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Natural Environment Research Council

EFFECTS OF GRAVEL EXTRACTION ON GROUNDWATER LEVELS AT WORTON RECTORY FARM 1989-1990

INTERIM REPORT

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Contents

1. Introduction

This interim report describes work carried out by the Institute of Hydrology (IH) during 1989 and 1990 in monitoring and modelling changes in groundwater levels during gravel extraction at Cassington Pit, Worton Rectory Farm, Oxford. It follows a previous report (1987) on a study of the likely hydrological effects of gravel extraction at the site. This earlier study was undertaken because of concern over effects on the nearby Yarnton Mead (comprising West and Oxey Meads) and Pixey Mead Sites of Special Scientific Interest (SSSI's). Any change in hydrological regime was considered a possible threat to the distinctive flora of these hay meadows.

Although the hydrological conditions of direct ecological importance are those in the plant root zone, the 1987 report was restricted to describing the estimation of groundwater level changes. The relationship between the water table height and the water content of the plant root zone, while believed to be close, was not formally considered, nor is it considered in this report.

The 1987 report gave predictions of the likely changes in groundwater levels using a hydraulic model covering the Worton Rectory Farm area. This extended over the region underlain by gravel north and east of the River Thames from a westerly point near the confluence of the Evenlode as far south and east as Wolvercote, as shown in Fig 1.

The region included in the model was chosen as far as practicable to be hydrologically self-contained, with groundwater entering and leaving either through the bed of the River Thames, or through the cross-sections near the Evenlode, across the former course of the Cherwell, and in the Wolvercote area. Within this region, under natural pre-extraction conditions, the Worton Rectory main ditch and the Kingsbridge Brook were the main sink for water derived chiefly from the Thames by bank infiltration

The model predicted the changes in hydraulic head expected over the region under various possible extraction and after-use plans. The predictions depended on field information on:

- boundary conditions
- aquifer geometry
- hydraulic conductivity
- storage coefficient
- other sources and sinks
- initial heads.

In any modelling of groundwater flow, estimates of conditions around the boundary of the modelled area must be specified, as numerical values of either the flux across the boundary, or the head of water along it. In the 1987 report, boundary conditions were considered specified head except along a portion of the eastern boundary, which was taken to be a no-flow boundary. An array of boreholes was drilled to estimate the aquifer geometry. The datum of the aquifer base, the base of the alluvium and of major internal structural changes in the gravel were measured. Pumping and packer tests were used to estimate the hydraulic conductivity and storage coefficient of the aquifer. The information from these tests was supplemented by inferences from grain size analyses of gravel samples. Meteorological variables and soil properties were measured at West Mead to estimate evapotranspiration and recharge to the aquifer following rainfall. Initial heads for model runs were estimated by interpolation from the array of borehole measurements made at any particular date. This fieldwork is described in detail in the 1987 report and in Dixon *et al.*, 1989).

The likely effect on groundwater levels of particular patterns of extraction and after-use was simulated by altering the numerical values of the aquifer properties as they appeared in the model. For example, the effect of a seal was modelled by setting the hydraulic conductivity of the aquifer to zero in the appropriate locations.

The main conclusions of the modelling were that there was a short term risk of significant drawdown below the Meads under dry working, and longer term flooding under some after-use strategies. In view of these predictions, planning consent for extraction was granted to the operator ARC in 1984 with a proviso that the groundwater levels below the Meads should not be altered so as to threaten the "survival and propagation of species". Implicit in the planning consent was the need for hydrological investigation before and during extraction. In autumn 1988 ARC therefore approached IH to continue their investigation into the extraction phase. Monitoring and modelling would be carried out by IH, who would report to ARC and NCC. Water levels would be monitored often enough to give adequate warning of excessive drawdowns. The modelling should predict, in advance of monitoring, the likely drawdown under different methods of working the pit. If necessary, ARC would undertake engineering works to maintain water levels. In the light of the hydrological predictions of the 1987 report changes in the proposed pattern of working were made. Under the new proposals extraction would begin in the Stage 1 area shown in Fig 1, moving on to Stage 2 after about two years. This scheme would provide information from Stage 1 operations to indicate the likely pattern of drawdowns during the more critical Stage 2 extraction closer to the Meads. A washing plant would be located outside the floodplain and extraction extended to Stages 3 and 4 at some time in the future according to demand for sand and gravel.

2. Monitoring and modelling 1989-1990 - General

2.1. INTRODUCTION

In any environmental impact study, monitoring and modelling play a dual role. In the present context, the purpose of modelling is to predict groundwater levels using existing information, including the results of monitoring, assuming certain patterns of future working of the pit. Monitoring results provide new information on the performance of the model, which may be used to refine it, and give new starting points for model runs. Ideally, monitored results correspond exactly with predictions from the model and monitoring becomes redundant. In practice no system is well enough understood to dispense with monitoring.

