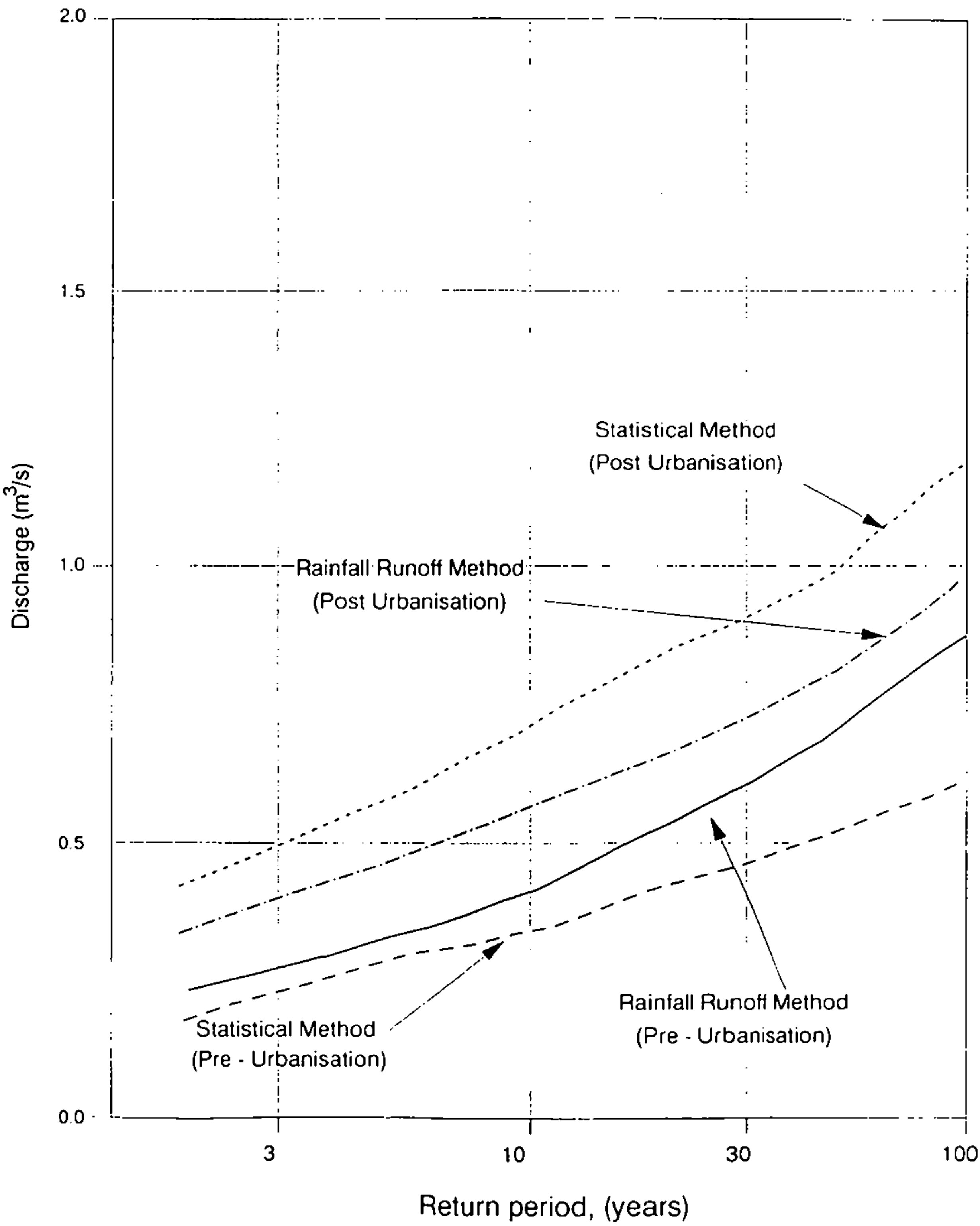



*FIGURE 25*

Flood Frequency