I N S T I T U T E O F H Y D R O L O G Y

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THE HYDROLOGY OF THATCHAM REEDBEDS

by

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ABSTRACT

Thatcham reedbeds have peaty, waterlogged soils and plant and animal communities which depend upon the high water table for their existence. This water table is threatened by the dewatering associated with gravel extraction from part of the site. A network of boreholes was installed, and observations made of groundwater levels and streamflow over the period August 1975 to December 1976. These measurements led to a description of the processes of water movement in the reedbeds and suggested management procedures which should minimise the damage caused to the wetland community by lowering of the water table.

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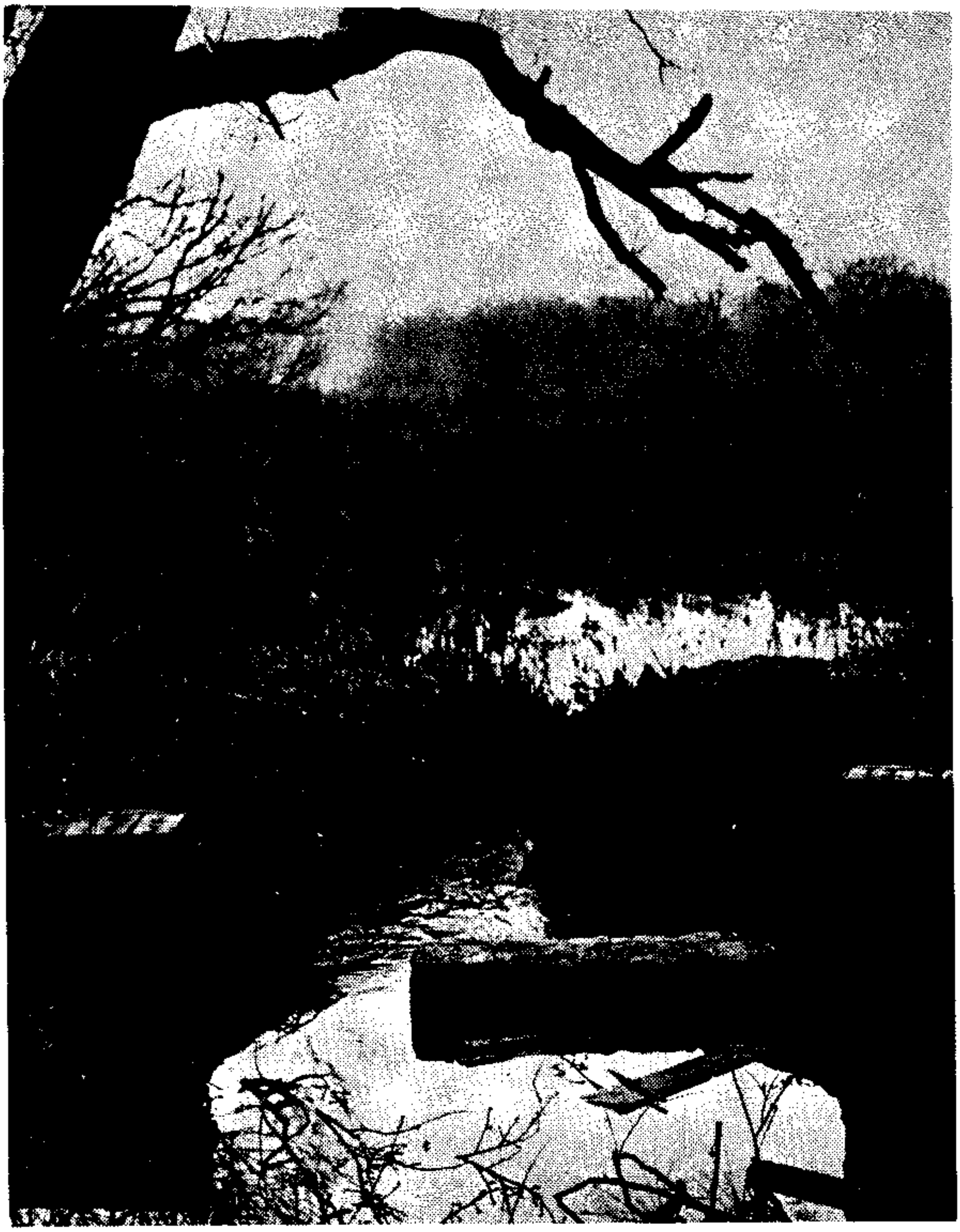


PLATE I The eastern end of the reedbeds (SU513664) showing flow from the Moor Ditch, January 1977.

1. INTRODUCTION

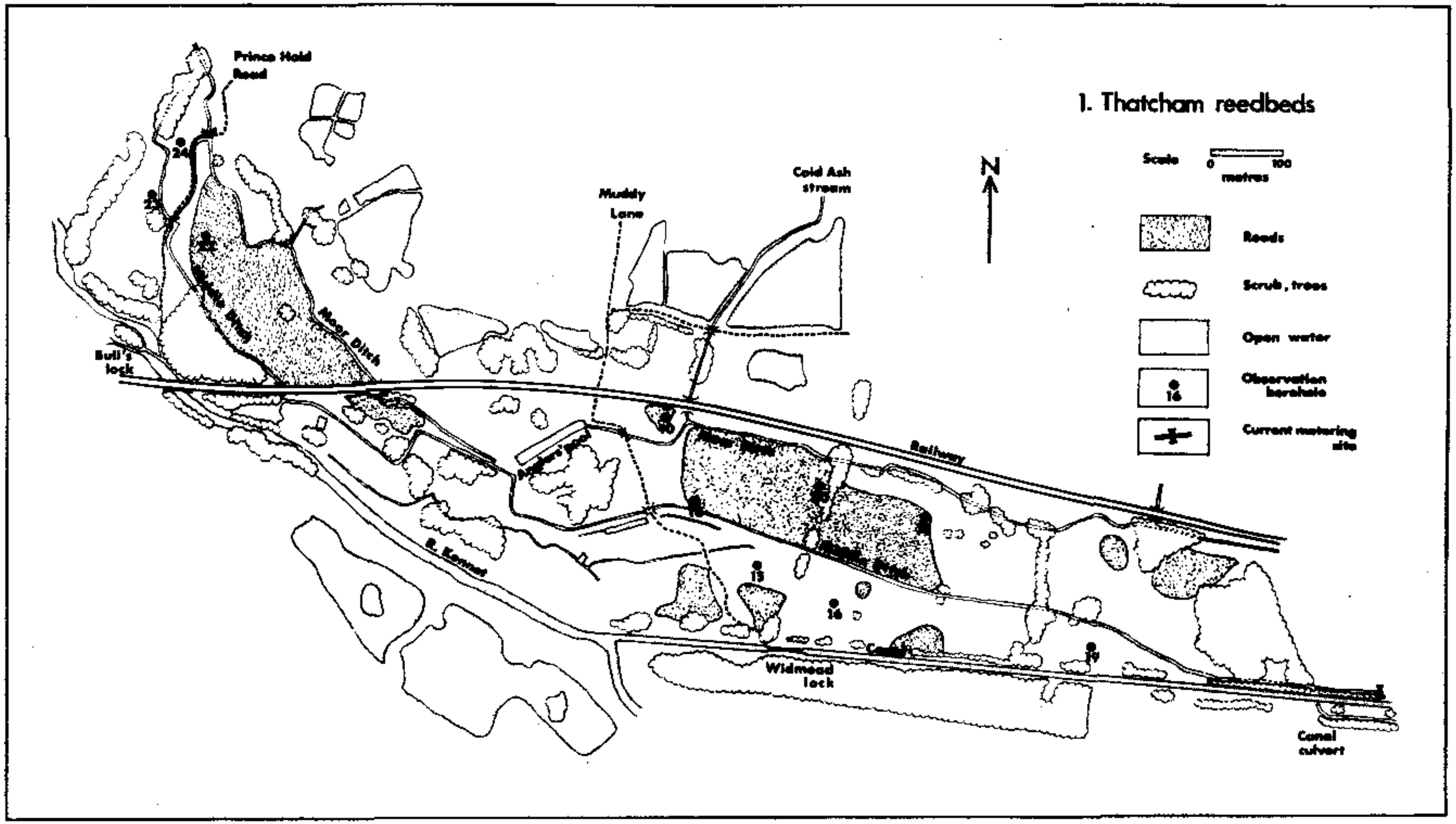
The Thatcham Moors area is an expanse of the floodplain and terraces of the River Kennet downstream of Newbury, Berkshire. Much of the portion lying in the floodplain has been designated as a Site of Special Scientific Interest, and it is here that the combination of waterlogged soils, liability to flooding and difficulty of access has prevented the use of the land for agriculture and industry, thus preserving one of the largest tracts of reedbed in the South of England.

The reedbeds and surrounding areas of scrub and herbaceous vegetation are the habitats of a large number of plant, insect and bird species of scientific and rarity value, and from the educational point of view there is particular interest in the succession from aquatic to swamp vegetation, and from reedbed to alder-dominated scrub (Newbury Borough Museum 1970a). Up to the present the area has been characterised by a high water table throughout the year, tending to prevent the rapid ecological succession which would otherwise occur as tree seedlings competed with the reeds.

The reedbeds are divided by the railway into two parts, that on the south containing the largest area of pure reed (Figure 1). A triangular area bounded on the north by the railway, on the south by the river and on the east roughly by the footpath from Muddy Lane to Widmead Lock is owned by the Newbury Angling Association, which has invited gravel extractors to dig out a number of large pools for fishing. The gravel extraction, which started in October 1976, will involve a lowering of the water table by about four metres during the period of digging, and the effects of this dewatering will be felt over the entire reed-bed area.

Newbury District Council proposes to designate the Thatcham Moors area for recreational and nature conservation use, and commissioned the Institute of Hydrology to study water movement in the reedbed area, to monitor the effects of the gravel extraction and to propose a management strategy which would lessen their impact on the reedbed community.

The Institute of Hydrology study began in August 1975 and was expected to last for one year. However, the study was extended to record the recovery from the drought of 1976, and the commencement of gravel extraction in October 1976 made it possible to obtain a complete year's data without drastic interference with the natural groundwater regime, followed by recording of the immediate effects of the dewatering operations.


1. Thatcham reedbeds
Scale
0
100
metres
Reeds
Scrub, trees
Open water
Observation borehole
16
Current monitoring site
N
Prince Hold Road
24
Moor Ditch
Bull's lock
Muddy Lane
Cold Ash stream
Railway
R. Kennet
15
16
19
Canal
Widmead lock
Canal culvert

2. GEOLOGY AND SOILS

The geological unit which has the most obvious effect on the reed-beds is the underlying valley gravel. The gravels rise to form terraces to the north of the river (at Lower Way Lane) and to the south. Beneath the reedbed the gravels lie on Reading Beds, which consist of clay and sand in variable proportion, but upstream at Hambridge Lake the gravels are reported to lie directly on the chalk (Newbury Borough Museum 1970b). It is likely that at this point substantial amounts of groundwater overflow from the chalk into the gravels and, if the gravels have not the capacity to transmit such quantities horizontally, rise upward to flow out as springs on the surface.

