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WORTON RECTORY FARM

ENVIRONMENTAL MONITORING AT YARNTON MEAD
AND PIXEY MEAD SSSI's

IH WORKING DOCUMENT (S33/366/1)

APPENDICES

Introduction

This report is presented as a working document relating to environmental monitoring at two sites of Special Scientific Interest (Yarnton and Pixey Meads) adjacent to the possible gravel extraction at Worton Rectory Farm (Oxon).

Its purpose is to provide and bring together the hydrogeological information which would allow proposals for an environmental monitoring programme to be developed. It is not intended to provide solutions at this stage to such questions as to how the site may be worked or what the consequences of various reinstatement options may be. This is not possible yet. At the first meeting with Nature Conservancy (NCC) Amey Roadstone (ARC) and Oxfordshire CC on 9th December 1983 no groundwater information existed for the site although Institute of Hydrology (IH) had good knowledge of the area to the south.

A crash programme of data collection was planned during January and February 1984 intended to allow realistic and long-term investigations to be planned. Data collected from this drilling and water level monitoring phase was presented in map form at a second meeting held at NCC (Newbury) on 5 March 1984. The purpose of that data presentation was to enable the principal parties access to what had rapidly been assembled in order that their own knowledge and interest would be superimposed upon some facts. Here IH present their proposals for a continued study aimed at collecting longer term groundwater and surface water information. The purpose of the continued study is seen to be:

(a) Examine groundwater and surface water conditions at Worton Rectory through summer and winter to determine the existing hydrological controls.

(b) Examine conditions at times of hydrological extreme over a period of 2 or 3 years.

(c) From these design a monitoring network around the SSSI sites at Yarnton Mead and Pixey Mead to allow control of groundwater and surface water conditions during any gravel working.

(d) Collect sufficient quantitative information to make proposals regarding how any gravel workings might proceed without detriment to the SSSIs.

(e) Examine reinstatement options relative to the conditions which exist now and which may be considered desirable after completion of any workings.

Notes to accompany the maps already presented are given as appendices. Since this is a working document these maps have not been reproduced again, nor has any extra work been made by IH.

In broad terms it has been agreed that IH would advise NCC on the programme of environmental monitoring should outline planning consent be given for the Worton Rectory site. It has also been suggested that once an acceptable programme has been agreed IH should act in the role of "honest broker" with regard to interpretation of the information and its use to predict the consequence of engineering works in advance of any gravel extraction. It has also been proposed that ARC will provide funding of IH activities related directly to any planning requirements for the gravel extraction and their affect on the environment. IH on their part would use the opportunity presented by their involvement to continue their research into the hydrogeology of the Thames floodplain within the setting of the Worton Rectory site.

Summary of groundwater conditions at Worton Rectory

The crash programme in January/February 1984 determined a saucer shaped groundwater body beneath Worton Rectory. Head controls on this system were the River Thames to the south with groundwater flow northwards from the river beneath Yarnton Mead toward the proposed gravel workings. This was in the opposite direction from that expected. To north and east groundwater moved towards the centre of the site from the margins of the floodplain. From the northeast groundwater also moved toward the site through a continuation of the floodplain gravels from the Kidlington area. Here the exploration programme had not been able to define the aquifer satisfactorily.

The central depression on the water table is caused by the recently re-excavated drainage ditch across the Worton Rectory site. Groundwater was being discharged from the gravels to the ditch at the time of the survey ultimately flowing out of the site through a siphon beneath the River Thames to join the river again in the Wolvercote reach after flowing along the western margin of Pixey Mead.

This stream appears also to exert a strong control on the piezometry and groundwater conditions beneath Pixey Mead and for that matter the area to the east between the Wolvercote Reach and the Oxford Canal. The stream again appears to be gaining groundwater from the Thames at Kings Lock via the gravels beneath Pixey Mead and probably from a leaking Oxford Canal.

At the time of the survey on 10 February groundwater within the area was at the shallowest depth (< 0.1 m to 0.7 m) beneath the two SSSI's but fell most rapidly in the north of Pixey Mead during a week long dry spell. At the time of the survey water levels beneath the two SSSI's stood above the top of the gravels. In effect the aquifer was confined by the alluvial clays and silts of the surface.

Large changes in groundwater level were observed during the week long dry weather spell (up to 25 cm fall). However it was not possible to assess detailed relationships between groundwater levels and the controlling river level since the Thames is regulated and head changes unrelated to weather at the site can occur at any time.

River profile data show that dredging has excavated the river through the alluvium into the gravels in the reach controlling leakage to the Worton Rectory site. It must be assumed that siltation could affect conditions here and that head/leakage relationships should change with time.

With regard to the drainage ditch there is no knowledge regarding summer flow conditions and no scope therefore to predict seasonal groundwater changes. Also a lateral drain from the Kidlington area enters the Worton Rectory site. Relationships between this and the gravel aquifer are unknown.

The very dynamic nature of the groundwater body, the rapid changes from confined to unconfined conditions and the unexpected importance of the whole surface water network prevented any short-term groundwater modelling studies. However, a computer flow net analysis was made assuming steady-state aquifer conditions to gain "ball park" estimates of the volumes of groundwater moving through the aquifer form.

From the grain size analysis permeabilities for the whole area of between 30 - 370 m/day were derived. These were low as compared to the single pump test result which could be directly related, 60 m/day as opposed to a minimum pump test solution of 150 m/day. According to the method of solution the pump test in fact indicated permeabilities of up to 500 m/day. The extremely wet conditions during the test severely constrains the confidence which can be placed in this value. A second test was regarded as too unreliable for use again because of surface water conditions.

Results of the flow net using the low permeability estimates suggest some 3800 m^3/day of river water entering the gravels at Yarnton from the Thames. Most appears to flow beneath the SSSI to the drainage ditch at Worton Rectory. Groundwater flow from the western and northern margin to the ditch was estimated in both cases at 300 m^3/day with some 200 m^3/day from the Kidlington gravels.