Curves at S4, Whole Catchment

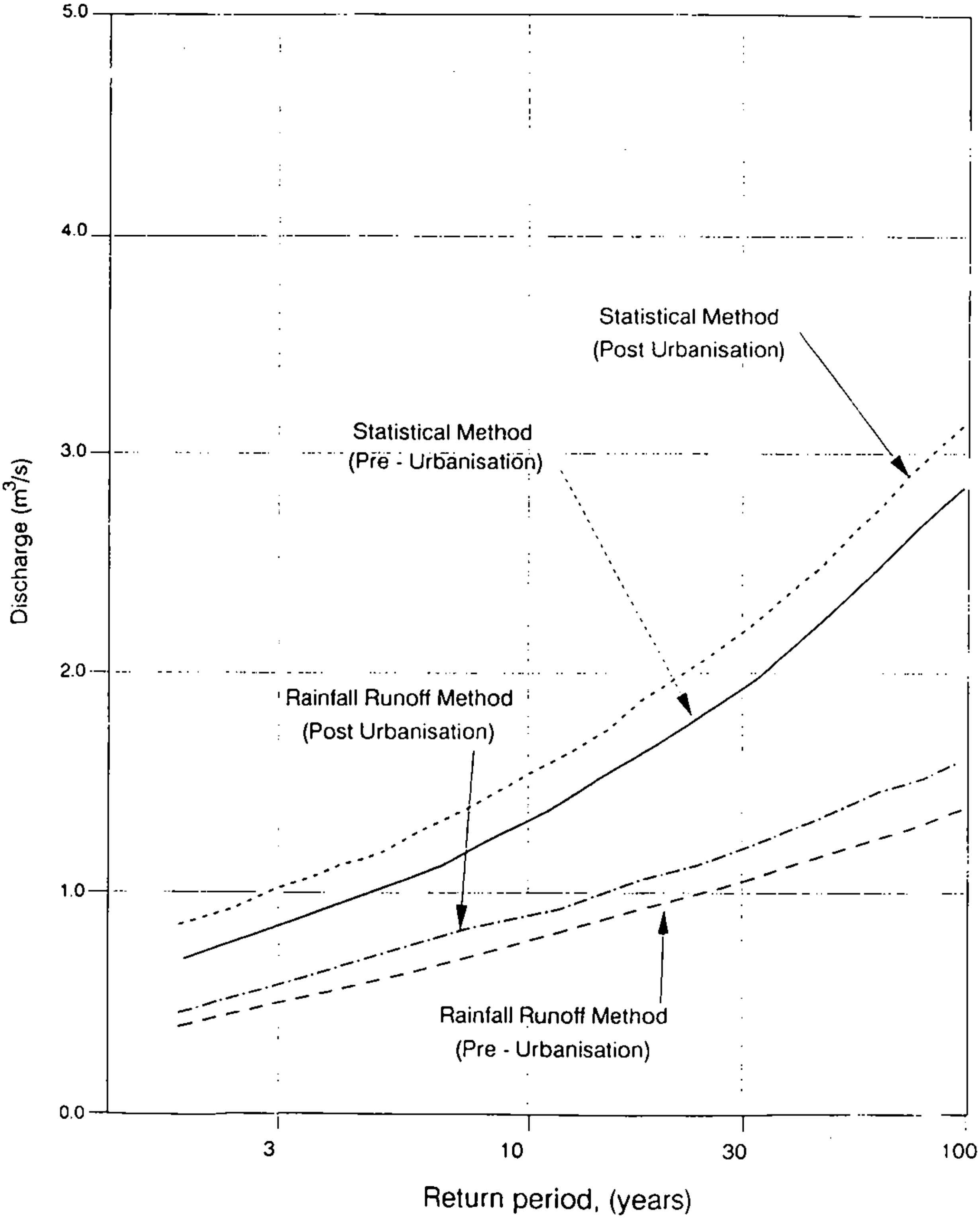