Equally, if no predictions are required, monitoring without modelling may be considered. However, without a model, monitoring is of no predictive value for management decisions, simply providing a record of events. Of course there may be a range of models of varying complexity which may be used with a monitoring scheme. At the simplest level, the model may be no more than an operator's informal opinion based on his experience. This may be quite adequate in some circumstances, but we are concerned here with the use of a model based on the reasonably well understood hydraulic behaviour of groundwater in aquifers.

2.2 MONITORING

In anticipation of a starting date for extraction of Stage 1 of May 1989, the network of groundwater and surface water monitoring sites was extended in October 1988 and the frequency of monitoring increased to give more information on the hydrological conditions preceding extraction.

Groundwater and surface water heads were monitored twice weekly over most of 1989 and 1990 initially at the locations indicated in Fig 2.1a & 2.1b. Measurements from this network of sites near the extraction area were augmented by more widely distributed data monitored approximately 3-monthly, as shown in Fig 2.2a & 2.2b. These extra sites cover all the modelled area and provide some verification of model predictions and boundary condition assumptions. The network consists of surface water sites, in most cases a stake in a pool or ditch, and groundwater sites, usually a cased 2-inch diameter well installed to the aquifer base.

Surface and groundwater levels were measured by hand from a reference datum, usually the top of a stake or well casing. Boreholes were removed when they became a hindrance to the operator. Additional wells were installed on Oxey Mead when Stage 2 extraction started, to give more detailed information during a period when large changes in groundwater levels were expected. This was preceded by a ground conductivity survey of Oxey Mead. The sampling frequency for some boreholes on Pixey Mead was also increased to twice weekly during Stage 2 working.

Automatic loggers were installed on some wells to give semi-continuous measurements of water levels. In April 1990 a flume was constructed at the outlet of the first settling pond built in the worked out Stage 1 area, with an automatic recorder to measure output to the Worton Rectory main ditch, and indirectly the pumping rate from Stage 2 into the settling pond.

The hydraulic characteristics of Kingsbridge Brook and Worton Rectory main ditch were estimated from current meterings. This information is required for a full description of surface water flow in the model area.

There was no further fieldwork to improve estimates of aquifer geometry or properties, but measurement of the soil moisture content were made weekly on West Mead to give estimates of recharge to groundwater and loss through evaporation.

2.3 MODELLING

The 2-d finite element model used for the 1987 report has been taken as a basis for modelling the effects of extraction during 1989-90, with the following changes:

- The grid has been altered to accommodate for the new extraction plan
- The edge of the area underlain by gravel to the north and east of the Thames is treated as a no-flow boundary. Along this boundary there may be some inflow of water horizontally through the soil, but this is not significant compared with water flowing out of the Thames, or through the remaining head boundaries near the Evenlode, across the former course of the Cherwell and at Wolvercote.

Head values at boundaries other than the Thames are not precisely known in practice, and this must allowed for in interpreting results. Values used are interpolated from water levels monitored at 3-monthly intervals.

Surface water flowing across model boundaries other than the Thames is implicitly accounted for in the treatment of the ditch system in the model. The head of water in the ditch system is assumed known and invariant in the short term. Internal interactions between groundwater and ditches and streams are treated by allowing a flux proportional to the head difference between their levels. The constant of proportionality (bed permeability) is set to 2.35 generally, a calibrated value taken from the 1987 report. Higher values are used for some ditch sections.

The contribution of infiltration of rainwater to groundwater levels is computed as in the 1987 model as any excess over evapotranspiration.

The treatment of the interaction between surface and groundwater in the model remains incomplete, in that a proper water balance is not computed. The present assumption, which remains unchanged from the original study, is of a fixed head within the ditch system. Water entering ditches from groundwater is assumed to be immediately lost downstream, while water lost to groundwater is immediately replaced by surface flow. It would be preferable to include a dynamic surface water component to the model, describing flow along ditches in terms of head differences and a measure of the resistance of the ditch bed to flow. Some of the data needed to formulate such a model have been collected, but the expense of routine monitoring of surface water flows proved prohibitive. In a ditch system which is seasonally weed-choked, the submodel resistance parameters are time varying, and their estimation is a research topic in its own right. The effect of the present assumptions is to make groundwater predictions which are above and below ditch levels too high and too low respectively. Improvements on these assumptions are being investigated, but treatment of surface water flow is likely to remain unsatisfactory.

The representation of rainfall recharge and evapotranspiration remains incomplete, but sufficient information is available to improve this part of the model. The effect of such improvement is not expected to affect significantly predictions of groundwater levels.