Across Worton Rectory the flow net predicted losses from groundwater (to the stream) of some 2700 m^3/day. This compared with actual IH current metering during the monitoring of 4150 m^3/d upstream of the Kidlington lateral drain. At the time of the survey this was discharging 8460 m^3/d into the area and clearly is an important factor at Worton Rectory.

The flow net also provided information relating to Pixey Mead. Here leakage of some 3000 m^3/d from the Thames at Kings Lock is predicted with about 2500 m^3/day from the Oxford Canal area. The implications is that Worton Rectory ditch along the western margin of Pixey Mead gains this water. Surface water gains of about 4000 m^3/day to the ditch, and 2000 m^3/day direct to the river at Wolvercote, were also predicted.

During the crash program it was clearly illustrated that, when high groundwater levels exist, the head control on the groundwater system is the river stage. It was also shown that the volumes of groundwater flow were very small relative to the surface water flow. There is reason to believe that these conditions will prevail during low groundwater conditions. These results allow us to conclude that during gravel extraction it will be possible to control the groundwater levels in the mead by using appropriate land drainage schemes. In view of the complexity of the groundwater system it is not possible at this stage to suggest the form these schemes should take thus we propose the future studies discussed in the next section

Proposals for future studies

The very long-term nature (25 years) of the phased gravel working and subsequent reinstatement of the Worton Rectory site presents a major planning problem. At this stage we feel it is unrealistic to make commitments to scheduled programmes of work for all possible phases of the site development. However we believe the investigation falls naturally into a number of distinct phases. The first of these is a pre-extraction study of approximately two years duration. The content of this study is proposed below.

Subsequent studies must be tied to the phased extraction and proposed after use. Each of these studies would incorporate hydrogeological information gained during the previous phases. The exact content of each study would be planned during the reporting of the previous stage.

We believe two years is a reasonable period for the pre-extraction study to find suitable periods of climatic variation and short-term extreme to define the dynamic nature of the area with some confidence. We propose modelling after this because only from within a calibrated understanding of the system could realistic predictions be made. Our views regarding the form of study relative to the planning safeguards which have been suggested during discussions are given below with explanation.

A. The February 84 monitoring was made immediately after a particularly wet period - at Wallingford rainfall between the 15th - 30th January exceeded the monthly average. River stage at the site was also very high. On 7th February it had only been exceeded on 90 occasions in the period 1894-1982. Conditions might therefore be described as approximating the normal maximum flood event. Groundwater levels were first monitored 3 days after the flood peak on 10 February by which time the river had fallen 30 cm. The second monitoring on 17th February followed a period without rainfall but river stage had risen 15 cm through flow regulation.

The groundwater monitoring which exists must therefore be seen against what might be described as high if not maximum winter levels. River stage in the main stretch, shown to be leaking, is controlled for navigation purposes and does not fluctuate wildly. However unusually high groundwater levels must be regarded for the rest of the site. Given the second control on groundwater by the drainage ditch, and without knowledge of summer surface weather conditions here, it is difficult if not impossible to envisage the summer groundwater configuration. It might retain its saucer shaped configuration, this seems quite likely, but following long periods with no surface flow the configuration could change significantly.

We believe groundwater monitoring over a full year is the minimum required to establish the dynamic response of the system as a whole. Routine monitoring on a regular time scale is desirable for modelling purposes but is perhaps not practical. The system must be sampled according to patterns of rainfall and with regard to Thames river stage. Climatic patterns here are such that a single year is unlikely to produce a range of reasonably normal conditions. Monitoring over 2 years on at least 12 occasions would be the minimum to produce a data set for modelling this system.

B. The existing borehole monitoring network needs some expansion. 2 extra sites are desirable within Worton Rectory Farm. Several more are needed in the Kidlington gravel tongue, perhaps 6, to describe the northeast groundwater and geology. A further 3 around the flooded gravel pit and the canal would also be desirable to assess the eastern boundary leakage zone. Elsewhere if the existing network could be maintained over 2 years, with water level recorders at the large diameter pump test sites, we believe the long-term natural groundwater conditions could be reasonable well described.

C. Clearly the reconnaissance has shown that surface water studies are as important as borehole observations. Stage readings in conjunction with borehole observations ought to continue. We would also suggest two stage recorders on the Worton Rectory ditch with occasional current metering to establish stage/discharge relationships. The main ditch and the Kidlington lateral in the vicinity of their confluence are proposed to recorder sites. These could be run in conjunction with the groundwater recorders on a monthly basis.

Some shorter term recording of surface water levels would also be desirable. The flooded gravel pit east of Pixey Mead and the Oxford Canal for a winter season are suggested in the vicinity of the suspected leakage. At other times these 2 recorders could be installed on the main ditch or its tributaries to assess the direct role of rainfall to runoff.

D. Aquifer properties clearly need to be established with more certainty. Sites WR15 and WR18 should be retested in dry weather. IH has recently ordered a submersible electric pump suitable for such work as part of its research programme. Two other test sites must be established ideally several others would be desirable. Firstly aquifer properties in the central zone of clean gravelly sand centred on Yarnton ought to be known. We would also envisage a pump test in the Kidlington gravel tongue close to the eastern boundary and would like also to include Pixey Mead.

In order to make time varying model studies detailed distributions of storage coefficients are essential. These can only be obtained from pumping tests.

E. Predictive studies either for water control during gravel working or for establishing after use alternatives must involve modelling. This will be much more expensive than just routine monitoring of the system with ad-hoc adjustment of engineering arrangements to match some prescribed hydrological condition. We must emphasise here that modelling is unlikely to remove the need for any long-term monitoring during working of the gravel. Modelling is the only realistic way of investigating engineering solutions in advance and thus reducing the risks of severe and unexpected environmental change.