*FIGURE 26*

Combined Flood Frequency Curves for Sub-catchments B & C

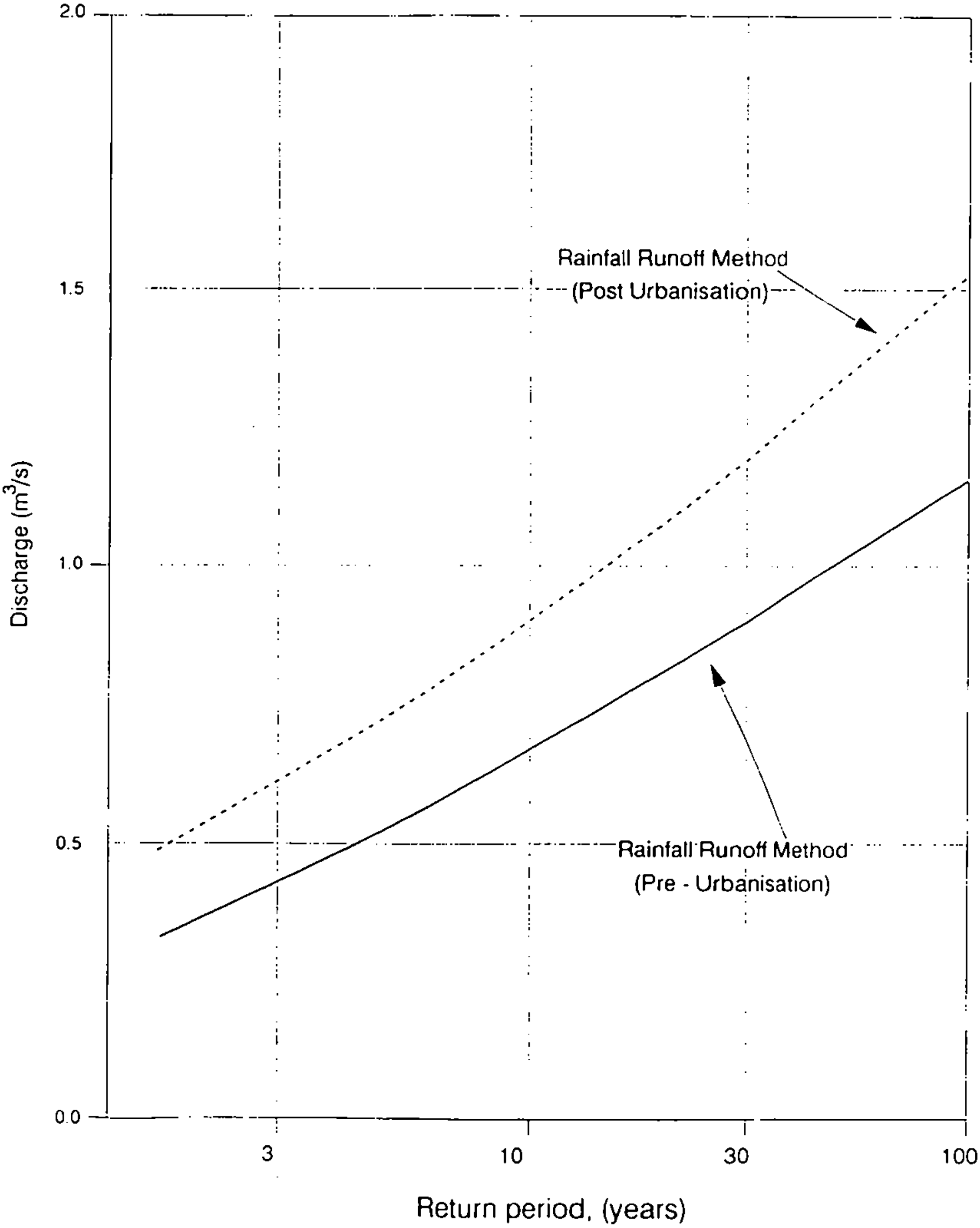



*FIGURE 27*