The valley gravels were deposited during a pluvial period in which rainfall and snowmelt caused the Kennet and its tributaries to flow at many times their present discharges. White (1907) describes picturesquely the circumstances of the deposition of the succeeding alluvium:

"The termination of the epoch of the valley gravel was marked by a great, and apparently rather sudden, diminution in the amount of water annually precipitated .... in the Kennet basin, and a corresponding shrinkage in the volume of the streams. From a considerable river fed largely by runoff, or surface water, carrying an abundance of mechanical waste, "(the gravels)" the Kennet dwindled to a small stream chiefly dependent, as at the present day, on the filtered water doled out to it by the springs. With its lessened (and more constant) volume it was no longer able to fill the old channel, and ... the shoals and banks in which it had hitherto arranged its burden of gravel now became obstructions to be circumvented or overflowed at low points. In the shallow depressions between such shoals the stream expanded into pools and lakelets, and on the bottom of these bodies of slack water were laid down the stiff basal clay, and the succeeding shelly loam and clay of the lower marl."

The lower marl is not obvious in excavations in the reedbed area, where the peat appears to have formed directly on the gravels. White continues:

"At a later stage the lakelets were encroached upon and choked by peat-moss, sedge and stouter forms of vegetation; the valley being ...... converted into a morass. The ... peat .... gradually levelled up the inequalities in the gravel, raised the lower parts of the valley floor by some 15-20 feet, and considerably augmented the area liable to floods. Hence when (owing to some climatic or other change) the conditions became less favourable for the growth of peat mosses, the lacustrine regime was restored and the Kennet floodplain was frequently covered by sheets of water whose wide extent may be inferred from the appreciable elevation above the river attained by the banks of upper marl and 'strand' which were accumulated in them."

The peat is a dark brown or black deposit consisting almost entirely of partially decayed organic matter, often containing the remnants of aquatic plants such as the stonewort *Chara*, peat-forming marsh plants such as the reed *Phragmites* and also the leaves, seeds and pollen of trees. At the base of the peat at Thatcham is an accumulation of tree trunks, branches and roots, often pierced by the living rootstocks of reed growing on the surface. The Reverend L Jenyns, in a paper presented to the British Association in 1845, said that:

"the trees found in the peat" (of the Cambridgeshire fens) "are for the most part remnants of the ancient forests, and are to be regarded as being enveloped in the peat, rather than forming an integral part of the peat itself."

The peat at Thatcham is of the extreme rich fen type (Moore and Bellamy 1974) having formed in water rich in calcium and other nutrients. The peat was formed slowly from the remains of aquatic plants, reeds and sedges which sank to the bottom of the shallow water. The mire thus grew up as a mat of peat with water flowing over it. Eventually the continued growth of the peat established a regime in which the main part of the surface flow was canalised and the surface was subjected to only intermittent inundation. This stage, obtaining at the present time, would naturally succeed to fen carr, in which trees such as alder or birch create a waterlogged woodland community. The peat is slightly alkaline, with a pH of about 7.5. Minerals still present in the peat make a valuable fertiliser when the peat is burned, and this was the basis of an important peat-digging industry around Newbury in the eighteenth and nineteenth centuries.

Above the peat, over much of the area, lies a bed of carbonate material variously described as algal marl, shell marl or malm. It is not strictly a marl, as it contains very little if any clay. The bulk of this material is a friable, unconsolidated deposit of calcium carbonate, containing very little vegetable matter, but large numbers of partially decomposed shells of freshwater molluscs, gastropods (snails) of the genera *Bithynia*, *Lymnaea* and *Planorbis*, and bivalves *Sphaerium* and *Pisidium* (orb-shells and pea-shells). These animals are all to be found at the present day in Hambridge Lake (Newbury Borough Museum 1970b).

The exact origin of the marl is obscure, but it seems likely that it began as a chemical precipitate removed from solution by a local increase in pH (alkalinity). A milky precipitate of calcium carbonate was observed in Holkham Lake, Norfolk in 1970, and was found to be caused by intense photosynthetic activity (unpublished report by Atomic Energy Research Establishment Harwell 1970).

Of particular interest are the concretionary structures in the marl, first reported by Jones (1854):

"Hard ovoidal, concentric masses of concreted marl, of various dimensions, up to the size of a man's head, occur here and there in this deposit; generally near the present course of the river."

Jones went on to say that the concretions were wholly composed of the more or less decomposed shells of fresh-water molluscs. However, one remarkable feature of the structures is the absence in them of recognisable shell fragments, although shells abound in the body of the marl.

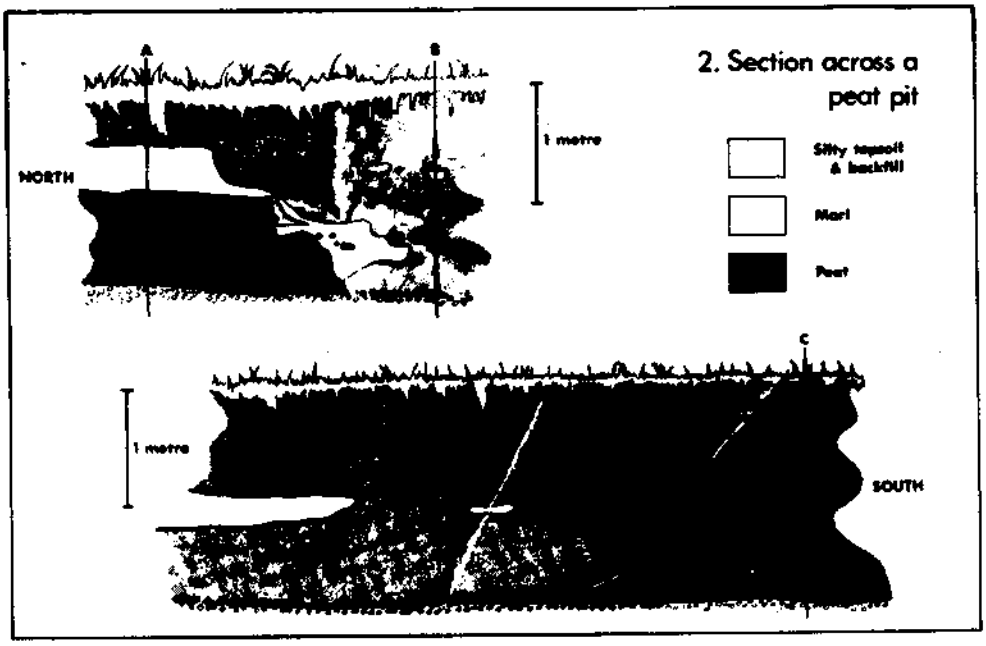
The marl may be observed in the ditch running alongside the footpath from Prince Hold Road to Bull's Lock, and in the spoil removed from the new excavations along the footpath from Muddy Lane to Widmead Lock.

Above the marl, where it is present, is a silty topsoil rich in humus and difficult to distinguish from peat.

In the new excavations along the footpath from Muddy Lane to Widmead Lock, it has been possible to observe three types of soil profile:

A	B	C
0.5 m silty topsoil	1.8 m silty backfill with peat and marl fragments	1.8 m peat
0.5 m marl		
0.8 m peat		
gravel	gravel	gravel

Profiles A and C are undisturbed, and the peat at the surface of C may still be actively forming. Profile B originates from the removal of the peat for burning, and its replacement with backfill material from various sources. The soil profiles are shown in Figure 2, which is a section across a peat digging.



2. Section across a peat pit

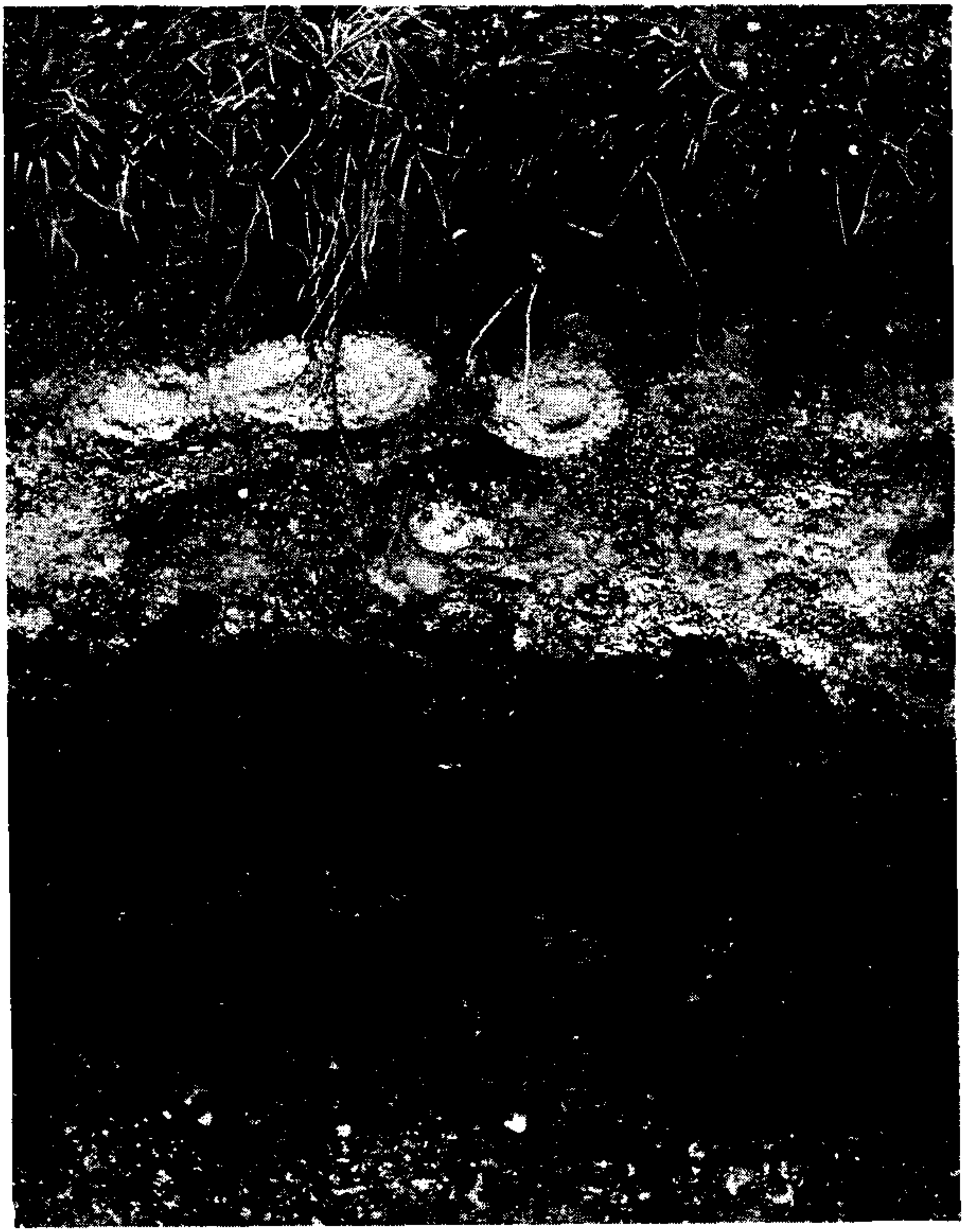


PLATE II Soil profile A - silty topsoil, marl (note concretionary structures) and peat over flint gravel, exposed in new excavation (SU506664), November 1976. Compare with Fig. 2.