A non-steady state, variable permeability, groundwater model with a linked surface water element is needed. We would envisage developing such a model at IH as part of our research during the two year monitoring period. Calibration of the model and its use in operational predictions for the Worton Rectory site would form a major element of this project reporting over a period of several months thereafter.

F. IH research is particularly concerned with the relationships between the nature of the sand and gravel and their aquifer properties. We would propose continuing this research on Worton Rectory samples and from elsewhere in the area of interest to IH. Laboratory studies and core permeability would be further investigated in parallel with the test pumping proposed above. We also propose to investigate constant head testing of small diameter boreholes to supplement the pump test field determination of aquifer properties.

G. Tracing of groundwater flow at potential leakage sites using groundwater chemistry and stable isotope studies (deuterium and oxygen-18) would also be introduced if necessary.

H. We also believe recent high resolution satellite imagery data is available for the site (50 m resolution). We would propose examining this data to determine its possible usefulness to the study.

A.1 DATA COLLECTION

EXISTING AVAILABLE INFORMATION

The collation of existing relevant geological and hydrological information on the flood plain west of Oxford included an area extending from Cassington and Yarnton in the north to Botley in the south - so as to include a large area to the south of Worton Rectory Farm previously investigated by IH (see Figure 1). The list below represents information available prior to further work carried out for the present study. Unfortunately the site investigation records for the Oxford Western By-pass (A34T) between North Hinksey and Pear Tree Roundabout were unavailable - possession of this report would have added considerably to our understanding of the geology of the area.

AVAILABLE GEOLOGICAL AND HYDROLOGICAL INFORMATION PRE-1984

BOREHOLE INFORMATION

69 boreholes drilled by IH between 1979-1983 of which most had geological logs and 22 had particle size analyses undertaken on collected samples. 55 of the boreholes remained as open observation wells

13 boreholes drilled for the Industrial Minerals Assessment Unit of IGS between 1971-1974, all with accopanying geological logs and particle size analyses.

2 boreholes whose records are with the hydrogeological records of BGS.

352 commercial boreholes including 201 holes drilled by ARC at Worton Rectory Farm which included bulk particle size analyses.

B.. TOPOGRAPHIC INFORMATION

Aerial photographs of the Thames Floodplain at a scale of 1:2500, contoured at 0.25 m interval, supplied by Thames Water Authority (TWA).

HYDROLOGICAL INFORMATION

Bed profiles of the River Thames between Eynsham and Osney locks supplied by TWA.

2. Head and Tail records for Eynsham, Kings, Godstow and Osney locks between 1979 and 1981 supplied by TWA.

Discharge estimates for the River Thames at Eynsham Weir between 1979-1981 supplied by TWA.

Flood frequency figures between Kings and Eynsham locks between 1894-1982 supplied by TWA.

Result of an I.H. investigation of groundwater in the alluvial aquifer of the Thames between Binsey and University Field Station between 1976-1981 and the results of a pumping test undertaken at Botley during October 1983.

A.2 FIELDWORK UNDERTAKEN DURING JANUARY AND FEBRUARY 1984

DRILLING

At the meeting of 19th December 1983 it was decided that IH and ARC would jointly undertake the installation of a number of wells at Worton Rectory Farm and on Yarnton Mead, thus extending the then existing IH groundwater monitoring network northwards into the main area of concern.

Drilling was subsequently carried out between 10th January 1984 and 27th January 1984. Borehole locations are shown on Figure 4 prefixed by WR. On Yarnton Mead and at Loop Farm 4 boreholes were drilled with the IH lightweight Marlow Drilling Prospectorpac, operating from a boat where vehicular access was prohibited. A split-lined flowthrough sampling bit was used to obtain small diameter cores for logging and photographing. At Worton Rectory Farm 18 borehole were drilled using an ARC track laying Craelius D6 ring with a continuous flight auger. The auger was driven to bedrock, then pulled with zero rotation to obtain bulk sand and gravel samples for subsequent logging and particle size analysis.

All 22 observation wells installed were of standard 2 inch steel pipe construction, the bottom 0.5 m perforated with about 100, 1/4 inch diameter drilled holes giving an open area of approximately 3%. The Craelius D6 was capable of driving 6 m lengths of capped pipe into a previously augered but collapsed hole with varying depths of penetration. Installation with the Marlow Prospectorpa followed a procedure previously developed by IH using a perforated leading length with the above specification with a welded drive point together with 1 m coupled plain lengths. Most wells were left about 1 m above ground level with a threaded top, necessary for subsequent permeability testing.

At sites WR15 and WR18 (see Figure 4) 8 inch diameter boreholes were drilled and 6 inch diameter plastic well casing installed for test pumping. Drilling was undertaken using the IH Pilcon Wayfarer 1500 shell and augerig. 4 inch diameter cores were obtained using a new technique developed by IH and Northumbrian Drilling Products Ltd. These cores are to be subjected to laboratory permeability testing and then cut using the IH liquid nitrogen technique for logging, (Dixon,1983) photographing and particle size analysis. Each pumping test well was screened for an interval of 1.05 m commencing 1.08 m above the base with a 1 mm slot size. Three observation wells were driven with the Marlow Prospectorpac at distances of 2,5 and 10 m from the pumped well at both sites.

All observation wells including those at the pumping test sites were developed. Where access permitted this was undertaken with compressed air using an 85 cfm compressor. On Yarnton meads and soft ground hand pumps were used. At both pumping test sites an air developed D6 installed well was driven beside a hand pumped developed Prospectorpac installed well for subsequent paired permeability tests.

B. SURVEYING

Most of the observation wells drilled during January 1984, together with other IH wells to the south were levelled and located by ARC surveyors. River stage recording sites (see below) and observation wells requiring relevelling were surveyed by IH between 2nd February 1984 and 17th February 1984. Both surveys achieved a closure of levelling generally within ± 0.01 m.