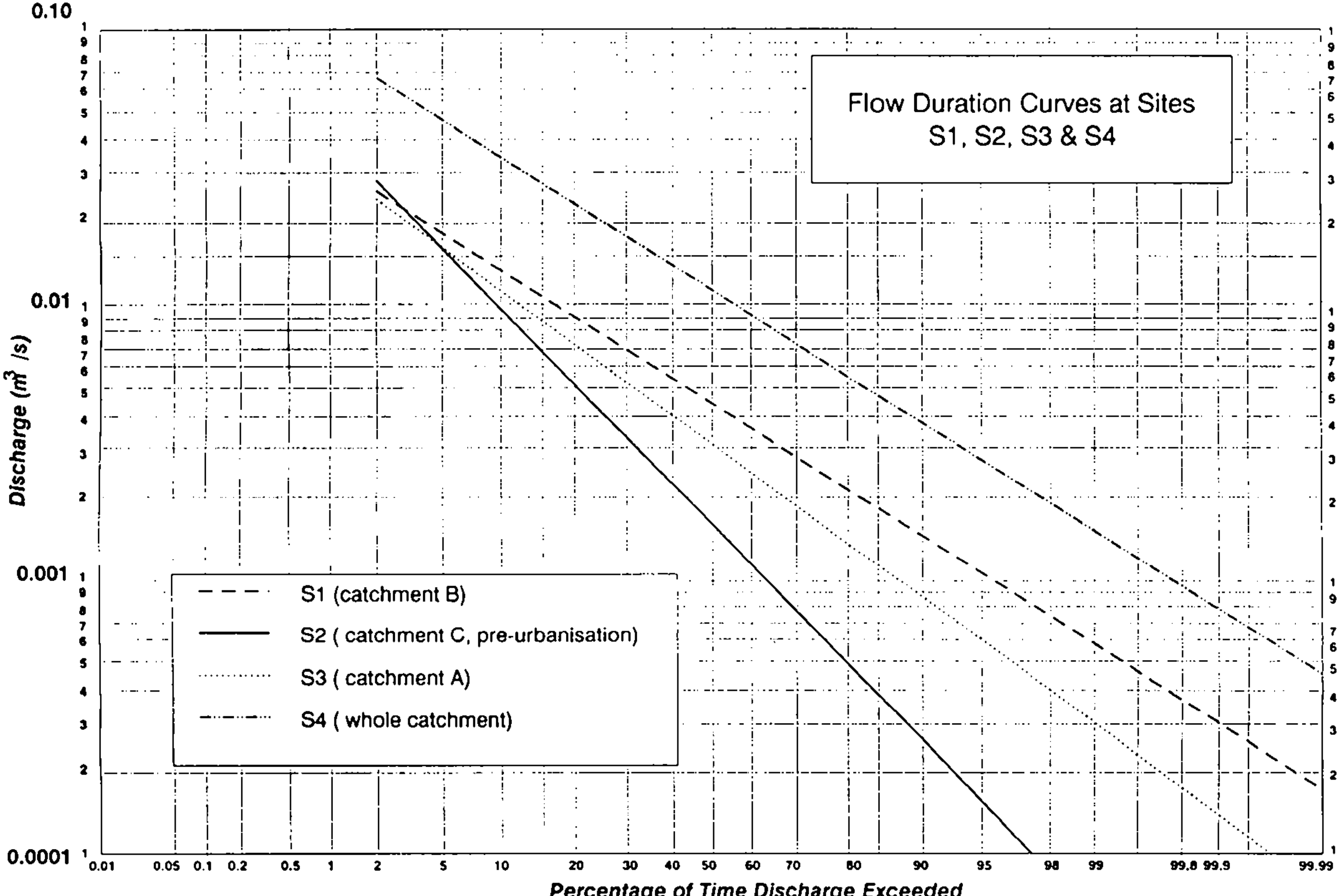
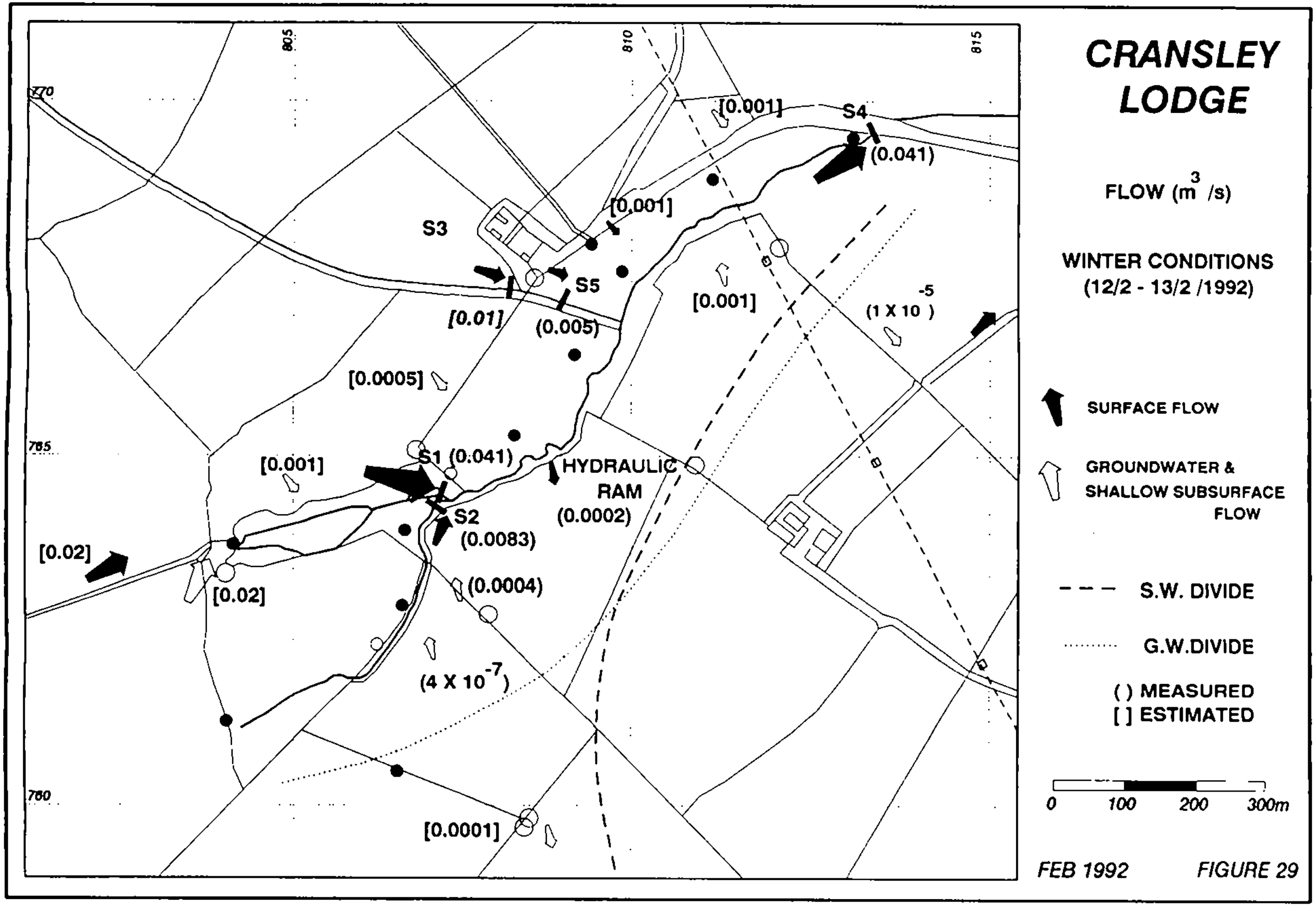