3. AGRICULTURAL BACKGROUND

The reedbeds have been subject to a number of changes which have taken place in recorded history. Mavor (1809) wrote "Windsor forest once extended up the vale of Kennet to Hungerford, and ...... this track (*sic*) was disforested by charter in 1226." The area of gravel terrace, now much excavated, known locally as Thatcham Moor can probably be identified with La Moure, one of the two common areas of pasture of Thatcham Manor in the Middle Ages. The name of the other common, Widmede, survives as the name of a lock on the Kennet and Avon Canal. It is tempting to suppose that Widmede may have encompassed the reedbed area south of the railway and the woodland and meadows between the canal and the river.

The peat of the Kennet valley was long used as a fuel, but Mavor reports that its value as manure was first realised in 1745. The peat was dug with a long spade from cuttings which were pumped manually to lower the water table. Debris, especially the marl, which was not valued for manure, was tipped forward into the excavation. The peat was dried and burned *in situ*, and the ash, its reddish colour indicating the presence of iron, was carted away and sold. Peat land, in spite of its low agricultural value, sold for very high prices because of its potential use as a source of fertiliser.

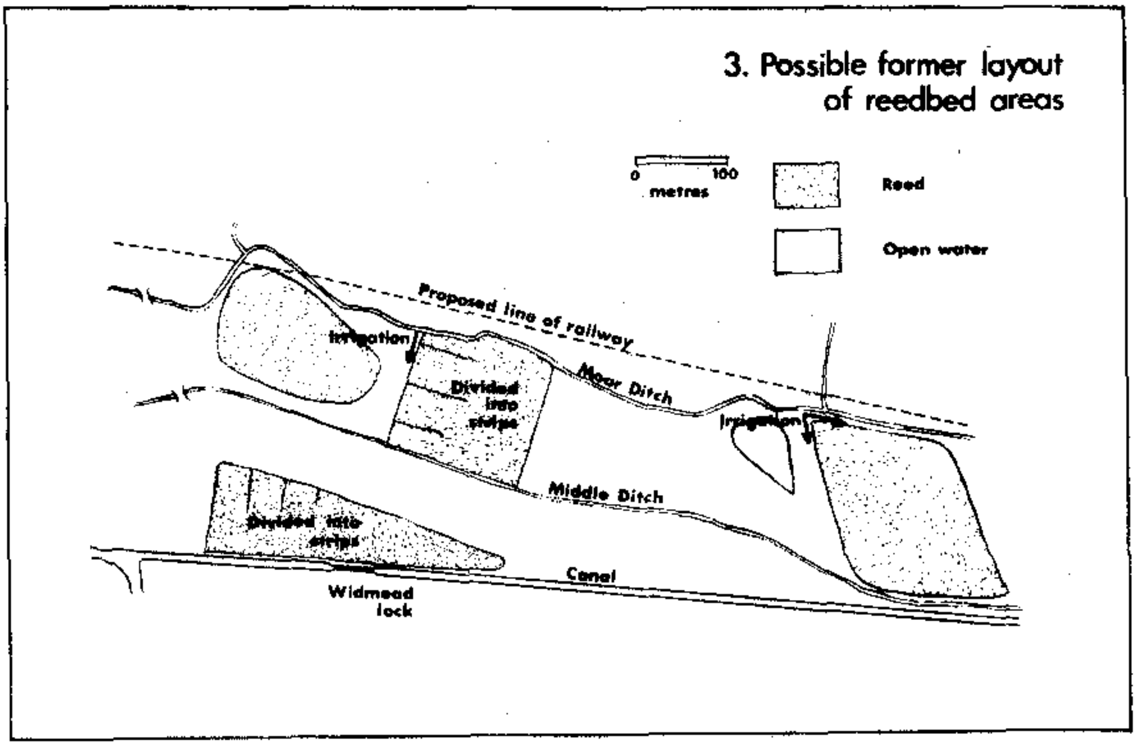
The peat pits were usually refilled with debris and levelled for use as osier beds or water meadows. Clutterbuck (1861) mentioned peat beds which had been "partially filled up, and now grow sedge or rushes (*sic*) or are more profitably planted with Osiers."

The new excavation alongside the Widmead Lock path has exposed a section through a peat pit (Figure 2). The southern face of the pit was excavated through a profile entirely of peat, while as cutting proceeded northward the diggers encountered the edge of a lens of marl above the peat. By the time the pit was abandoned, about 25 metres south of the Middle Ditch, the marl was about 0.5 metre thick. The pit was filled with debris consisting of peat blocks, marl and silt, and was obviously left for a number of winters before being filled completely, as the section through the northern edge shows the collapse of the vertical face in the marl. Spade marks were found on the peat at the northern edge.

The peat industry expanded in the eighteenth and nineteenth centuries, with the enthusiasm for land improvement, but the operation of manuring with peat ashes probably declined in importance when a more scientific approach to fertiliser application was made possible by the development of agricultural knowledge and the chemical industry.

Little reference can be found to the reedcutting industry which existed at Thatcham. The reedbeds were maintained by irrigation works, traces of which still remain, and by regular controlled burning, which tends to protect the stands of reeds from invasion by tree seedlings (Newbury

Borough Museum 1970a). By no means all of the area consisted of reed stands: an enclosure map of the early nineteenth century, kept in St. Mary's Church, Thatcham, shows four main areas likely to be cut for reeds. Two of the areas were divided into strips about 50 m wide, a similar system of division to that practised at Yarnton, Oxfordshire, where the rights to cut strips of grassland are re-allocated annually. The presence of a gatepost south of the bridge over the Middle Ditch, and of hedges elsewhere, suggests that much of the enclosed land was used as rough pasture. Figure 3 shows a possible arrangement of the area under reeds, based on the Thatcham map.



3. Possible former layout of reedbed areas

4. VEGETATION

Although a botanical survey of Thatcham reedbeds is published elsewhere (Frankham 1977) it is appropriate here to point out the relationships between vegetation and hydrological environment which are apparent at Thatcham.

The most important single species represented at Thatcham is the common reed *Phragmites communis*, which forms a number of extensive pure stands, as well as being part of the mixed community of grasses, sedges, other herbs and scrub around the edges of the main reed areas (Figure 1). Periodic flooding favours the reed, as it tends to keep down other species in the early part of the year. In May and June the main reed growth occurs, and by July the reeds are tall and dense enough to exclude much of the light from the ground surface, preventing the growth of other species. The best growth of reed, measured by the criteria of the height of the stem or the length of the panicle or flowerhead, is thus in depressions in the ground surface liable to flooding. It will be noticed that there is frequently a 'step down' into a reedbed. The marl, where it is known to occur, seems to be unfavourable to the reed, probably because of its resistance to the penetration of the deep rootstocks, preventing the reeds from obtaining access to the water reservoir of the peat.

5. PRECIPITATION AND EVAPOTRANSPIRATION

Fundamental hydrological measurements which must accompany any study of stream discharge or groundwater levels are observations of precipitation and evapotranspiration. Evapotranspiration is a term including both direct evaporation from physical elements such as open water or wet soil, and transpiration from biological elements, namely plants. It is difficult to measure actual evapotranspiration directly, so in most cases the value used is either the potential evapotranspiration or the potential open water evaporation, which can be stimated from meteorological variables such as incoming solar radiation, wind speed and humidity (Penman 1963).

Daily rainfall is measured by the Thames Water Authority at Newbury Sewage Treatment Works (Ordnance Survey Grid Reference SU 503672), using a standard 5-inch (127 mm) diameter raingauge with the rim set at 12 inches (305 mm) above ground level.

In the absence of the data necessary for the estimation of potential evapotranspiration, which is the evapotranspiration to be expected if biological and soil moisture constraints are not present, it was decided to use estimates of potential open water evaporation made from meteorological variables recorded by automatic weather stations at the Institute of Hydrology, Wallingford (SU 617898) using Penman's formula (Plinston and Hill 1974).

Actual evapotranspiration from the reedbeds at Thatcham is complicated by a number of factors. Eisenlohr (1966), describing evapotranspiration from prairie potholes supporting growths of sedge, bulrush and reedmace standing in water, outlined a number of mechanisms whereby the presence of these plants controls evapotranspiration rates. The plants reduce evaporation from the water surface by sheltering it from the wind, and also by shading it from incoming radiation. However the plants themselves transpire through a very large leaf area, making use of water abstracted by the roots. The resultant evapotranspiration rate is less than the potential open water evaporation in winter because of the sheltering effect of the dead stems, but could exceed the open water evaporation in summer, when the plants are growing and transpiring. A number of authors give values for the ratio of annual evapotranspiration from reedswamps to annual open water evaporation. These results are presented in Table 1.

TABLE 1 Ratio of annual measured evapotranspiration to annual open water evaporation for reedswamps, Annual E_s/Annual E_w

Author	Plant community	Ratio Annual E_s/Annual E_w
Gelboukh (1963)	*Phragmites*	0.8 to 2.5
Eisenlohr (1966)	*Carex* *Scirpus* *Scholochloa* *Typha*	0.7 and 0.8
Rijks (1969)	*Papyrus*	0.4 to 0.8
Linacre *et alia* (1970)	*Typha*	0.7
Smid (1975)	*Phragmites* *Carex*	0.9 to 1.9

The seasonal variation of the ratio of measured evapotranspiration to open water evaporation was found by Eisenlohr to take the form of a rise commencing in May to a maximum in August, followed by a decline to a minimum level which remained constant from the beginning of October to the end of April. The maximum value of the ratio was about 1.2, the minimum 0.5.

At Thatcham the reeds are not in general standing in water, but the water table is very close to the surface, and it is unlikely that transpiration and evaporation would be controlled by water availability under normal conditions. The reed growth commences in May, and it is probable that the seasonal variation in the ratio of evapotranspiration to open water evaporation is very similar to that observed by Eisenlohr.

Table 2 shows the monthly rainfall, potential open water evaporation and estimated evapotranspiration.

The rainfall record for the period is far from typical. The year May 1975 to May 1976 will be remembered as a drought period, the driest such period over the United Kingdom since records began. (Perry 1976, Ratcliffe 1976). The winter of 1975-76 was extremely dry, and the summer of 1976 was also abnormal, which did nothing to relieve the drought. The hydrological observations at Thatcham must be taken therefore to represent the driest conditions likely to occur naturally, and it may be concluded that groundwater levels which occur in the future lower than those observed in the summer of 1976 are affected by human interference.