C. SURFACE WATER MEASUREMENTS

River stage recording sites were located and installed between 2nd February 1984 and 17th February 1984 amounting to a total of 31 from Cassington to Botley, supplementing the groundwater monitoring network. Measurements of stream flow were carried out during the monitoring day of 10th February 1984. (Figure 3).

D. PUMPING TESTS

Pumping tests were undertaken on 23rd January 1984 at WR15 and 27th January 1984 at WR18. Two 4 inch Sykes Univac pumps were used, one to pump from the well, the other to discharge waste to nearby drains. Both suction and delivery were reduced to 2 inch diameter to give space in the well for a transducer and to use an existing manometer gauge on 2 inch delivery pipe. Water levels in the observation wells were recored manually with dippers. Discharge was measured with an orifice bucket and monitored with a manometer on the delivery pipe mentioned above.

E. GROUNDWATER MONITORING

A total of 78 observation wells were monitored on 2 occasions; 10th February 1984 and 17th February 1984 during falling groundwater conditions. The 31 river stage recording sites were also monitored on the same occasions.

A.3 GEOLOGY

A. INTRODUCTION

Most of the region within and around the study area is dominated by the Thames Valley with its Quaternary alluvium and river terrace deposits overlaying Mezozoic Oxford Clay (see Figure 2). Here the hitherto eastward course of the River Thames is deflected northwards and then southwards as it skirts the higher ground of Wytham Hill, a Corallian outlier noted for its cambered slopes (Arkell, 1947).

The alluvial aquifer ~~which~~ bordering the Thames in this region comprises First or Floodplain Terrace with small areas of second or Summertown-Radley Terrace where these patches are in hydraulic continuity. Generally speaking the aquifer can be considered as consisting of relatively thin, fluvial sands and gravels sandwiched between bedrock clay and overlaying alluvial mud. Figure 2 shows the boundary of the alluvial aquifer within the study area. Worton hamlet lies on Second Terrace with most of the farm and the meads on lower lying alluvium covered First Terrace. Drilling by ARC at Worton Rectory Farm has indicated that hitherto mapped strips of Oxford clay separating the first and second terraces do not appear to exist and the figures have been amended accordingly. No attempt has been made to subdivide the first or second terraces as undertaken by the Geological Survey (sheet no 236) as there appears to be no lithological or stratigraphical basis for doing so.

B. ALLUVIUM

Most of the Thames floodplain is mapped as alluvium (see Figure 2) Notable exceptions occur on Port Meadow and to the north and south of Binsey. Elsewhere thicknesses of up to 4 metres occur (3.9 m of alluvium was proved at UFS13). The alluvium is a soft mud, often with much shelly and organic material with occasional discrete peat horizons towards the base. Cores of a 2 metre thick peat layer were obtained in September 1983 from PX9 on Oxey Mead underlying alluvial mud and overlying sand and gravel. It is hoped that such organic horizons will enable reconstruction of the ecological history of the floodplain environment.

Particle size analysis (using a sedigraph machine) showed alluvium at UFS18 to be 65% clay and 35% silt whereas alluvium exposed at a river bank section of Seacourt Stream (GR SP 4750 0974) showed 40% clay and 60% silt. X-ray diffraction of the same muds at both sites showed a high smectite, intermediate kaolinite and low illite clay mineralogy.

The alluvium of the Thames Floodplain in this region is considered by Oxford Archaeology Unit (pers. comm. Messrs Lambrick & Robinson) to be of Iron Age date or more recent on the basis of a number of radio carbon dates and contained artifacts. It is postulated that the alluvium represents overbank flood deposits, the product of soil erosion caused by early defforestation.

The thickness of alluvium (together with soil) is shown in Figure. 9 Areas of thick alluvium have been proved to border the River Thames as far downstream as the confluence of Kingsbridge Brook, to underlie Pixey Mead, to border Seacourt Stream south of Wytham and to underlie the nothern part of Worton Rectory Farm. Reference to the base of alluvium (or top of sand and gravel) map (see Figure 7) offers an explanation for the varying thicknesses of alluvial cover. A surface somewhat different to the present floodplain topography is evident with a 'channel' system accounting for areas of thick alluvium (see Figure 7). A 'palaeo -channel' system appears to have drained Worton Rectory Farm northwards, then eastward and finally southwards to join a 'palaeo-Thames channel' at the present confluence of the Thames with Kingsbridge Brook. The main 'palaeo-Thames channel' then seems to have flowed across Pixey mead to follow the present Seacourt Stream. Again, Oxford Archaeology Unit (pers. comm Messrs Lambrick & Robinson) believe this suballuvial surface to represent the floodplain topography at the end of the last cold phase of the Pleistocene, preserved as a buried topography by later deposition of alluvium (c.2500 years BP). This hyothesis has not been entirely corroborated by recent drilling for this study. No evidence of palaeosols were found, which would be indicative of a 'fossil ground surface'. Furthermore, WR14 and WR20 both showed the boundary between alluvium and sand and gravel to be interlayered mud and sand laminae suggesting continuous deposition at these localities at least.

SAND AND GRAVEL

GEOMETRY

The geometry of the sand and gravel body is shown on the map 8 of sand and gravel thickness which because most of the aquifer is confined, approximates aquifer thickness. Thicknesses of over 5 m are present in the mid-floodplain areas between alluvium filled channels. Generally the thicker the alluvium covering, the thinner the underlying gravel. The base of the sand and gravel maps (Figure 6) shows a more subdued topography than the base of the alluvium map but a 'channel' system is discernible. A more complex series of 'palaeo channels' appear to have flowed south eastwards under Worton Rectory Farm to join a main south flowing channel in the vicinity of Godstow.

COMPOSITION

The sands and gravels of this area are largely composed of fine to coarse, rounded to subrounded limestone pebbles with minor amounts of ironstone, quartzite, flint and quartz usually in a matrix of mainly medium to coarse carbonate and quartz sand. The fines are mainly silt sized carbonate and quartz with about 30% clay (smectite, kaolnite and illite all well represented).