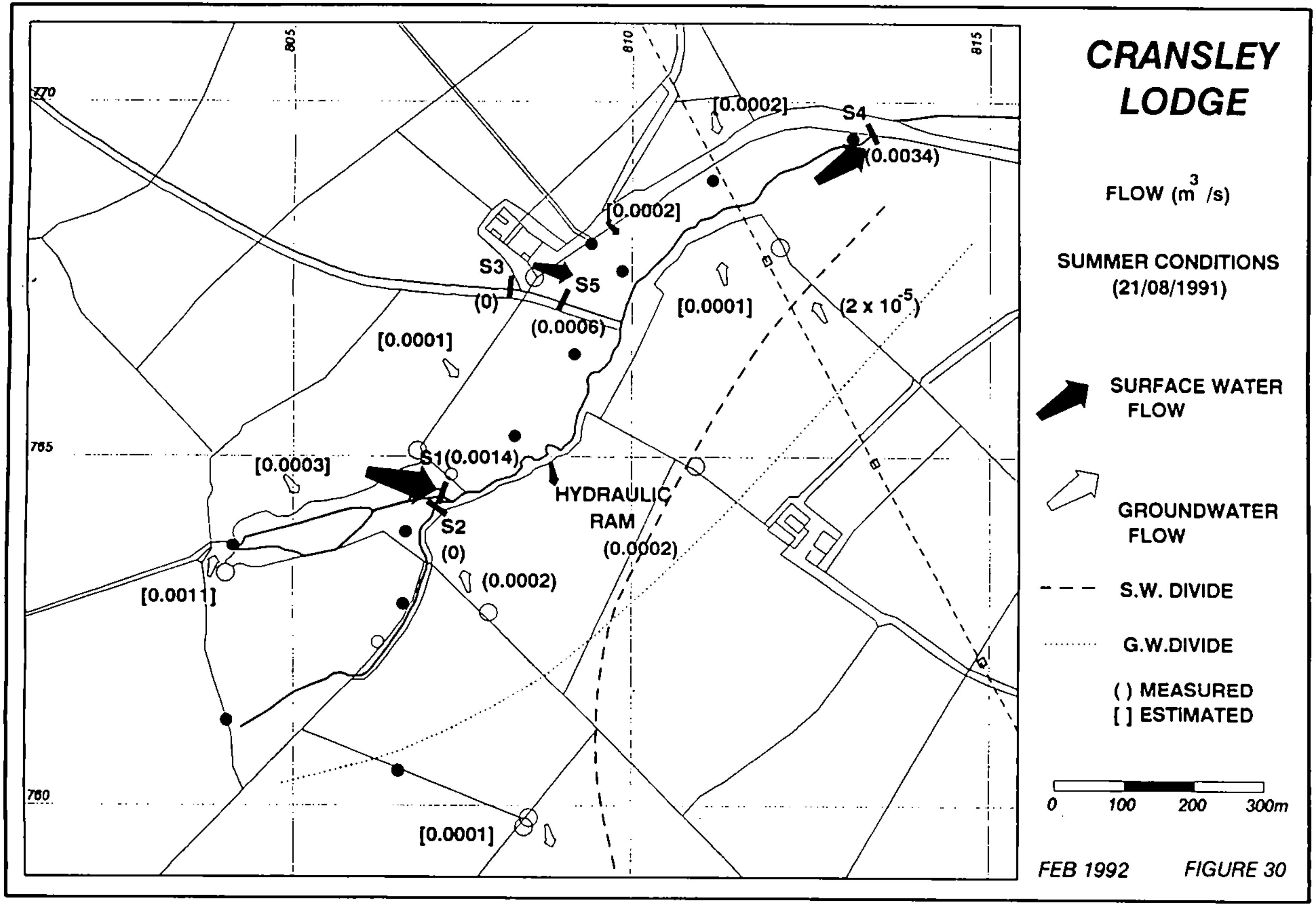
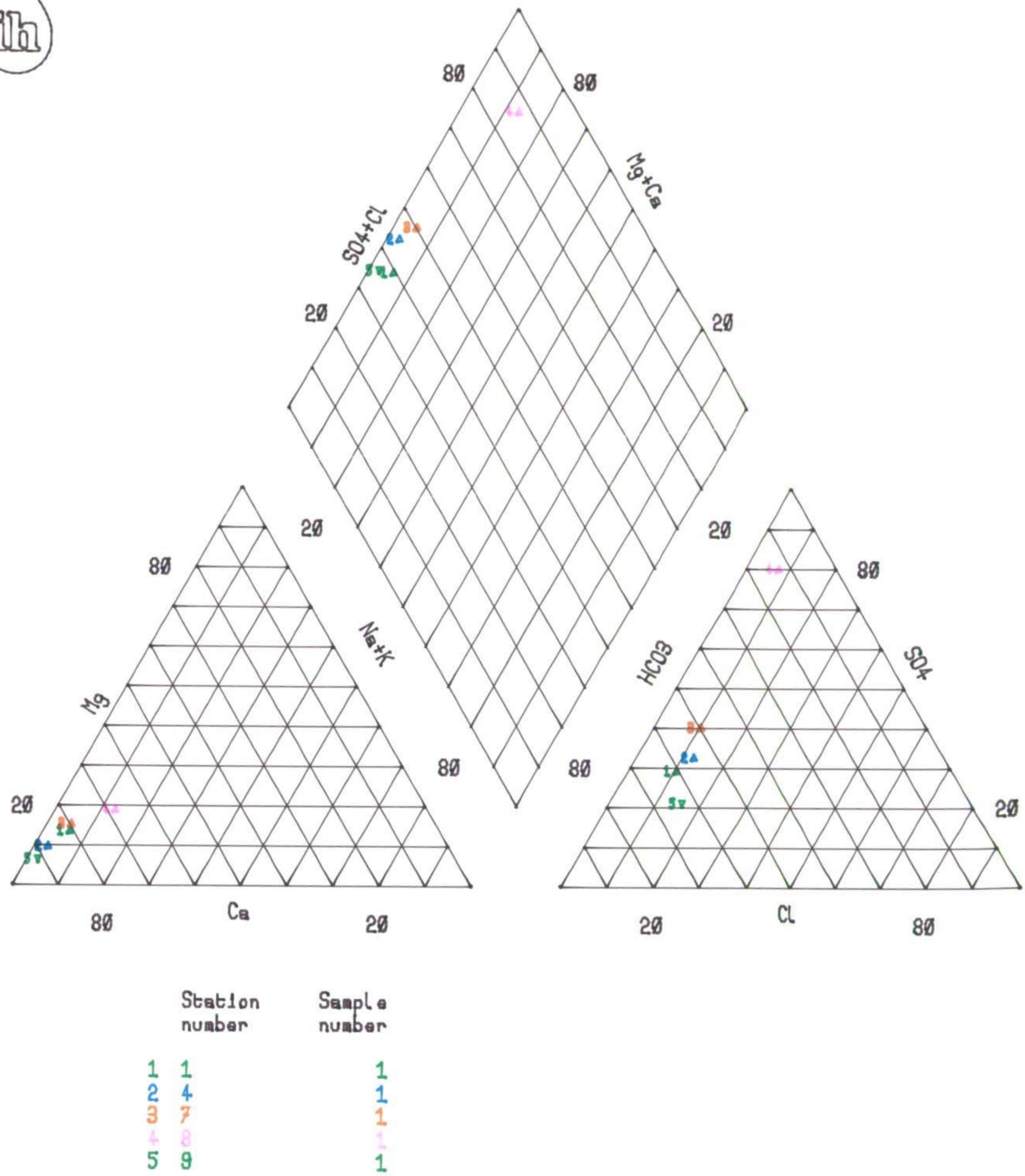