TABLE 2 Rainfall, evaporation and evapotranspiration

Month	Rainfall	Evaporation	Ratio E_s/E_w	Estimated evapo-transpiration
	mm	E_w, mm		E_s, mm
Aug 1975	26.4	111.9	1.2	134.3
Sept	117.6	69.3	0.9	62.4
Oct	19.4	23.2	0.5	11.6
Nov	52.8	5.6	0.5	2.8
Dec	29.9	3.4	0.5	1.7
Jan 1976	16.4	8.3	0.5	4.2
Feb	23.7	10.6	0.5	5.3
Mar	17.3	36.0	0.5	18.0
Apr	10.2	67.9	0.5	34.0
May	33.1	108.1	0.6	64.9
Jun	68.0	146.5	0.9	131.9
Jul	25.1	145.3	1.0	145.3
Aug	26.0	107.5	1.2	129.0
Sept	108.0	49.9	0.9	44.9
Oct	111.1	22.7	0.5	11.4
Nov	90.6	5.4	0.5	2.7
Dec	102.8	2.5	0.5	1.3

6. STREAMS

The two main ditches crossing the reedbeds are flowing streams which were in the past an important part of the irrigation network. The Moor Ditch has its source in a marshy area north of the confluence of the Rivers Kennet and Lambourn. This marsh is at the downstream limit of the area where the valley gravels lie directly on the chalk, and can be expected to be the site of a significant outflow of chalk groundwater into the gravels; the water flowing in the Moor Ditch is almost certainly groundwater emerging in springs along the bed and in Hambridge Lake. A lateral inflow into Hambridge Lake from the Kennet has now been closed (Newbury Borough Museum 1970b).

The Moor Ditch, after crossing the line of the railway, flowed along the northern edge of the reedbed area, and at two points at least water was taken through sluices to feed irrigation ditches leading southwards (Figure 3). Both these outlets are still open, and the Moor Ditch when full is an important source of water for the reedbeds.

The Middle Ditch originally drained from the area north of the railway designated as the Local Nature Reserve, having as principal source a spring near the Kennet (SU 497668). On the Thatcham map referred to above the ditch is shown with its source at the point where it now crosses the Bull's Lock footpath. The Middle Ditch is now a distributary of the Moor Ditch, much of its flow coming from a branch of the Moor Ditch flowing southward along the boundary of the Local Nature Reserve.

Both ditches formerly flowed through separate culverts under the railway, then approached within a few metres of each other, to diverge again when the Middle Ditch crossed the reedbeds to flow along the southern edge at the foot of the canal embankment. The map mentioned above shows that little change was made to the courses of the ditches by the construction of the railway.

There have been several recent diversions of water from the Moor Ditch to the Middle Ditch, which is generally about 0.5 metre lower. In 1965 the Newbury Angling Association excavated a fishing lake along the course of the Moor Ditch near the railway crossing, and diverted the whole flow of the Ditch into the nearby Middle Ditch. In February 1976 the Newbury District Council diverted much of the flow along a new ditch parallel with the Bull's Lock footpath across the Local Nature Reserve. The remaining flow in the Moor Ditch, including a small intermittent release from the Sewage Works, has since been diverted by the gravel extractors into the Middle Ditch to allow the use of the Moor Ditch culvert for road access to the Newbury Angling Association site. The Middle Ditch is also being used to carry water extracted from the new pits. Figure 1 is taken from an aerial survey carried out in April 1976.

Two streams enter the Moor Ditch from under the railway. The more westward of these streams flows from Cold Ash and carries a large flow derived from land drainage in winter, but very little in summer. The other stream is smaller, and has its source in springs in the gravel terrace.

After crossing the reedbed, the Middle Ditch flows along the foot of the canal embankment, and before the construction of the canal may have crossed the line of the canal to join the Kennet upstream of the outflow of the Moor Ditch. A culvert was constructed to carry some or all of the flow under the canal into the old lower course, but this is now blocked, and the flow continues along the north side of the canal to join the Moor Ditch and the Kennet below Monkey Marsh Lock.

Hydrological measurements on the Moor and Middle Ditches during 1975 and 1976 have comprised:

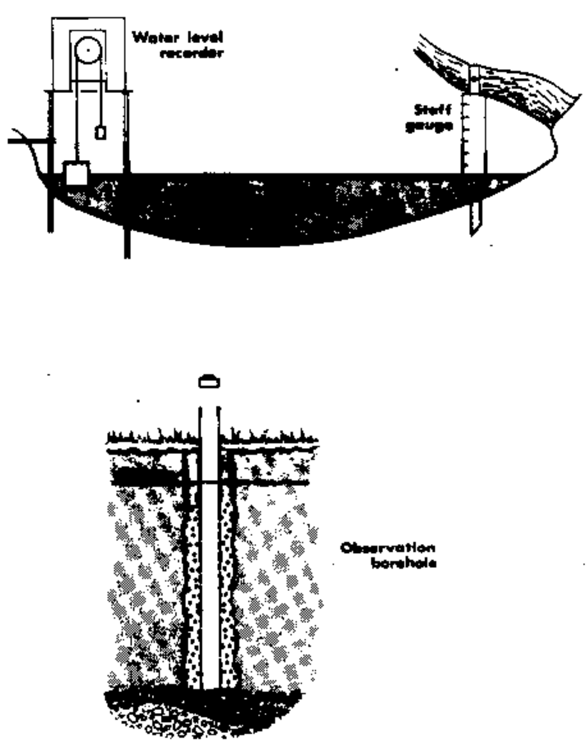
(i) installation and operation of a water level recorder on the Middle Ditch downstream of the canal culvert (SU 516662) for a short period in 1975

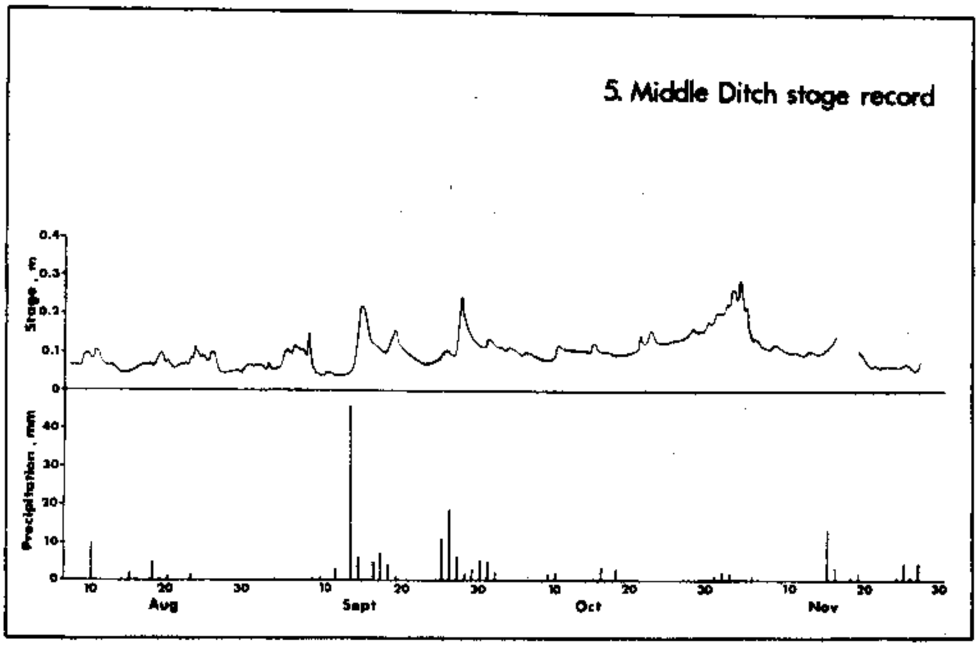
(ii) staff gauge observations at the recorder site and at the bridges over the ditches in the Local Nature Reserve (SU 499670 and SU 498669)

(iii) measurement of the discharge by current metering at the three sites mentioned above, and estimation of the discharge of the Cold Ash stream.

The water level recorder was installed on a straight reach of the Middle Ditch close to the canal, and was accompanied by a staff gauge (Figure 4). The recorder was operated successfully until the end of November 1975, when it was no longer concealed by the hedge, and the shelter was disturbed. The recorder was then removed. The recorder trace (Figure 5) shows that the ditch flow did not vary greatly over the period: the highest flow encountered, after the rainstorm of 13 September, was estimated from Manning's formula (Chow 1955) as 0.38 m^3/s, approximately double the discharge obtained by current metering on four occasions. Small, approximately diurnal, fluctuations in stage were caused by a leakage from the sewage outfall at Bull's Lock. The leak remained undiscovered until February 1976, when the reeds were burned. The dependence of the water level stage at the recorder site on downstream conditions was shown by the slow rise in stage, not caused by rainfall, in late October, when the ditch was blocked by a fallen tree and debris built up slowly to impede the flow. This dependence on variable downstream controls would make it impossible to rate the section for continuous discharge measurement even if a recorder could be sited securely.

4. Instruments





Staff gauge measurements and current metering have endorsed the conclusion drawn above: that the ditch flow does not vary greatly with time. At no time were the ditches observed in spate, and there were no trash marks to record past floods. The staff gauge measurements were of limited value, as observations at the recorder site were subject to the backwater condition mentioned above, and levels in the upper reaches of the ditches were controlled by the state of vegetation in the channels.

The ditches were gauged on several occasions by the velocity-area method. This method, described in British Standard 3680 Part 3, involves the measurement of depth and water velocity on a number of verticals spaced across the stream, and integration of the velocity with respect to depth and distance across the stream to yield the discharge. The water velocity was measured by a Valeport current meter calibrated at the Hydraulics Research Station at Wallingford. The Valeport meter is a freely rotating propeller whose revolutions are counted electrically, and whose rate of rotation is converted into water velocity by the use of empirically determined equations.

The lower Middle Ditch site has a simple section (Figure 4) and was gauged by the 0.6 depth method, which is based on the assumption that the mean velocity on a vertical line is equal to the velocity measured at a point 0.6 of the depth from the surface. By this method only one velocity need be measured on each vertical. The upper Moor Ditch site is about three metres downstream of an old rectangular notch weir, and the distribution of velocity is rather complex. At this site, therefore, the velocity was measured at three points on each vertical, 0.2, 0.4 and 0.6 of the depth from the surface. The upper Middle Ditch flows through a submerged culvert into a pool of slowly moving water impeded by vegetation downstream, and velocities were measured at points spaced in a 0.1 metre grid immediately downstream of the culvert.

After crossing the gravel pit area north of the railway the Cold Ash stream channel is blocked by fallen trees, and much of the flow is dissipated, forming a marshy area (formerly reedbed) along the north side of the railway embankment. Some of the flow still finds its way through the culvert under the railway, to emerge north of the Moor Ditch. The discharge of the stream before it reaches the obstruction was estimated as 0.2 m^3/s on 7 January 1977.

The Cold Ash stream enters the Moor Ditch just to the east of the footpath, and when it is flowing its discharge divides here into two streams, one of which flows into the anglers' pool, while the other flows down the Moor Ditch and out into the reedbeds at two points (Figure 3). The flow into the anglers' pool was estimated on 7 January 1977 as 0.04 m^3/s, and that into the reedbeds at the far end of the site also as 0.04 m^3/s. The results of current metering are presented in Table 3.