STRUCTURE

Owing to the paucity of exposures, comment on structure and facies is limited. Many of the boreholes drilled by ARC at Worton Rectory Farm indicate complex sequences, for example BH No 137 shown on Figure 5 Similarly the river bank exposure along Seacourt Stream showed a laterally persistent planar crossbedded sand lens at GR SP 4733 0983 in close proximity to a massive gravel unit at GR SP 4744 0975.

Pit faces at Stanton Harcourt in the Second Terrace (Dix Pit) have been studied by Bryant (1982, 1983a and 1983b) who concludes deposition of the gravel in a cold environment (Upper Pleistocene) by a river regime (arctic proglacial analogue). He has recognized various facies on the basis of detailed logging. Work undertaken by IH in conjunction with Bryant has shown that his bar facies have lower permeabilities. (399-451 m/day*) whereas his channel facies show high permeabilities (641-1144 m/day*). As structure is an important but little understood control on permeability of alluvial aquifers it is hoped that the

* Based on grain size analyses of pit face samples using Boonstra and de Ridders method (1981)

recently developed gravel sampling technique Dixon (1983) as undertaken at WR15 and WR18 will improve our understanding.

TEXTURE

The texture of the sands and gravels have been analysed in some detail in this study by interpreting grading results from IH, IGS and ARC boreholes with the aim of estimating permeability from grain size distributions.

The % gravel (> 5 mm), % sand (0.075-5 mm) and % fines (<0.075 mm)* of bulked borehole and individual weighted mean borehole samples are shown in Figures 18 to 21 . Variation is evident, for example fines content decreases from valley sides to the middle of the floodplain. These three diagrams are synthesised into Figure 22 which shows the distribution of the deposit types*. The valley sides are dominated by GRAVELLY SAND with silt, whereas clean GRAVELLY SAND and SANDY GRAVEL occur in the central parts of the floodplain. This same trend is evident when looing at variation of ϕ mean and ϕ standard deviation†. These parameters although more abstract, do take into consideration the entire particle size distribution. ϕ mean tends to decrease (ie particles coarsen) from Worton Hamlet across the meads towards the Thames. Variations in permeability estimates (using Boonstra and de Ridder method) based on grading results show a similar trend varying from 20 m/day at Worton hamlet to 370 m/d at UFS13 and 238 m/day at IMAU Borehole 41 SE 11 [GR SP 4818 1065].

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* Particle size limits and material names as used by the extractive industry.

† $\phi = -\log_2 d$ where d = diameter in mm. The ϕ mean and ϕ SD are computed by the method of moments.

These grain size parameters (and the permeabilities derived from grain size distributions) are weighted means of samples from individual boreholes or bulked samples from groups of borehole samples. Work undertaken by IH at Browns Pit (First Terrace) and Dix Pit (Second Terrace) at Stanton Harcourt indicates considerable vertical variation. The ϕ mean from 22 face samples taken from 4 channel sections in close proximity varid from -0.68 to -1.64 although the weighted means of the ϕ means for each of the 4 channels showed reasonable agreement (-1.12, -1.07, -1.05, -1.04). Similarly permeability estimates (using Boonstra and de Ridders method) gave individual sample k values ranging from 50 to 537 m/day yet the weighted means of the k values for each of the 4 channels again showed good agreement (260, 222, 212, 200 m/d).

It must also be noted that the grain size statistics and corresponding permeability estimates were derived from samples obtained using different drilling techniques. Gradings from Worton Rectory Farm were obtained from augered samples whereas the rest were derived from bailed samples. Again work by IH at Stanton Harcourt (Browns Pit) has shown that although the weighted mean of the ϕ mean and k values showed reasonable agreement between bailed and augered sampling (with the augered samples giving a slightly lower k value) the face sampling gave higher values (see table below), Similar high ϕ means and k values were obtained from the Seacourt Stream exposure.

It appears therefore that the observed textural variation and hence the permeability estimates from gradings within this study area is greater than can be accounted for by chance or variation in sampling technique.

Results of paired comparison test of sampling techniques at Browns Pit, Stanton Harcourt.

	Bailed	Pit Face	Augered	Pit Face
wt mean ϕ mean	-0.78	-1.05	-0.64	-1.04
wt mean K (m/day)	165	212	113	199

A.4 HYDROGEOLOGY

A. Setting

The second half of January and the first week in February were wet, at Wallingford rainfall between 15th and 31st January exceeded the monthly average. This resulted in very high river stages in the study area with overbank flooding at Yarnton and Portmeadow and surface water in many other areas. The highest water levels were recorded on 7th February at Kings Lock; headwater 59.071 mAOD, tailwater 58.756 mAOD. Thames Conservancy records (1984-1982) for frequency of flood water levels indicate these were exceeded on 92 and 82 occasions respectively suggesting that this was about the normal maximum winter flood event.

The first full monitoring of groundwater levels throughout the area was made on 10 February at which time the tailwater level at Kings Lock had fallen some 30 cm and standing surface water had almost disappeared. No rain fell during the following week and the network was therefore resampled on 17 February by which time standing water had virtually disappeared throughout the area. River levels were a little lower at Kings Lock (headwater 58.94 mAOD, tailwater 58.311 mAOD) but had been raised some 15 cm above the lowest of the week early on the morning of 16 February.

The setting for this study is thus a fairly unusual dry winter period of relatively high water levels following a flood event.

B. Groundwater Conditions

Groundwater levels fell between 5 cm and 25 cm during the week 10-17 February (Fig 13) but essentially the same overall pattern of groundwater flow was maintained. The aquifer conditions on 10 and 17 February are shown as a contour plan of the groundwater surface in Figures 10 and 12. Broadly the Thames between Hagley Pool and Kings Lock (along Yarnton Mead) divides the area into two quite distinct zones.