Flow Duration Curves at Sites
S1, S2, S3 & S4
S1 (catchment B)
S2 ( catchment C, pre-urbanisation)
S3 ( catchment A)
S4 ( whole catchment)
0.10
0.01
0.001
0.0001
Discharge (m3 /s)
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
Percentage of Time Discharge Exceeded

FIGURE 28

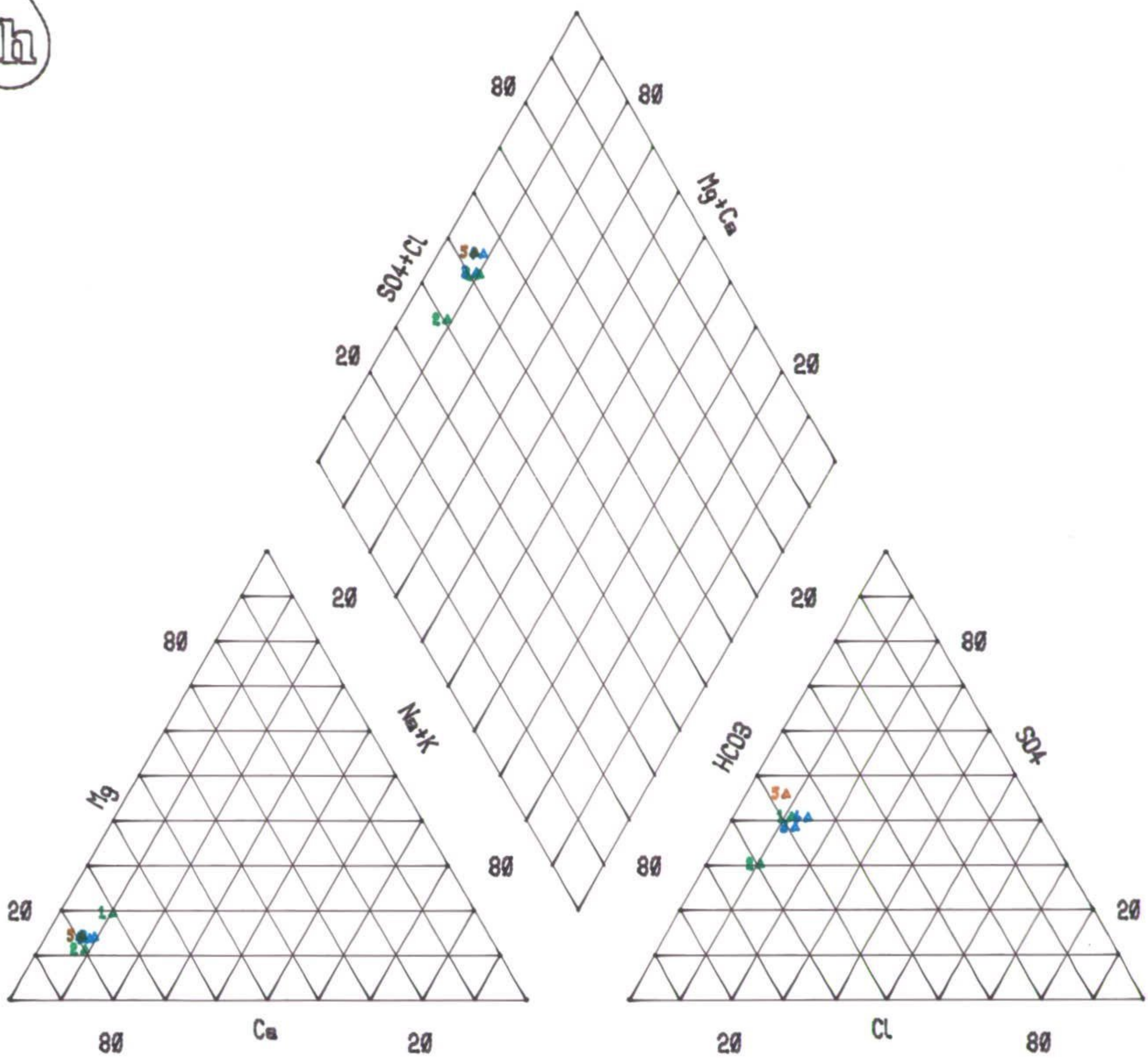


FEB 1992 FIGURE 29


CRANSLEY
LODGE
FLOW (m3 /s)
SUMMER CONDITIONS
(21/08/1991)
SURFACE WATER
FLOW
GROUNDWATER
FLOW
S.W. DIVIDE
G.W.DIVIDE
( ) MEASURED
[ ] ESTIMATED
0
100
200
300m
FEB 1992
FIGURE 30
805
810
815
770
765
760
S1
S2
S3
S4
S5
HYDRAULIC
RAM
(0.0034)
(0.0014)
(0.0006)
(0.0002)
(0)
(0)
(0.0002)
(2 x 10-5)
[0.0002]
[0.0002]
[0.0001]
[0.0001]
[0.0003]
[0.0011]
[0.0001]