3. Monitoring and modelling 1989-1990 - Extraction

3.1 STAGE 1 - MONITORING

Stage 1 was worked from the north-west corner, starting on 16 May 1989. A trench some 30 m wide was excavated to the base of the gravel along the western edge of the area. Groundwater flowing into the pit was pumped to adjacent ditches. This resulted in a rapid decline in groundwater levels in nearby boreholes and a progressive fall in the water level in Long Pond, until by June 1 it was almost dry. This had not been predictable with certainty because the bed permeability of the pond had not been fully investigated. To overcome these problems, excess water from the pit was redirected into Long Pond from June 1. As an additional protective measure, sealing of the western edge of the trench with alluvium began on June 20. These two operations led to stabilisation of water levels west of the pit, and a recovery in the boreholes closest to Long Pond. As excavation of the trench moved along the southern boundary of Stage 1 in mid to late summer, drawdowns in the area between Stage 1 and the A40 increased, with a fall in water level extending to Oxey Mead. During this period water was pumped from the pit to Worton Rectory main drain. Variations in the location and operation of the pump, the irregular patterns of sealing and pit-face extension account for some fluctuation in water levels in boreholes. The lowest water levels in those boreholes close to the southern edge of the pit were recorded as the exposed pitface moved past. Water levels slowly recovered over the autumn and by late November were similar in all unworked areas to those during the previous winter.

The effect of extraction on groundwater levels as indicated by monitoring is demonstrated in two sequences of figures. Figures 3.1a to 3.1g show the approximate extent of working of Stage 1, and the location of the seal, with groundwater contours on a succession of dates through the summer of 1989. Figures 3.1h to 3.1i give time series of water levels at a selection of wells over the whole year. The contour diagrams show the extension of the region of drawdown around the pit during June, with the recovery in water levels behind the seal as it extends along the west and south edges of the pit. Figure 3.1h shows water levels in four wells to the west and south-west of Stage 1. The rapid fall in water levels in late May is evident, followed by recovery after sealing. The effect of pumping to Long Pond is also apparent at well WR17. The large fluctuations in December are due to the beginning of working Stage 2, followed by flooding at the end of the year. Figure 3.1i shows in June the west to east divergence in water levels along a line of wells south of Stage 1. As the summer progresses the divergence disappears, and the most westerly well recovers soonest.

Water levels as far as Oxey Mead fell below levels recorded from 1984-86. Although summer 1989 was dry it is unlikely that the water table in the absence of extraction would have been below 57.4 m at Oxey Mead. This compares with the 57.0 m measured.

3.2 STAGE 2 - MONITORING

Working Stage 2 followed a similar pattern to extraction of Stage 1, with the excavation of a trench along the western, then southern boundaries of the worked area. However, the trench was lined on its outer side by Oxford Clay from the start and was dewatered by pumping to a settling pond in the worked-out area of Stage 1. Digging started in November 1989, but was interrupted by flooding until March 1990. When extraction began again in the spring, the presence of a short length of exposed outer pit face led to significant drawdowns below Oxey Mead, extending south of Wolvercote Millstream to Pixey Mead. There was recovery following sealing, and the maximum drawdown was always closest to the unsealed section of outer pit face. By June 1990 water levels below Oxey Mead were as much as 1.5 m below normal summer levels. This was of sufficient concern to prompt the construction of a recharge ditch along the north side of the A40. This raised water levels below the western end of Oxey Mead by 50 cm to 1 m over a 2 week period. The recovery continued as the seal moved eastwards. In mid-summer, water levels below the eastern part of Oxey Mead continued to fall as the exposed face moved east. The first phase of extraction of Stage 2 finished in August 1990 with the trench and seal extending right along the southern edge and some 100 m up the eastern edge of the pit. Following the last phase of sealing th e south eastern corner of the pit, the water level below the eastern end of Oxey Mead rose 1 m in 2 weeks, and water levels generally below Oxey Mead were then some 50 cm below normal summer levels.

The features described are indicated in the contour plots Figs 3.2a to 3.2f and time series Figs 3.2g to 3.2i. The recovery in water levels in the western part of Oxey Mead following the excavation of a recharge ditch is apparent from Figs 3.2a and 3.2b, and the effectiveness of the seal is clearly demonstrated from the sequence of contour maps. Figure 3.2g shows water levels in four wells situated west and south-west of Stage 1, nearest the recharge ditch. Its rapid influence on water levels after June 20th is evident. the gradual increase prior to this is due to sealing. Figure 3.2h includes four more easterly wells. These show the progressively later recovery due to sealing. The most easterly wells are PX67A and PX9PVC, which show almost no response to the recharge ditch, but a sharp relatively late increase in water levels following sealing. Finally, Fig 3.2i shows four wells some distance south of Stage 2. PX13, nearest the river and most influenced by it, shows little effect of the extraction. PX14 shows separate effects of the recharge ditch (June) and later sealing (July-August). This well is close to Wolvercote Millstream, which is not in hydraulic continuity with groundwater.