TABLE 3 Discharge of Moor and Middle Ditches, determined by current metering

Date	Site	Discharge, m^3/s
7. 8.75	Middle Ditch at recorder site	0.215
10. 9.75	"	0.213
5.11.75	"	0.220
14. 7.76	"	0.173
10. 9.75	Middle Ditch at Bull's Lock footpath	0.104
24. 9.75	"	0.128
5.11.75	"	0.085
14. 7.76	"	0.041
10. 9.75	Moor Ditch at Bull's Lock footpath	0.059
24. 9.75	"	0.099
5.11.75	"	0.097

7. GROUNDWATER LEVELS

The central part of the Thatcham hydrological study was the observation of groundwater levels at a number of points scattered throughout the area. Ten shallow boreholes were installed for this purpose, and staff gauges were positioned on two ponds thought to be in hydraulic connection with the groundwater.

The network of boreholes (Figure 1), seven in the area between the railway and the canal, three in the Local Nature Reserve north of the railway, was designed on the following criteria:

(i) the boreholes should sample a variety of botanical and hence hydrological environments, from pure reedbeds to mixed vegetation comprising sedge, meadowsweet and others, which advance on the reedbed from its margins.

(ii) there should be a concentration of the network towards the footpath, on the fringe of the area of proposed gravel extraction, with some remote sites at the eastern end of the reedbed to act as controls.

(iii) subject to the requirement that the boreholes be unaffected by the presence of footpaths, location of and access to the sites should be reasonably easy.

Borehole design and installation

The water table in the reedbeds is generally close to the ground surface, and there is no reason to expect confining geological strata which might divide the aquifer horizontally into distinct components. Thus boreholes could be shallow without being unrepresentative. An important factor in the design was the difficulty of access to the sites: holes had to be hand-dug and it was found that it was impossible to penetrate the gravels.

The design of the boreholes is shown in Figure 4. The casing was of 38 mm diameter PVC tubing, 2 m long, and the lower metre was drilled so that the open area of the screen was about 5%. The casing was fitted with a screw cap, which could be tightened or removed with a 9/16 inch Whitworth spanner. In the case of the shallower holes, part of the upper (blank) casing was removed so that the well cap was close to the ground surface.

The boreholes were excavated to 1.9 metres in depth, or to the gravels, using a Jarrett auger. The resulting hole was about 125 mm in diamter. Spacers were fitted to the lower end of the casing, and it was run down into the hole through a temporary 100 mm diameter PVC tube. The space between the inner and outer casings was filled with 10 mm gravel, and the outer casing progressively removed, until the lower metre of the hole was packed with gravel. A length of 70 mm diameter tube was used to ram the gravel down. The upper metre was packed with excavated peat and soil.

A wooden peg near each hole identified the borehole and provided a check on the datum height, which was measured at the top of the casing with the screw cap removed.

Visiting the boreholes

Boreholes were read at fortnightly intervals, using an electric contact gauge. This instrument consists of a probe mounted on a graduated tape. A light on the probe is switched on when two pointed contacts are bridged by the water in the borehole. Using this instrument it is possible to measure groundwater levels to the nearest millimetre.

A striking feature of Thatcham is the luxuriance of the vegetation in summer. This caused two problems:

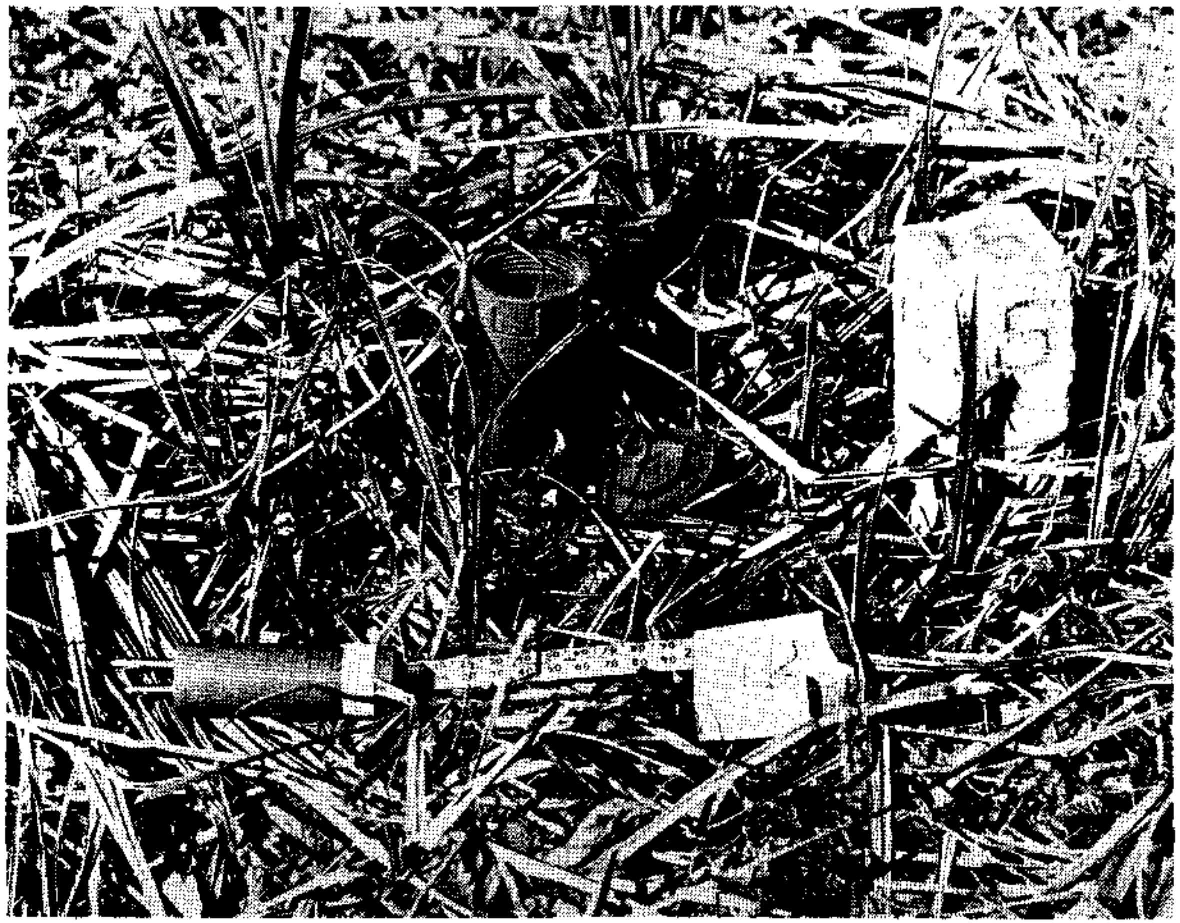


PLATE III Borehole 15 with cap removed. Electric contact gauge in foreground.

(i) access to the borehole sites. Most of the boreholes were near the footpaths or the canal towpath. However, boreholes 20 and 21 were very remote, and it was necessary to beat a track across the centre of one of the most luxuriant reedbed areas.

(ii) location of sites. It was possible to find only one of the wooden pegs which were sited on a preliminary visit in April 1975. It proved to be possible to maintain a 2 metre diameter open area around each hole, and the paths beaten through the reeds on the fortnightly well round stayed open. However, the effect of wind almost obliterated these paths on several occasions. Three boreholes were lost because of rapid vegetation growth in the spring of 1976, but one (borehole 16) was later relocated.

Elements of groundwater hydraulics

Groundwater is liquid water which is present in the interstices between particles of soil or rock. Most rocks, with the exception of very tight formations such as granite and marble, have the form of a granular matrix with very small pores which are interconnected to form continuous pathways through which groundwater can flow. If the pores are completely filled the material is said to be saturated. Groundwater tends to move downwards through partially filled pores under the action of gravity, so that there is a division of the soil and rock profile into an unsaturated zone and an underlying saturated zone. The upper boundary of the saturated zone is the water table.

Groundwater flowing through a saturated porous medium is opposed by a resistance which results from the viscous drag of the pore walls on the slowly moving liquid. To maintain a groundwater flow, therefore, a force is required which for steady flow will exactly balance the resistance forces. The force tending to maintain movement arises from the gradient of the field of groundwater potential (in the same way that the force of gravity may be considered to arise from a field of gravitational potential).

The groundwater potential ϕ at a point is the sum of the fluid pressure and the height above datum:

$$\phi = p + z$$

where p is the pressure, expressed in metres of water in excess of atmospheric pressure, and z is the height of the point above any datum. Since only potential gradients are of interest, the datum is arbitrary, but may conveniently be taken as sea-level. At low velocities the resistance exerted by the medium is proportional to the velocity and hence the flow is proportional to the potential gradient applied. Darcy's Law (see for instance Todd 1959) expressed this relationship in the equation for flow through an element of porous medium with cross-sectional area A.

$$Q = KA \frac{d\phi}{dx}$$

where ϕ is the potential and movement of groundwater is in the x direction. The coefficient K is known as the permeability of the medium and is usually expressed in units of metres per day (m/d). Naturally occurring porous media such as chalk, gravel and sandstone, which have quite high permeabilities (greater than 1 m/d) are known as aquifers.

The potential, or piezometric head, is conveniently measured in metres of water by the observation of water levels in wells. The water level in a well in a water table aquifer is at the same height as the water table around the well.

Measurement of water levels in a number of wells, as at Thatcham, may give a map of the water table surface, which can be interpreted to yield the direction of groundwater flow, and, if the permeability is known, its magnitude. Groundwater moves in the direction of steepest slope of the water table surface, ie. at right angles to the contours, and the flow across a contour is given by

$$Q = KbIL$$

where b is the thickness of the aquifer, I is the gradient of the water table surface (the hydraulic gradient) and L is the length of contour under consideration.

Another important parameter of a water table aquifer is the specific yield, which is defined as the amount of water released from the aquifer per unit fall in water table height. The specific yield is usually quoted as a percentage. For example, an aquifer with specific yield 10% would give up 0.1 metres depth of water per metre fall in water table. The specific yield is usually much smaller than the total water content, particularly in the case of peat, where much of the water is held in the humus structure, and does not drain when the water table is lowered.

Analysis of the groundwater level data

Borehole data are presented in Tables 4, 5, 6 and 7. Table 4 gives the depth of the borehole and the height of the datum (casing top) above ground level and Ordnance Datum, Table 5 the depths to water from ground level and Table 6 the height of the water table above a somewhat arbitrary 'mean' level. The mean level is obtained by comparison with the record for boreholes 13 and 15 over the 12-month period August 1975 to July 1976. Table 7 contains the groundwater levels referred to Ordnance Datum.