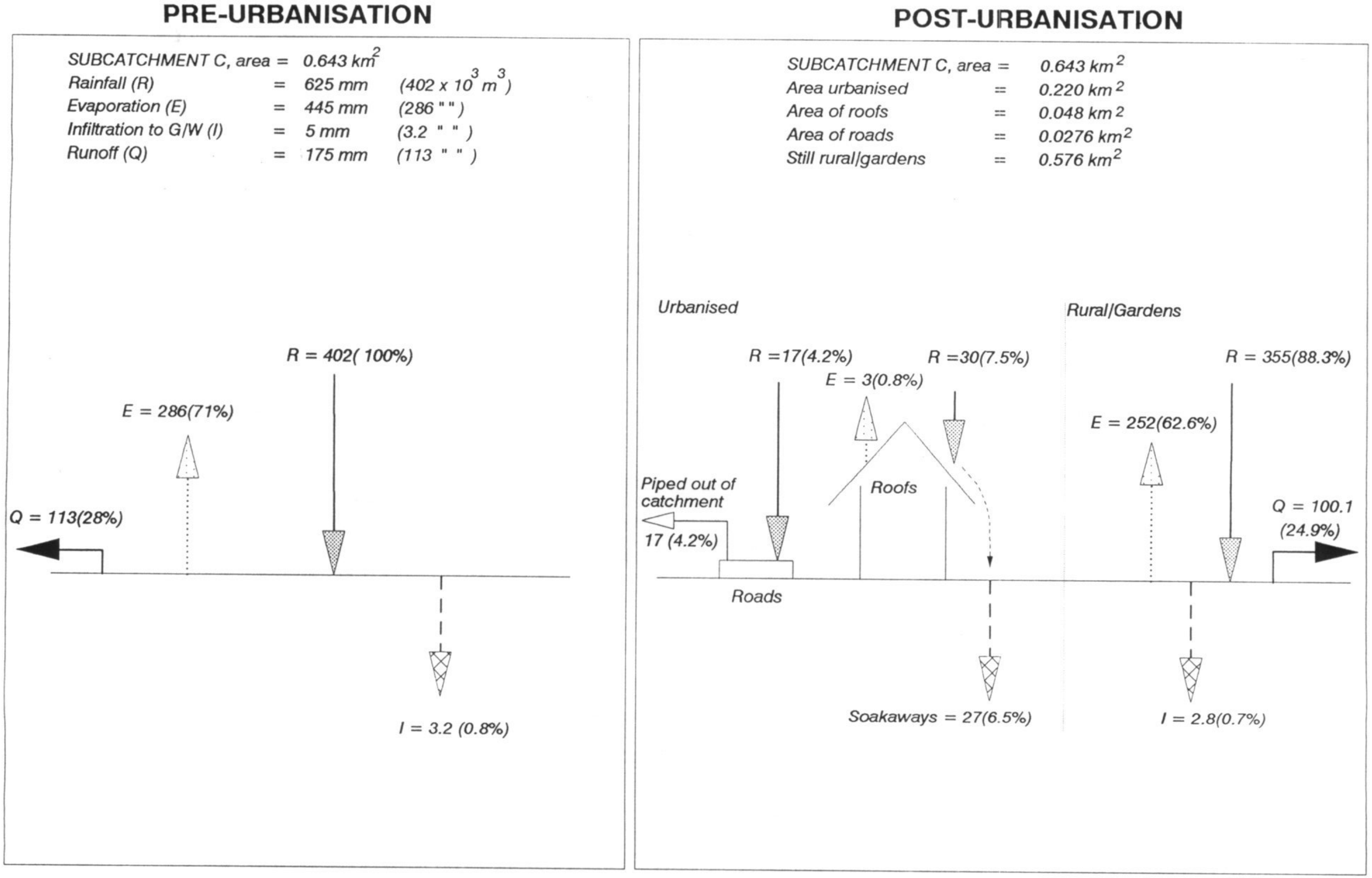

Piper Diagram of Selected Winter Samples
Figure 31




| | Station number | Sample number |
|---|---|---|
| 1 | P1 | p1 |
| 2 | P1 | 2 |
| 3 | S1 | 3 |
| 4 | S1 | 4 |
| 5 | S5 | 5 |

Piper Diagram of Selected Summer Samples
Figure 32

# WATER BALANCE




All values x $10^3$ $m^3$

All % - relative to total water (precipitation) input to catchment

FIGURE 33

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