Downstream of Kings Lock groundwater movement is approximately from north to south with flow towards the western edge of the floodplain at Seacourt stream southwest of Binsey. This is a pattern seen on many occasions since

1976 in our research. Extra boreholes constructed for this survey provided a more widespread picture than we have had previously particularly in the Pixey Mead area. Groundwater elevations on 10 February were almost as high as we have ever recorded but we are fairly confident that the overall flow pattern in this southern area will not change dramatically into the summer.

North of the Thames at Kings Lock groundwater flow is quite different and unexpected. The surface of the groundwater body is saucer shaped with radial flow inward.

Perhaps the most important aspect of groundwater movement as it relates to Yarnton Mead is a clear recharge mound beneath the Thames with flow northwards from the river beneath the SSSI towards the proposed mineral extraction. This was not expected, our work elsewhere suggested groundwater flow in the opposite direction (north to south) from the proposed mineral extraction to the river.

Within the Worton Rectory site recently cleaned surface drains have an important influence upon this piezometry. Water moving from the river through the gravels is discharged back to the surface at the ditch apparently over large distances. Groundwater from the north, east and west either from aquifer dewatering or from transfers across the alluvial boundary also emerges into the ditch.

Our borehole network does not adequately cover the gravels to the northeast of Worton Rectory between Yarnton and Woodstock road. In the time available it was not possible to gain access for drilling sites here.

Relationships between water table and geology are shown in Figures 11, 14 and 15. Depth to groundwater is given in Fig. 11 for the 10 February. At the SSSIs they are at shallowest depth, less than 0.5 m generally, but in shallow depressions it is virtually at ground level. Within the area of Worton Rectory Farm water levels were up to 1.8 m below surface reflecting the depressed water table around the drainage ditch.

C. Relationships with Surface Water

A geological cross-section (Fig. 14) shows the attitude of groundwater level relative to the alluvial/gravel boundary for 10 February. Across the area these stand variously within either the gravels, the alluvium, or the soil layers. Generally we have to assume that the alluvium is either of very low permeability or is impermeable and therefore in places the aquifer is essentially confined. The cross-section also illustrates the effects of dredging the Thames and of ditch deepening. These engineering works penetrate the alluvium making direct contact with the underlying sands and gravels.

Figure 15 shows the distribution of confined and unconfined conditions for 10th February. Both SSSIs are areas of confined aquifer. Yarnton Mead has a smaller head (0-1 m) than Pixey Mead (1.0 m - 2.5 m) although water levels fell rapidly at the latter sites during the following week. Shallow confined groundwater levels at the SSSI's may be of significance to the protected plant communities. If so then clearly it would be important to have knowledge of groundwater levels during summer months.

Relationships between groundwater and surface water are shown in Figs 16 and 17 where river stage is above groundwater level these are shown as influent. Potentially these are zones where surface water can enter the groundwater system providing that permeable beds also occur. The main system of the Thames, the Dukes Lock cut and part of the Oxford Canal are potential leakage sites.

Minor water courses appear to have water levels below groundwater level. They are thus shown as effluent and capable of receiving inflow from groundwater again providing that a hydraulic connection exists. Generally the minor water course conditions are more difficult to assess since they are characterised by true gradients whereas these are controlled by locks on the river. Generally we would anticipate hydraulic connections to be localised at sites of large inputs or outputs where topography, head and high permeability conditions coincide.

D. Aquifer Properties

We have attempted to assess the permeability of the aquifer to enable quantitative statements to be made regarding the volume of water involved in the aquifer system. This is one of least known and potentially most interesting aspects of the study.

Aquifer properties are conventionally determined by pumping tests, however, there are surprisingly few available for the shallow gravel aquifers of the UK partly because of the small available head for such work but also due to a certain lack of interest in this environment and the high cost of such work. Relationships between particle size and permeability are known in a general sense mainly from American research. However the applicability of such results appears to be very limited perhaps partly because of the wide range of texture, size and compaction characteristics of coarse alluvial sediments. This is the main area of IH research interest. To date we have had to be mainly concerned with geotechnical problems concerning how to obtained finely representative sedimentary samples from exploration drilling. No serious pumping test evaluation has yet been undertaken.

However for the reconnaissance study two short pumping tests were arranged in an attempt to compare results with existing ideas of grain size distribution permeability.

The estimation of aquifer permeability from grain size distribution provides a method of obtaining values at a large number of points within the area of interest. Although the method is less accurate than the use of aquifer tests, it has the advantage of providing a picture of the overall trends in the permeability distribution within the area.

The grain size distribution of any sample can be characterised by the specific surface (u), which is defined as the ratio of the total surface area of the particles in the sample to the surface area of an equivalent weight of spherical particles of the same material of diameter 1 cm. The specific surface for a sample can be determined from the results of grain size analysis using the method described by Boonstra and de Ridder (1981). The permeability K can then be expressed in the form

$$K = \frac{\alpha}{U^2}$$

where the factor α depends on various characteristics of the sample (such as shape of paraticles and voids, porosity, etc). If the permeability is in m/day, then the value taken by α has been found to vary between 31×10^3 and 71×10^3 (Boonstra and de Ridder). In this study, estimates of permeability have been made using $\alpha = 50 \times 10^3$. The values obtained and the regional trends observed in the resulting permeability distribution are in broad agreement with the patterns of gross textural variation (Fig 22). At Worton Rectory Farm a gravelly sand with silts corresponds to values of 30 m/day to 100 m/day permeability. Clean gravelly sand and sandy gravel beneath the two SSSI's show permeabilities generally of 100 m/day to 200 m/day rising to 370 m/day at one site.

Pumping tests have been carried out at 3 sites. Two sites, WR-15 and WR-18, lie within the Worton Rectory area while the site, HFM-3, is 500 m northeast of Botley and round about the south of the study area.