The data of Table 6, water table heights above the estimated mean level, are plotted in Figure 6. Levels rose sharply in September 1975, continued to rise until mid-December, and then started a slow decline until June 1976, when they began to fall steeply to their lowest values in July and August. Another steep rise in September was followed by a sudden drop in October when dewatering commenced in the gravel extraction site. While boreholes 13 and 15 at the periphery of this site went dry, and the level in borehole 16 began

TABLE 4 Borehole details

Number	Depth	Height in m of casing top above		Dominant plant types around borehole
	m	(i) ground level	(ii) Ordnance datum	
10	1.45	0.12	68.60	Reed
13	1.05	0.12	68.07	Reed
15	1.45	0.11	68.25	Sedge
16	1.9	0.09	67.92	Reed and Sedge
19	1.2	0.12	67.69	Reed
20	1.55	0.45	68.28	Reed
21	1.9	0.12	67.87	Reed
22	1.0	0.08	not surveyed	Reed
23	1.1	0.18	not surveyed	Sedge
24	1.1	0.12	not surveyed	Sedge

TABLE 5 Depth to water from ground level (metres)

Date	Borehole number: 10	13	15	16	19	20	21	22	23	24
13.8.75	0.583	0.175	0.376	0.293	0.430			0.053	0.251	0.231
27.8.	0.600	0.159	0.365	0.281	0.435	0.036	0.367	0.050	0.253	0.242
10.9.	0.682	0.174	0.372	0.258	0.425	0.219	0.384	0.055	0.260	0.266
25.9.	0.509	0.131	0.324	0.134	0.285	0.126	0.134	0.043	0.252	0.216
8.10.	0.490	0.126	0.321	0.127	0.292	0.090	0.071	-0.060	0.232	0.224
22.10.	0.530	0.133	0.337	0.138	0.286	0.095	0.065	0.069	0.250	0.229
5.11.	0.510	0.104	0.292	0.117	0.205	0.075	0.034	0.051	0.244	0.216
19.11.	0.429	0.101	0.300	0.074	0.180	0.069	0.002	0.046	0.165	0.212
28.11.	0.405	0.121	0.312	0.070	0.194	0.080	0.016	0.051	0.177	0.233
17.12.	0.196	0.131	0.331	0.093	0.243	-0.050	0.116	0.058	0.192	0.252
2.1.76	0.517	0.155	0.372	0.129	0.295	-0.010	0.210	0.065	0.231	0.265
14.1.	0.500	0.212	0.400	0.137	0.301	0.114	0.217	0.079	0.254	0.271
29.1.	0.608	0.213	0.405	0.154	0.321	0.163	0.274	0.050	0.244	0.196
12.2.	0.545	0.136	0.370	0.102	0.258	0.039	0.198	0.010	0.195	0.230
27.2.	0.606	0.258	0.444	0.155	0.280	0.206	0.219		0.298	0.310
12.3.	0.662	0.238	0.452	0.160	0.275	0.235	0.245		0.273	0.299
26.3.	0.744	0.308	0.485	0.186	0.280	0.267	0.242		0.315	0.318
8.4.	0.677	0.295	0.467	0.200	0.300	0.205	0.253		0.315	0.310
15.4.	0.651	0.217	0.422	0.140	0.220	0.220	0.207		0.245	0.294
28.4	0.769	0.317	0.474	0.226		0.274	0.284		0.315	0.510
13.5.	0.679	0.261	0.451	0.182		0.250	0.247		0.337	0.335
4.6.	0.745	0.289	0.450	0.235		0.225	0.284		0.337	
11.6.	0.811	0.373	0.480	0.317		0.256	0.350		0.444	
25.6.	0.735	0.276	0.445	0.264		0.244	0.389			
2.7.	0.873	0.420	0.529			0.335	0.556			
14.7.	0.880	0.398	0.510			0.325	0.583			
30.7.	dry	0.416	0.528			0.349	0.549			
26.8.	dry	0.406	0.542			0.365	0.617			
15.10.	0.261	0.311	dry			0.080	0.080			
27.10.	0.800	0.715	0.799	0.045		0.318	0.148			
5.11.	dry	dry	dry	0.077		0.614	0.217			
9.12.	0.100	dry	dry	0.275	-0.054	-0.050				
7.1.77	0.118	dry	dry	0.380		-0.025	-0.045			
'Mean' depth to water	0.605	0.227	0.408	0.193	0.331	0.170	0.241	0.114	0.291	0.336

The 'mean' depth to water is an estimated mean for the 12-month period August 1975 to July 1976

TABLE 6 <u>Height of water table above estimated 'mean' level (metres)</u>

Date	Borehole number: 10	13	15	16	19	20	21	22	23	24
'Mean' level depth from g.l.	0.605	0.227	0.408	0.193	0.331	0.170	0.241	0.114	0.291	0.336
13. 8.75	0.022	0.052	0.032	-0.100	-0.099			0.061	0.040	0.105
27. 8.	0.005	0.068	0.043	-0.088	-0.107	0.134	-0.126	0.064	0.058	0.094
10. 9.	-0.077	0.053	0.036	-0.065	-0.094	-0.049	-0.143	0.061	0.051	0.070
24. 9.	0.096	0.096	0.084	0.059	0.046	0.044	0.107	0.071	0.059	0.120
8.10.	0.115	0.101	0.087	0.066	0.039	0.080	0.170	0.174	0.059	0.112
22.10.	0.075	0.094	0.071	0.055	0.045	0.075	0.176	0.045	0.041	0.107
5.11.	0.095	0.123	0.116	0.076	0.126	0.095	0.207	0.063	0.047	0.120
19.11.	0.176	0.126	0.108	0.119	0.151	0.101	0.239	0.068	0.128	0.124
28.11.	0.200	0.106	0.096	0.123	0.137	0.090	0.225	0.063	0.114	0.103
17.12	0.409	0.096	0.077	0.100	0.088	0.220	0.125	0.056	0.099	0.084
2. 1.76	0.288	0.072	0.036	0.064	0.036	0.180	0.031	0.049	0.060	0.071
14. 1.	0.105	0.017	0.008	0.056	0.030	0.056	0.024	0.035	0.037	0.065
29. 1.	-0.003	0.014	0.003	0.039	0.010	0.007	-0.033	0.064	0.047	0.140
12. 2	0.062	0.091	0.038	0.091	0.073	0.131	0.043	0.104	0.096	0.097
27. 2.	-0.001	-0.031	-0.036	0.038	0.051	-0.036	0.022		-0.008	0.026
12. 3.	-0.057	-0.011	-0.044	0.033	0.056	-0.065	-0.004		0.016	0.037
26. 3	-0.139	-0.081	-0.077	0.007	0.051	-0.097	-0.001		-0.024	0.018
8. 4.	-0.072	-0.068	-0.059	-0.007	0.031	-0.035	-0.012		-0.024	0.026
15. 4.	-0.046	0.010	-0.014	0.053	0.111	-0.050	0.034		0.048	0.042
28. 4.	-0.164	-0.090	-0.066	-0.033		-0.104	-0.043		-0.024	0.026
13. 5.	-0.068	-0.034	-0.043	0.011		-0.069	-0.006		-0.044	0.003
4. 6.	-0.140	-0.062	-0.042	-0.042		-0.055	-0.043		-0.156	
11. 6.	-0.206	-0.146	-0.072	-0.124		-0.086	-0.109		-0.153	
23. 6.	-0.128	-0.049	-0.037	-0.071		-0.074	-0.148			
2. 7.	-0.268	-0.193	-0.121			-0.165	-0.315			
14. 7.	-0.275	-0.171	-0.102			-0.155	-0.342			
30. 7.		-0.189	-0.120			-0.179	-0.308			
26. 8.		-0.179	-0.134			-0.195	-0.376			
15.10.	0.344	-0.084				0.090	0.161			
27.10.	-0.195	-0.488	-0.391	0.150		-0.148	0.093			
5.11.				0.116		-0.444	0.024			
9.12.	0.505			-0.082		0.224	0.291			
7. 1.77	0.487			-0.187		0.195	0.286			

TABLE 7 Groundwater levels above Ordnance Datum (metres)

Date	Borehole number:						
13. 8.75	67.90	67.78	67.76	67.54	67.14		
27. 8.	67.90	67.79	67.78	67.55	67.13	67.79	67.38
10. 9.	67.80	67.78	67.77	67.57	67.15	67.61	67.37
24. 9.	67.97	67.82	67.82	67.70	67.29	67.70	67.62
8.10.	67.99	67.82	67.82	67.70	67.28	67.74	67.68
22.10.	67.95	67.82	67.80	67.69	67.28	67.74	67.69
5.11.	67.97	67.85	67.85	67.71	67.37	67.76	67.72
19.11.	68.05	67.85	67.84	67.76	67.39	67.76	67.75
28.11.	68.08	67.83	67.83	67.76	67.38	67.75	67.73
17.12.	68.28	67.82	67.81	67.74	67.33	67.88	67.63
2. 1.76	68.16	67.80	67.77	67.70	67.28	67.84	67.54
14. 1.	67.98	67.74	67.74	67.69	67.27	67.72	67.53
29. 1.	67.87	67.74	67.74	67.68	67.25	67.67	67.48
12. 2.	67.94	67.81	67.77	67.73	67.31	67.79	67.55
27. 2.	67.94	67.69	67.70	67.68	67.29	67.62	67.53
12. 3.	67.82	67.71	67.69	67.67	67.30	67.60	67.51
26. 3.	67.74	67.64	67.66	67.64	67.29	67.56	67.51
8. 4.	67.80	67.66	67.67	67.63	67.27	67.63	67.50
15. 4.	67.83	67.73	67.72	67.69	67.35	67.61	67.54
28. 4.	67.71	67.63	67.67	67.60	<67.26	67.56	67.47
13. 5.	67.81	67.69	67.69	67.65		67.59	67.50
4. 6.	67.74	67.66	67.69	67.60		67.61	67.47
11. 6.	67.67	67.58	67.66	67.51		67.57	67.40
23. 6.	67.75	67.67	67.70	67.57		67.59	67.36
2. 7.	67.61	67.53	67.61			67.50	67.19
14. 7.	67.60	67.55	67.63			67.51	67.17
30. 7	<67.58	67.53	67.61			67.48	67.20
26. 8	<67.58	67.54	67.60			67.47	67.13
15.10	6 .22	67.64	<67.48			67.75	67.67
27.10	67.68	67.24	67.30	67.79		67.51	67.60
5.11	<67.58	<67.04	<67.23	67.75		67.22	67.53
9.12	68.38	<67.04	<67.23	67.56		67.88	67.80
7. 1.77	68.36	<67.04	<67.23	67.45		67.86	67.80