The drop in water levels in late August shown by many wells is due to pumping a triangular piece of stripped ground just west of Yarnton track, and north of the A40.

3.3 STAGE 1 - MODELLING

During the extraction of Stage 1, changes in head in response to gravel removal, sealing and pumping were computed by modelling. The aim was to simulate the measured changes in groundwater levels at surrounding boreholes, and to recalibrate the 1987 model where necessary. The model was run using some simplifying assumptions about the recirculation of water pumped to ditches or Long Pond. Ideally modelling of this circulation requires accurate knowledge of the bed permeability or a direct measure of seepage through the stream bed and also of the volume of water being pumped. Stage 1 extraction was modelling from 16 May 1989, using initial heads interpolated from the full array of groundwater monitoring points. Simulated water levels are contoured in Figs 3.3a to 3.3g for dates corresponding to those for which measured heads are plotted in Figs 3.1a to 3.1g. The two sets of figures should therefore be directly comparable. The simulated contours are more complete because there are not limited by the constraint of sparse data. The model tends to perform poorly over the extreme north west corner of the local area (which is not of primary importance), but otherwise captures the changes in head during working reasonably well. The worst simulations are for August 18. The model simulations are quite sensitive to the precise locations of the seal and extracted trench. These are to some extent schematic and only roughly estimated for any given date, and it is likely that the approximation for August 18 is poor.

3.4 STAGE 2 - MODELLING

The model could not be run during early 1990 because of flooding of the Worton Rectory Farm area. Modelling Stage 2 began on May 14, the first date at which data over the whole model area were available. By this time the western edge of Stage 2 had been excavated and sealed on its outer edge with Oxford Clay bulldozed from the aquifer base. The model was used to simulate changing heads as extraction, sealing and the construction of a recharge ditch proceeded along the southern boundary of Stage 2. The simulation continued to the end of the present phase of working stage 2 when sealing and extraction had reached 100 m along the eastern edge adjacent to Kingsbridge Brook. Simulated heads are shown in Figs 3.4a to 3.4f, which may be compared with contours of measured data shown in Figs 3.2a to 3.2f. The simulations use a value for bed permeability of the recharge ditch an order of magnitude larger than for the remainder of the ditch system. A higher value is expected since the ditch was cut directly into gravel. Simulations are generally within 30 cm of measured groundwater levels in areas of particular interest, notably Oxey Mead. This suggests the parameters of the model are reasonably representative in this region, and other simulations given by the model will have similar accuracy.

4. Additional modelling

4.1 SEALING EASTERN EDGE OF STAGE 2

The first phase of extraction of Stage 2 is now complete, leaving a trench along the western and southern boundaries of the Stage 2 area, sealed with Oxford Clay on the outer side. About 200 m of the eastern edge has also been excavated and sealed partly with Oxford Clay and partly with alluvial material dredged from the adjacent Kingsbridge Brook. Working will later be extended northwards along the eastern boundary. It is of interest to know the likely effect of sealing along this stretch. With no seal, some drawdown below nearby fields to the east may be expected, but this may be of lesser concern if it does not extend below Pixey and Oxey Meads. Modelling results shown in Figs 4.1a and 4.1b show likely drawdowns with and without sealing of this eastern boundary during dry working of Stage 2. The natural water levels in the north eastern section of the mapped area are of the order of 58 m. Although there is significant drawdown in this area without sealing, this effect does not extendto Oxey Mead. However, nearby fields to the east of Stage 2 would be affected, possibly to the detriment of vegetation in the area.

4.2 RETROSPECTIVE ANALYSIS OF EFFECT OF SEALING STAGE 2

The Oxford Clay seal and recharge ditch were installed along the southern boundary of Stage 2 at some cost to the operator. The usefulness of these measures can be seen by running the model assuming neither seal nor recharge ditch to be present. Figures 4.2a to 4.2e show simulated drawdowns below Oxey and Pixey Meads from May 16 1990 with these assumptions. These five contour plots may be compared with Figs 3.2a to 3.2e and 3.4a to 3.4e. Even allowing for some uncertainty in model predictions there would almost certainly have been extensive drawdown of around 2 m below Oxey Mead for several months during the summer.

4.3 LONG TERM EFFECT OF SEALING STAGE 2

The extraction of gravel at Stages 1 and 2 and their sealing with Oxford Clay restricts the flow of groundwater from the west to a strip below Oxey Mead.