At all the sites the sequence is similar with about a metre of silts overlying the main sequence of gravels. These become increasingly silty near the base. The gravel sequence at WR15 is about 5 m while about 3 m at the other two sites.

Pump test sites were drilled by a Pilcon percussion rig with 1.05 m of screen placed just above the aquifer base. Three driven observation wells were emplaced at 2, 5 and 10 m from the pump well. Before testing all the wells were developed by airlift.

The tests were conducted at a constant pump rate until steady state conditions were established with water level measurements taken in all the wells.

The analysis of the results proved to be complex mainly because of constraints imposed by the available drawdown in the pumped wells due to the relatively thin aquifer. A summary of the results are given in Table 1. It was unfortunate that it was not possible to solve the test at WR-18 but this was mainly because of the constraints imposed by the available drawdown although pump problems and surface water also contributed. Results are shown as transmissivty, the product of permeability and aquifer thickness, rather than as permeability. Several methods of solution are given.

We had also hoped that a pneumatic input test method could be used on the observation boreholes. However work on the boreholes at the WR-15 site showed that the method was very dependent on the degree of development of the well. If the borehole had been airlifted for some time the short duration of the input test was such that the water in the well or in the immediate vicinity of the well over responded and that the recovering water level overshot or 'bounced' making the interpretation of the results suspect.

Direct comparison of Boonstra and De Ridders method and pump test is only available at WR-15. With a saturated thickness of just over 5 m permeability of between 150 m/day and 600 m/day are implied for the pump test as compared with about 60 m/day from grain size.

The very wet conditions at the time of the test pumping at WR-15 (and especially at WR-18) casts some doubt regarding the results. However similar results were obtained at HFM3 (tested earlier in the year) and the Theim solution at WR-15. The result is some three times that of the grain size method but generally we must place more confidence in the pump test result. This is more in keeping with results from elsewhere.

Table 1: Aquifer Transmissivities (m^2/d)

		OW2	OW5	OW10	average
WR-15	Jacob	3410		1090	
	Theis		1480		
	Theim				800
WR-18	No solution				
HFM-3	Theis	546	513	470	
	Theim				500
	distance/drawdown				460

A.5 COMPUTER STUDIES

During this feasibility study it was intended to carry out reconnaissance modelling the aim of which was to improve our understanding of the aquifer. Due to the short term nature of the feasibility survey any modelling work had to be carried out using models already in existence at IH. Since most of our work is carried out in arid and semi-arid regions these models generally treat the aquifer as being in steady state or they are very simple time varying models. The dynamic nature of the aquifer being examined, which was clearly identified during the field work and the subsequent data analysis, meant that none of these models were applicable. Hence the idea of carrying out detailed modelling work had to be abandoned.

Because of the dynamic nature of the flood plain aquifer large quantities of both spatial and temporal data would be needed in order to develop and adequately calibrate a mathematical model. This data would have to include details of the spatial variation of aquifer thickness, the distribution of confined and unconfined areas and also a large amount of information on the spatial distribution of storage coefficient. The storage coefficient data is essential since both the geometry of recharge mounds and also the manner and rate at which they disperse is a function of aquifer storage. Detailed data on the interaction between the large number of surface drainage channels in the area and the groundwater system is also required. For calibration purposes regular water tables over several seasons would be required with corresponding stage measurements on surface water channels. In an attempt to ensure good model calibration this data should be collected for several years before the model is used to extrapolate beyond it s calibration period.

If the field data, as described above, were available we feel confident that a mathematical model could be developed that would adequately describe the flood plain aquifer under natural conditions. We also feel that this data collection and model calibration should be undertaken since it is only through mathematical models that any quantitative idea of the effect of the proposed gravel extraction schemes can be obtained. Clearly this model could also be used to investigate any land drainage schemes which were proposed to alleviate any undesirable effects. Because of our experience in the flood plain environment we feel that IH is a well qualified establishment to carry out this work and we would of course be more than willing to do so.

Even though no modelling work was carried out during this study the computer was used to aid data analysis and result presentation. The computer analysis was confined to the area shown in Map 3. Most of the boundaries of this area are natural - either due to outcrops of Oxford Clay or the juxtaposition of younger river terraces. The only non-natural boundaries are those across which the rivers Thames and Cherwell flow - these have been chosen to be far enough from the Worton Rectory area so that their location will not affect our analysis within that area. In order to present results the computer analysis area was divided into a grid which consisted of 244 nodes. The grid was finer close to the River Thames so that the steeper hydraulic gradients could be adequately represented. In general the grid point spacing was 200 m but adjacent to the Thames it was reduced to 100 m. In the Worton Rectory area the grid coincided with that used by ARC. Clearly, except in the Worton Rectory area, the grid points will not corresponds to the points at which field data is available. In order to obtain the grid point values of various parameters interpolation between the data points was carried out. Once the data at the grid points had been obtained the computer was used to map permeabilities (Fig 23), water level and base of aquifer elevations. The computer was also used to calculate and map saturated thicknesses (Fig 23A) and transmissivities (Fig, 24). Where appropriate maps were produced for both the 10/2/84 and 17/2/84 data collection exercises.

Internodal flows were calculated for the two sets of water level elevations. This was done using the following formula,

$$F_{i,j} = (h_i - h_j) * T_{ij} * \text{WIDTH/LENGTH}$$

where : F_{ij} is the flow from node i to node j

h_i and h_j are respectively the hydraulic heads at nodes i and j

T_{ij} is the internodal transmissivity (calculated as the harmonic mean of the transmissivities at nodes i and j)

WIDTH is the width over which the flow is occurring

and LENGTH is the length over which the flow is occurring

By summation of the flows to and from a grid point the implied recharge or discharge could be estimated. This is the amount of recharge or discharge that would be required to maintain the observed water table if the aquifer were in a steady state. As stressed earlier this is not the case but we felt that the implied recharges/discharges were the only way in which we could gain insight into the complex inter-relationship between the groundwater system and the numerous surface water channels in the area under study. Because of the dynamic nature of the aquifer the implied recharge/discharge analysis was carried out for both of the data collection exercises. The results of this analysis are shown in Maps 25 and 36.