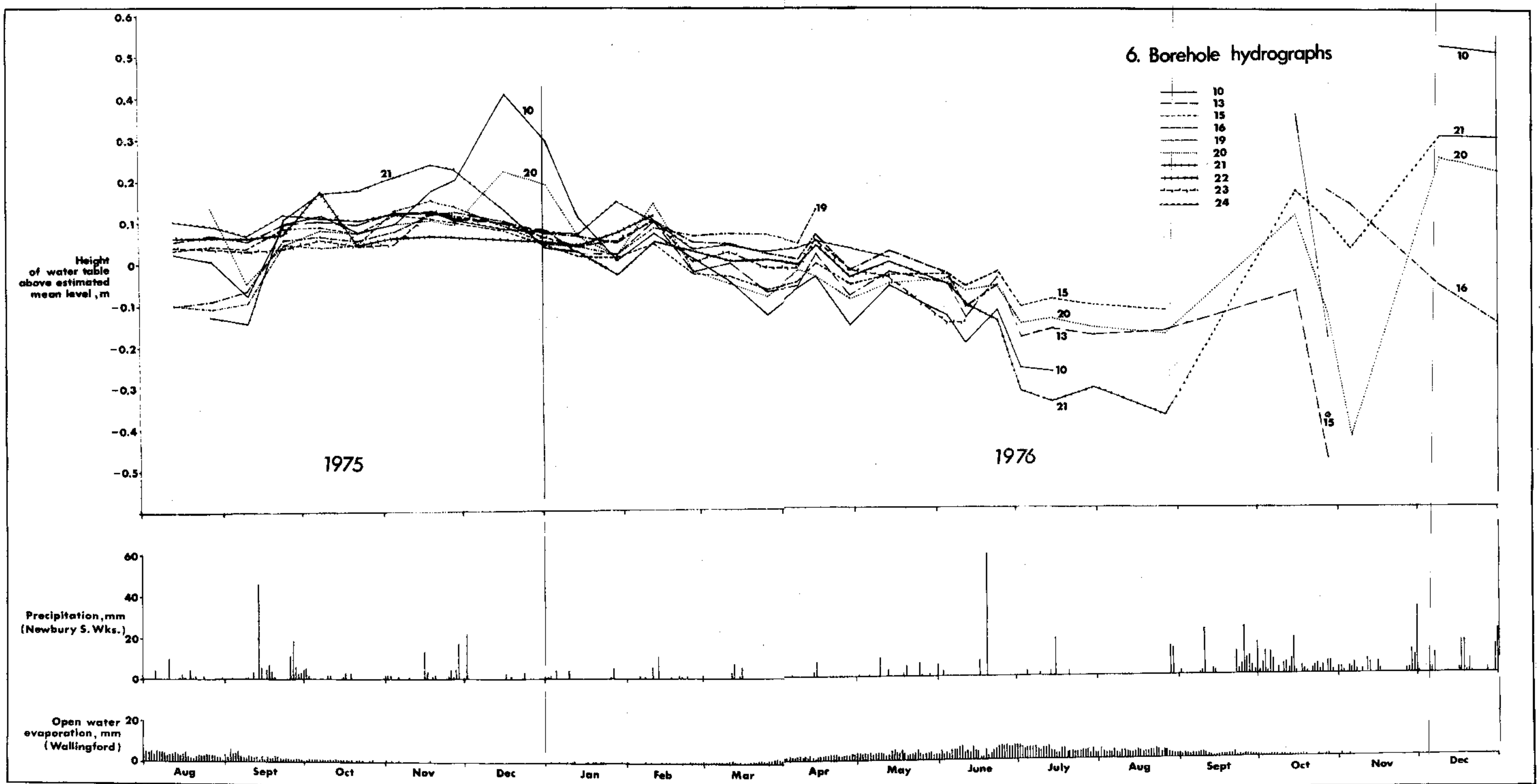
to decline, the boreholes along the northern edge near the Moor Ditch recovered in November and December as water from the Cold Ash brook filled the ditch.

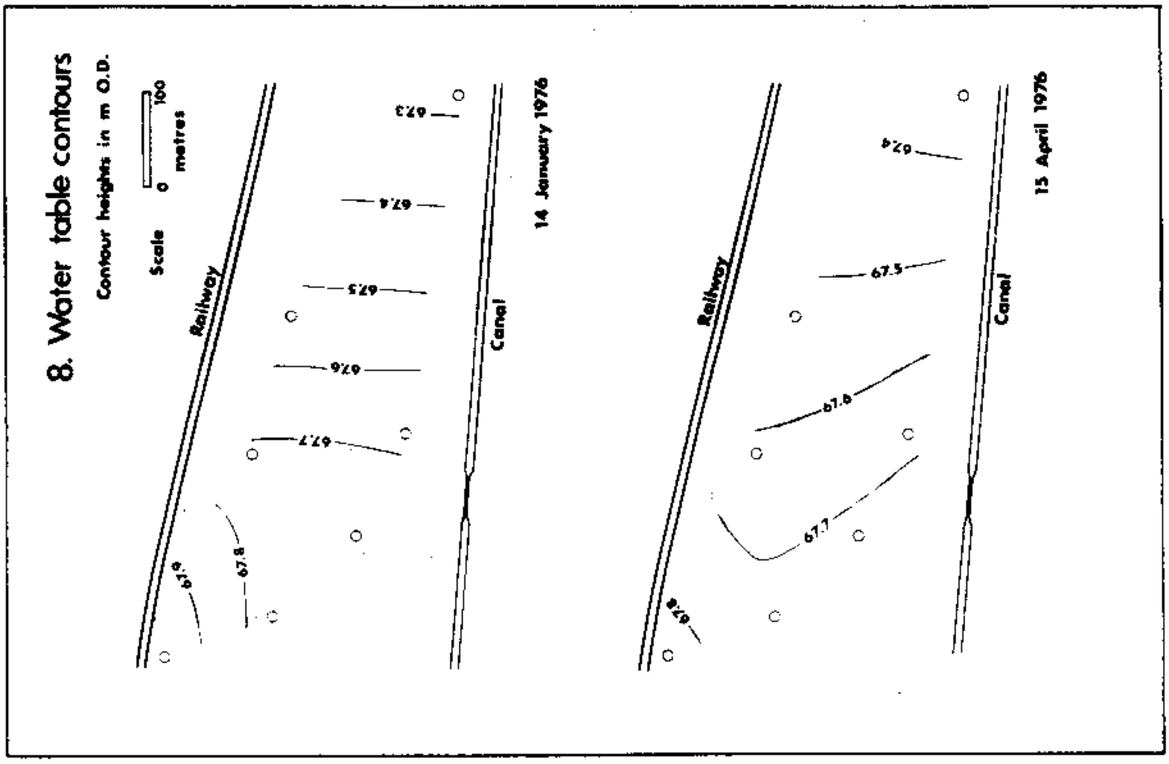
The proposed topographic surveying of the site by the 42 Survey Engineer Regiment has now been cancelled, owing to the pressure of other commitments. However, a limited amount of surveying was undertaken by the Institute of Hydrology, and was confined to the levelling of two cross-sections and some of the boreholes. Using the data from this survey it was possible to draw the contour maps of the water table surface shown in Figures 7, 8 and 9. The cross-sections (Figure 10) show that the ground surface is extremely flat, but two of the shallow depressions of the section A-A coincide with areas of reed, endorsing the statement in section 4. The Moor Ditch is generally about 0.5 metre higher than the Middle Ditch, while the canal level is up to two metres higher than the reedbed surface. Groundwater flow is primarily from the west to the east of the site, with a tendency for flow from north to south in the vicinity of borehole 10. This mound in the water table is probably a consequence of the flow of the Cold Ash stream, which recharges the gravels north of the railway even when it does not reach the Moor Ditch. The gradual fall in the water table in the west of the site can be seen clearly by watching the progress of a single contour, for example the 67.7 metre contour. In April and June 1976 a trough appeared beneath the main reedbed area. This may have been caused by the continued transpiration of the deep-rooted reeds, while the short-rooted plants in the other areas could no longer draw on the groundwater. In September the drought was broken by heavy rainfall, and levels in the boreholes rose.

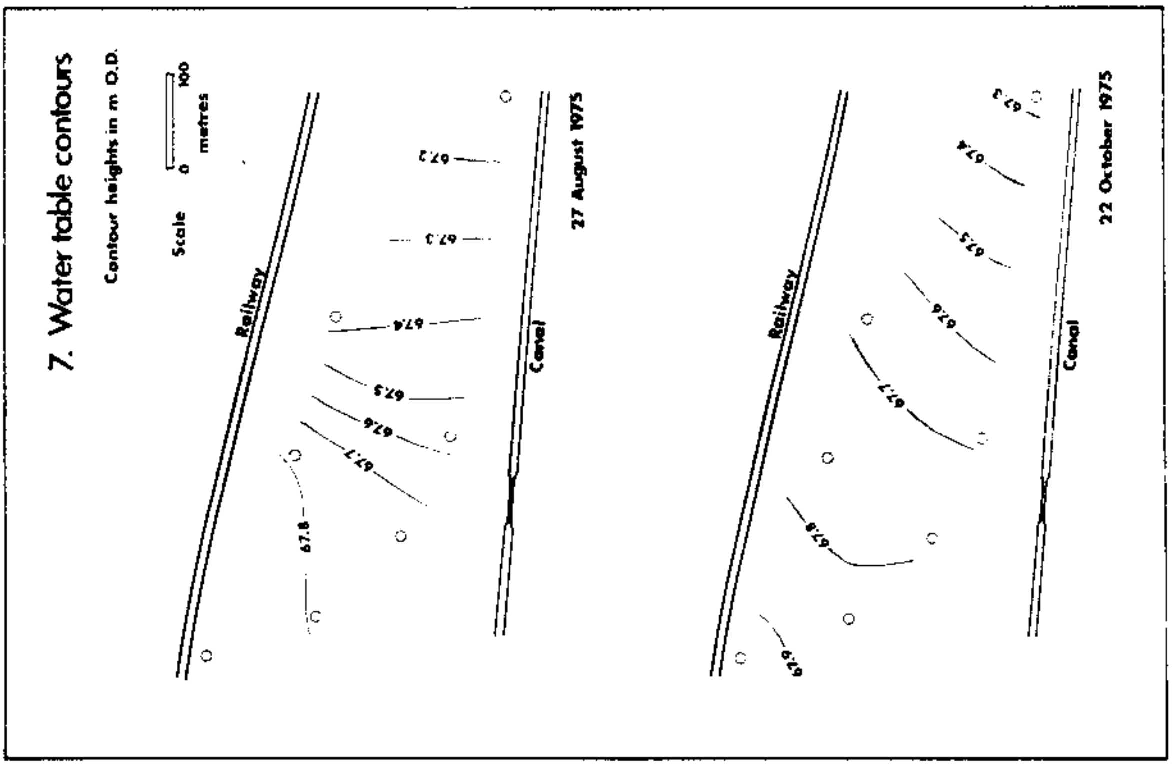
In October the gravel extractors began operations by digging a perimeter ditch parallel with and south of the Middle Ditch (Figure 9). Water from this ditch was pumped into the Middle Ditch near the Moor Ditch culvert. Two more ditches, one parallel with and west of the footpath, the other parallel with and north of the river and canal, were later joined into this dewatering system, and the water level in the ditches was lowered to about 66.5 metres above datum. Removal of the overburden of peat and marl then began in the area outlined by the ditches. The final contour map shows the beginning of the effects of the dewatering. A cone of depression centred on the perimter trench of the new excavation extended as far as borehole 20. However, a leakage from the canal of about 0.001 m^3/s, just downstream of Widmead Lock, had maintained levels around borehole 16. This leakage had stopped by 5 November, when the canal level in the reach between Widmead and Monkey Marsh Locks fell below bank level.