Water levels here may also now be influenced by the newly-dug ditch running north of the A40 and parallel to it. In future this may carry water redirected from Worton Rectory main ditch. Simulations of long term groundwater levels below Oxey Mead are contoured in Fig 4.3. In this figure groundwater is assumed to be in equilibrium with water in the ditch, that is, there is no net flux between groundwater and water in the ditch. Under these circumstances, the predicted water level below Oxey Mead in the region of 58.0 to 58.2 m is some 30 cm above that expected before extraction. However, the ditch penetrates the gravel aquifer and is in good hydraulic continuity with it. Because of this and the high hydraulic conductivity below Oxey Mead, the groundwater level will closely follow the ditch water level. This provides a means of controlling water levels below the Mead. Historically, heads below Oxey Mead have fallen to 57.5 m in summer. In principle this could be attained by excavating the new ditch a further 50 cm, and ensuring adequate drainage into Kingsbridge Brook.

5. Conclusions

1. The presence of an exposed unsealed face gave maximum drawdowns at Oxey Mead beyond those expected of some 40 cm in 1989 and 1.5 m in 1990. Because of the effectiveness of the seal once in place, the greatest drawdowns were only experienced for periods of a few weeks in summer. Drawdowns in both 1989 and 1990 were around 25 and 50 cm respectively below Oxey Mead for periods of several months.

2. While in operation, the recharge ditch constructed along the northern edge of the A40 was effective in partially restoring water levels. In the absence of a seal or recharge ditch, water levels below Oxey Mead would have been between 1.5 and 2.5 m below normal for most of the summer of 1990, with no significant recovery as long as pumping of the pit continued.

3. There is at present substantial drawdown to the north-east of the pit. This does not extend to any significant effect around the seal as far as south as Oxey Mead. However it will continue to exist as long as there is no seal in place along the north-eastern part of the Stage 2 area, and over an extended period may affect crops and other vegetation in the area.

4. In the longer term, assuming Stage 4 is extracted and sealed in much the same way as Stage 2, there will be a rise in water levels below Oxey Mead of some 30 cm above those experienced under natural conditions, assuming no further engineering works are undertaken. In the presence of the diverted Worton Rectory ditch this could be prevented subject to suitable control of the ditch level.

References

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Dixon, A.J., Bradford, R.B., Cooper, D.M., Reeve, C.E. and Tucker, D.K., 1989. A hydrogeological assessment of the impact of proposed sand and gravel extraction on an adjacent ecologically sensitive floodplain environment - A case study. Proc. 6th Extractive Industry Conference. Gaskarth and Lumsden (eds). Birmingham Univ.