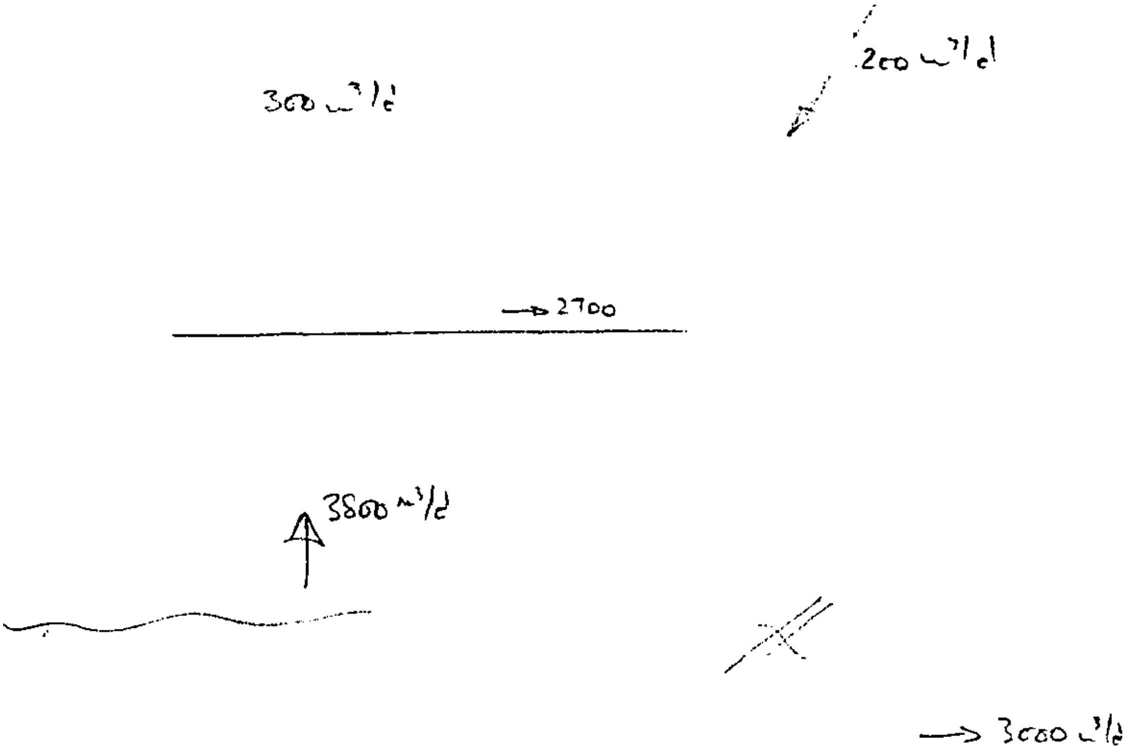
In order to put the implied recharges/discharges into context the computer was also used to estimate the volumes of water lost at each grid point between the high water table observed on 10/2/84 and the somewhat lower one observed a week later. This was done by assuming a 1% specific yield for the alluvium and a 10% specific yield for the gravel/sand material of which the aquifer was composed. At grid points where groundwater was lost from both the alluvium and the gravel a weighted mean of the two specific yields was used. The results of this analysis are shown in Map 28.

Implied recharge, discharge relationships are given in Figures 25 and 26 for the two separate piezometers.

Results of the flow net using the <u>low</u> permeability estimates suggest some 3800 m^3/day of river water entering the gravels at Yarnton from the Thames. Most appears to flow beneath the SSSI to the drainage ditch at Worton Rectory. Groundwater flow from the western and northern margin to the ditch was estimated in both cases at 300 m^3/day with some 200 m^3/day from the Kidlington gravels.

Across Worton Rectory the flow net predicted losses from groundwater (to the stream) of some 2700 m^3/day. This compared with actual IH current metering during the monitoring of 4150 m^3/d upstream of the Kidlington lateral drain. At the time of the survey this was discharging 8460 m^3/d into the area and clearly is an important factor at Worton Rectory.

The flow net also provided information relating to Pixey Mead. Here leakage of some 3000 m^3/d from the Thames at Kings Lock is predicted with about 2500 m^3/day from the Oxford Canal area. The implications is that Worton Rectory ditch along the western margin of Pixey Mead gains this water. Surface water gains of about 4000 m^3/day to the ditch, and 2000 m^3/day direct to the river at Wolvercote, were also predicted.



200 m³/d
300 m³/d
2700
3800 m³/d
3000 m³/d

These are favourable results given that groundwater conditions at the SSSIs probably need to be conserved throughout any gravel extraction. Engineering solutions should easily handle such relatively small water volumes. Given perhaps 3 fold underestimate of permeability even then no serious engineering difficulty with regard to volume is implied. However in view of the complicated piezometry, the very dynamic character of the aquifer system and the clear important connections between ground and surface then patterns of groundwater flow must be regarded as very vulnerable to disturbance. Here is the need for further study. Firstly the sensitivity of the system as monitored during the winter high water level condition needs to be established by continued observation into and through dry weather periods. Within a groundwater model we believe the consequences of altering surface water recharge/discharge relationships should be explored to assess the systems dependence upon drainage patterns. This we believe could determine the engineering strategy required. Patterns of gravel extraction might also be simulated and linked to drainage options, again to explore engineering strategies.

① Small volumes of water (fairly relative to surface flow), lack

② Thames stage   WR ditch are head controls

③ Complex wet surface [?] dynamic system, gw-sw interconn"

pattern vulnerable to change

cf to dry season

use model to alter rech/disch pattern

linked to extract" + drainage options

Q Can wt be maintained below mead ?

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