In December 1976 the cone of depression had intensified, so that boreholes 13 and 15 had gone dry, but the discharge of the Cold Ash stream into the Moor Ditch had raised the water table around the northerly boreholes 10, 20 and 21 to its highest recorded level. The level in borehole 16, on the outer limit of the cone of depression, was still declining (Figure 6), showing that the cone was still extending eastwards.

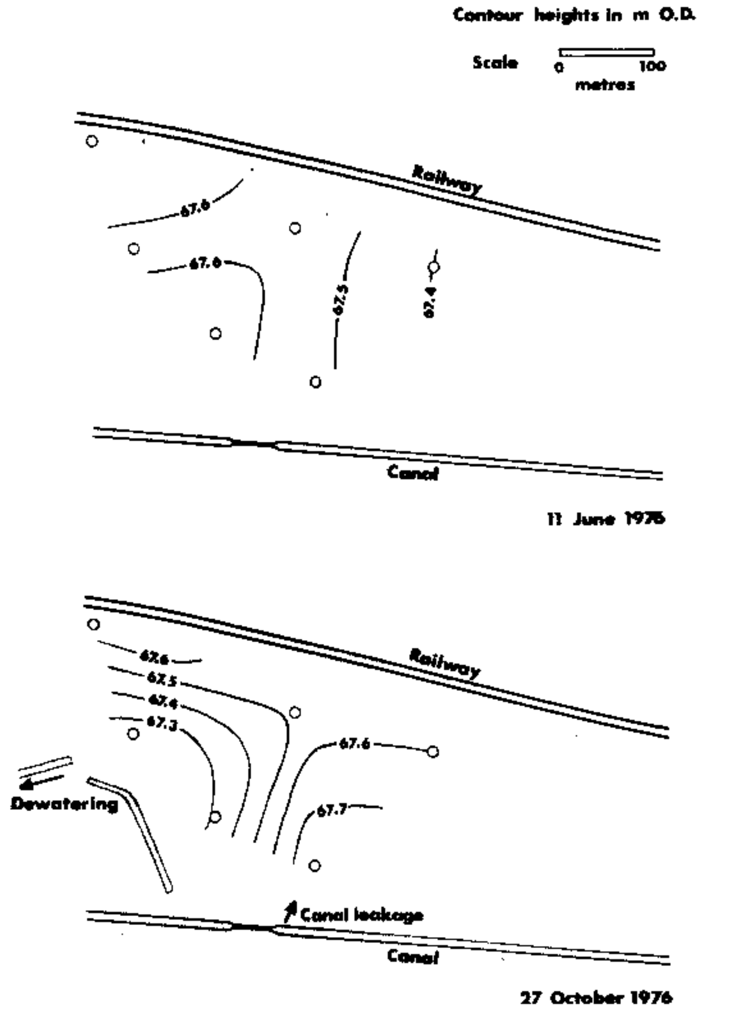
An estimate may be made of the groundwater flow from west to east,


6. Borehole hydrographs
10
13
15
16
19
20
21
22
23
24
Height of water table above estimated mean level, m
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1975
1976
Precipitation, mm (Newbury S. Wks.)
60
40
20
0
Open water evaporation, mm (Wallingford)
20
0
Aug
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

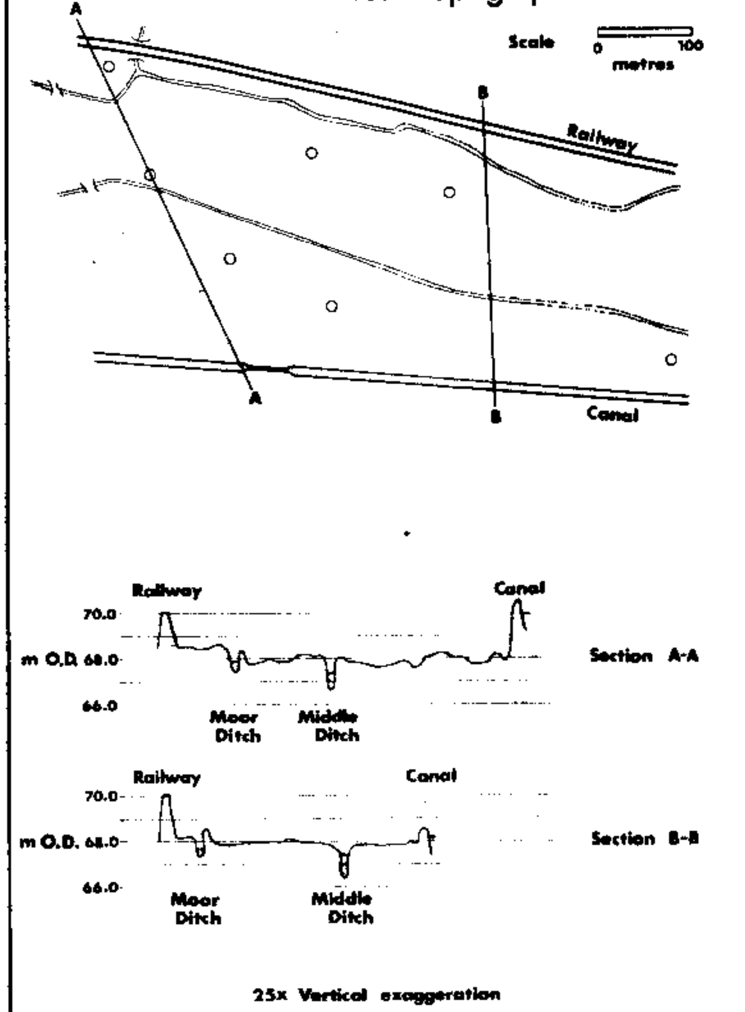

8. Water table contours
Contour heights in m O.D.
Scale 0 100 metres
Railway
Canal
67.3
67.4
67.5
67.6
67.7
67.8
67.9
14 January 1976
67.4
67.5
67.6
67.7
67.8
15 April 1976


7. Water table contours
Contour heights in m O.D.
Scale 0 100 metres
Railway
Canal
67.2
67.3
67.4
67.5
67.6
67.7
67.8
27 August 1975
67.3
67.4
67.5
67.6
67.7
67.8
67.9
22 October 1975

9. Water table contours



10. Topographic sections



assuming a peat and gravel depth of 5 metres and a permeability of 100 m/d. The permeability is probably typical of poorly sorted gravels (Bear 1972, p. 136). From the equation

$$Q = KbIL$$

we obtain $Q = 140\ m^3/d$, or about $0.0016\ m^3/s$. It is obvious that this is a very small figure when compared with the stream flow across the site, and that the discharge of a stream (or a canal overflow) on to the area will be of much more importance than a change in the groundwater flow.

Using the precipitation and evapotranspiration figures tabulated in section 5, it is possible to construct a simple model of the groundwater reservoir. The specific yield of the peat, which is the aquifer whose water content actually changes, was estimated as 15% (a single laboratory determination resulted in 17%) and it was considered that the difference between precipitation and evapotranspiration infiltrated into the saturated zone.

The results of this simple model were predictions of the water table over the study period which varied over a range of 2.3 metres. Clearly, since the actual range of borehole levels encountered up to September 1976 was about 0.8 metres, some other process had intervened to limit the extent of the variation.

An excess precipitation on the reedbed area of 100 mm (cf October 1976), which would raise groundwater levels by 0.667 m, would cause an increase in the monthly discharge of the Middle Ditch of only 10% (assuming that the study area is 52.5 ha). Thus much of the excess precipitation could drain into the ditches and cause little rise in the water table. Similarly in summer the ditches could sustain levels. The consequence of this would be a gradient from the streams into the interior of the reedbed areas, exactly as observed in June 1976 (Figure 9).

The measurement of runoff from the reedbed area would require careful instrumentation of all input and output streams, with continuous recording of discharge. This was not possible within the budget of the study. However, an important conclusion which can be drawn from the existing data is that streamflow across the reedbeds is extremely important in draining excess precipitation and in sustaining groundwater levels in summer.

8. CONCLUSIONS AND RECOMMENDATIONS

The Thatcham hydrological survey has shown that natural groundwater levels do not fall far below the ground surface even in a very dry season, and provided that this state is maintained, the reeds will be able to obtain the water required for transpiration in summer. However some flooding in spring would probably be desirable to prevent succession to other species.

The extraction of gravel over a period of years will lower the water table and put the reeds under some moisture stress in summer, reducing their ability to compete. The gravel extractors propose to dewater to the base of the gravels, estimated at about 63.5 metres above Ordnance Datum, about 4.5 metres below ground level. Over a period of several years, this lowering of the water table will cause a cone of depression extending eastwards from the footpath, encompassing the most important area of pure reed. In winter, the flow of the Cold Ash brook into the Moor Ditch will maintain the levels along the northern edge and hence across part of the reedbed. However in summer if the flow of the brook does not cross the railway, as occurred in 1976, nothing can prevent the serious lowering of levels right across the area, possibly below the base of the peat. This would cause a reduction in the supply of soil moisture available to the reeds during their period of maximum growth and transpiration, and by stunting the reed growth would allow invasion by other species more tolerant of dry conditions. A similar situation would obtain in the Local Nature Reserve, which is a comparable distance to the northwest of the extraction site, were it not for the fact that the ditches there are overgrown and discharge some of their flow on to the reedbed surface.

To prevent the summer dewatering of the reedbed area, a supply of water is required at the northern boundary, along the line of the Moor Ditch. This water could be obtained, in principle, from the Middle Ditch, particularly as this ditch will be receiving a substantial discharge from the dewatering operation. Another possible source is the Cold Ash brook, which at present dissipates its summer flow in the area of waste ground north of the railway, and does not reach the culvert under the railway. Levels along the southern boundary could be maintained by a small discharge from the lower reach of the canal. This water initially comes from the River Kennet, and its use for irrigation would require the approval of the Water Authority and the Kennet and Avon Trust.

The quantity of water required is difficult to compute, as it depends upon a property of the gravels, permeability, which has not been measured, on the rate of movement of water downward through the peat, and also on the efficiency of the spreading process. A simple calculation of the maximum summer evapotranspiration rate multiplied by area gives about 0.03 m^3/s. Allowing for losses a flow of 0.05 m^3/s would probably be sufficient.

The reedbeds require some protection from intrusion and flattening, as the beating down of standing reeds to make paths allows the growth of other herbaceous plants and reduces the resistance of the reed stands to wind damage. The excavation of narrow trenches around and across the reedbeds would isolate sensitive areas and provide a distribution network for the spreading of irrigation water.

As a check on the efficacy of the irrigation scheme, it is recommended that water level observations should be made in a new network of boreholes consisting of a deepened borehole 13, boreholes 16 and 21, and two new boreholes to be sited in the centre of reedbed areas, one south of the sewage outfall pipe and north of the railway, the other in the centre of the reedbed between boreholes 13 and 20. Observations need only be made at monthly intervals during the summer, less frequently in winter.

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