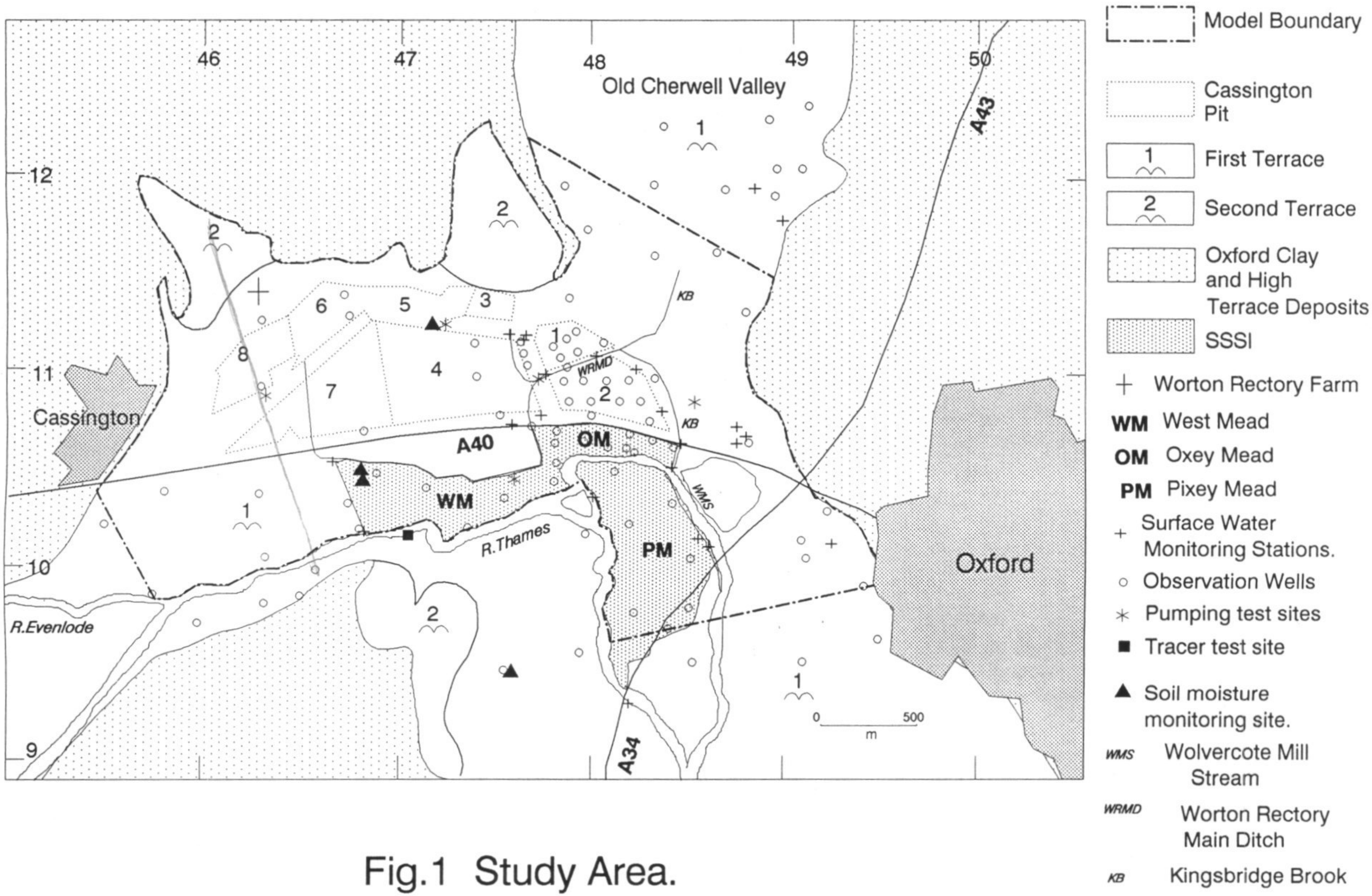
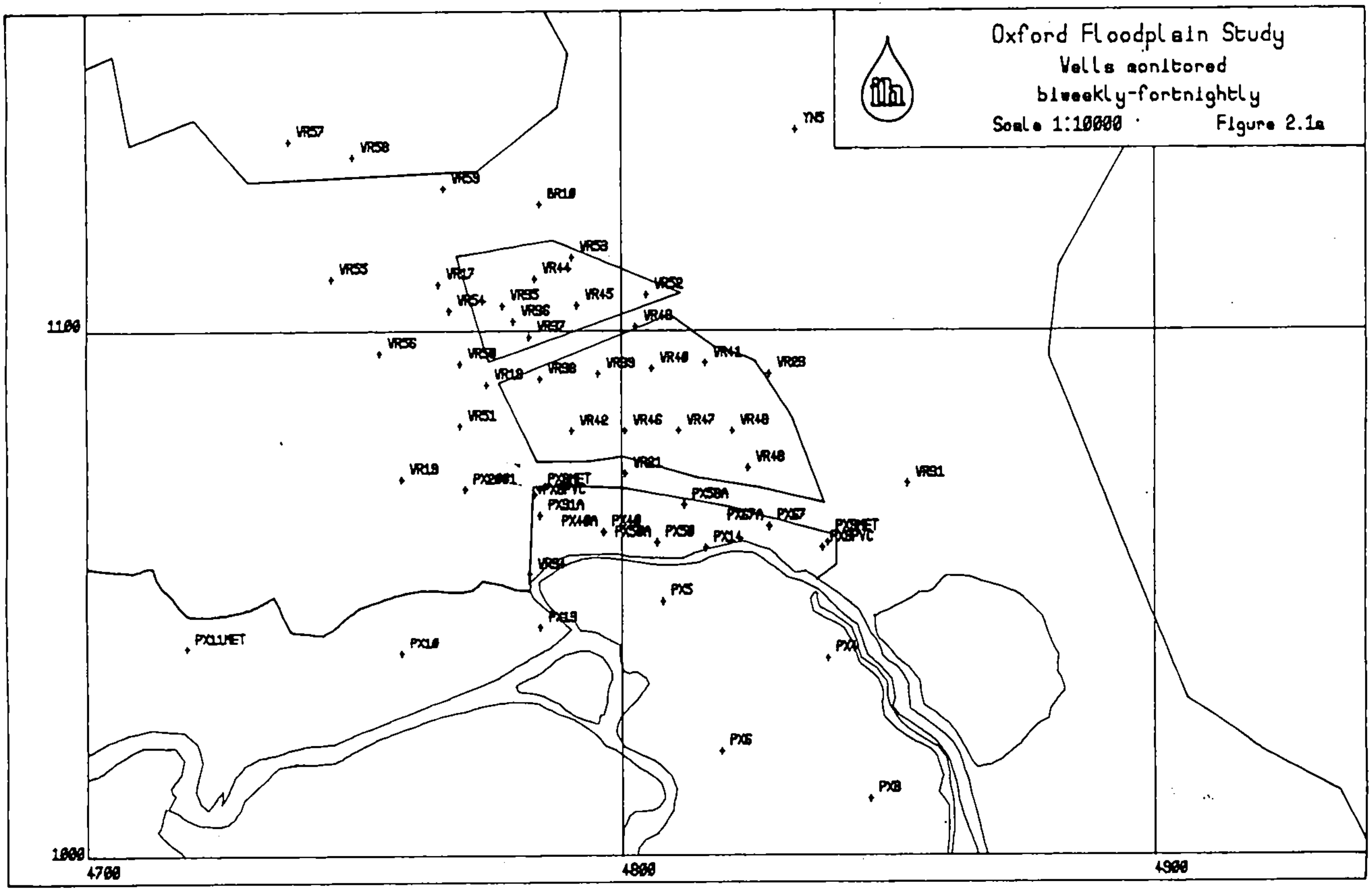


Fig.1 Study Area.



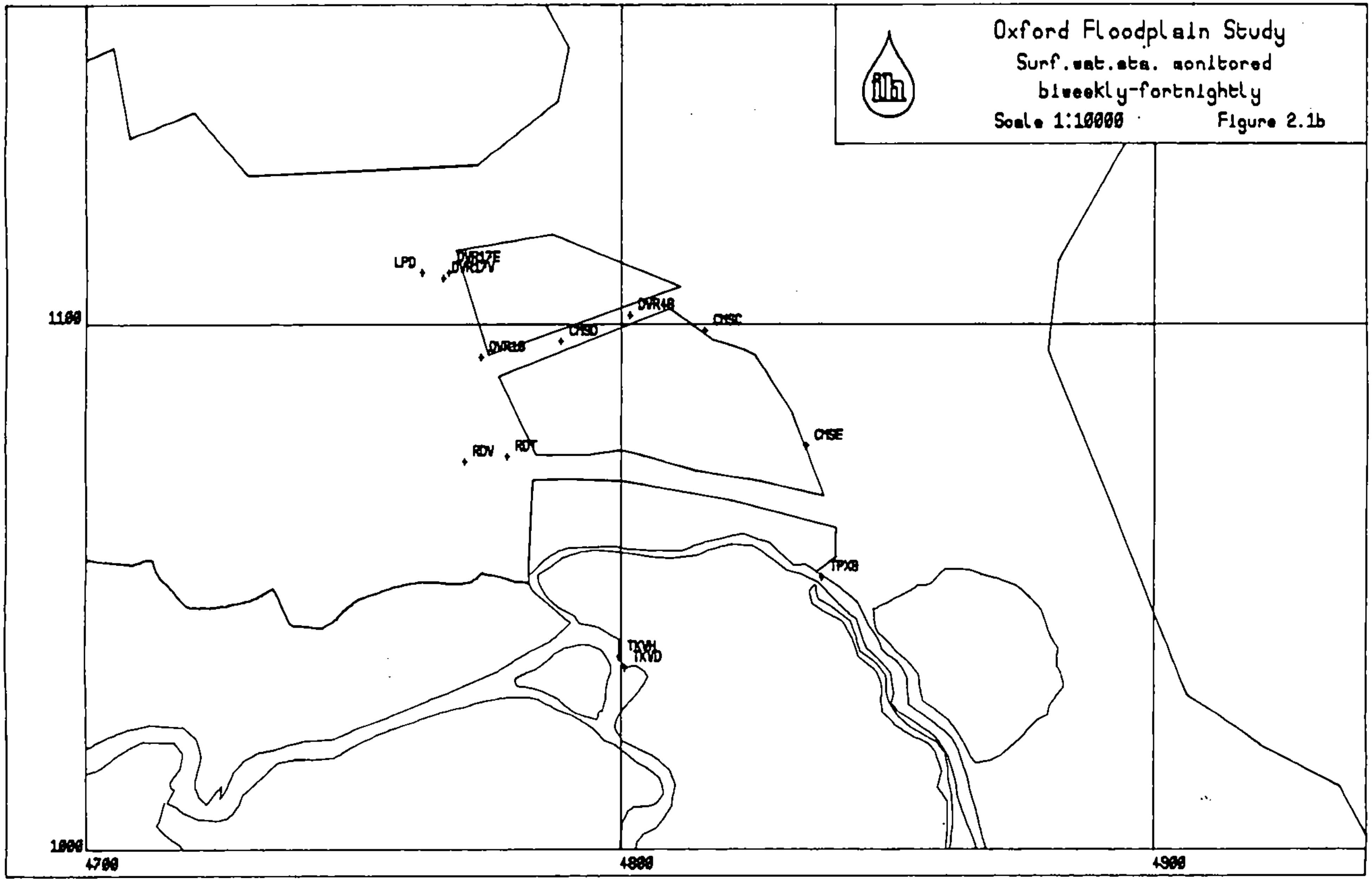
Oxford Floodplain Study

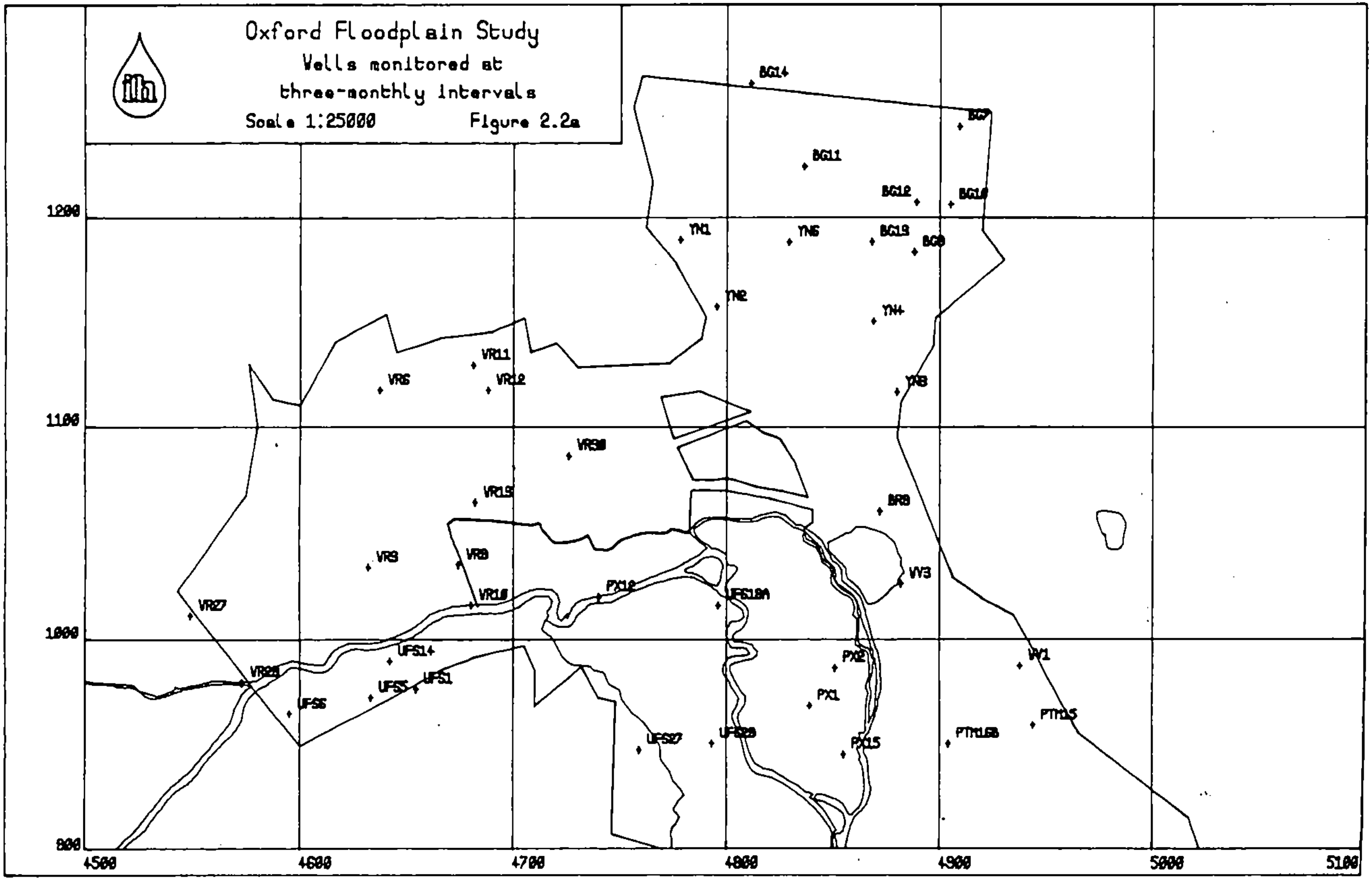
Wells monitored

biweekly-fortnightly

Scale 1:10000

Figure 2.1a


Oxford Floodplain Study
Surf.wat.sta. monitored
biweekly-fortnightly
Scale 1:10000
Figure 2.1b
LPD
DVR17E
DVR17V
DVR18
CMSD
DVR48
CMSC
CMSE
RDV
RDT
TPX8
TKVH
TKVD
1100
1000
4700
4800
4900



Oxford Floodplain Study
Wells monitored at
three-monthly intervals
Scale 1:25000
Figure 2.2a

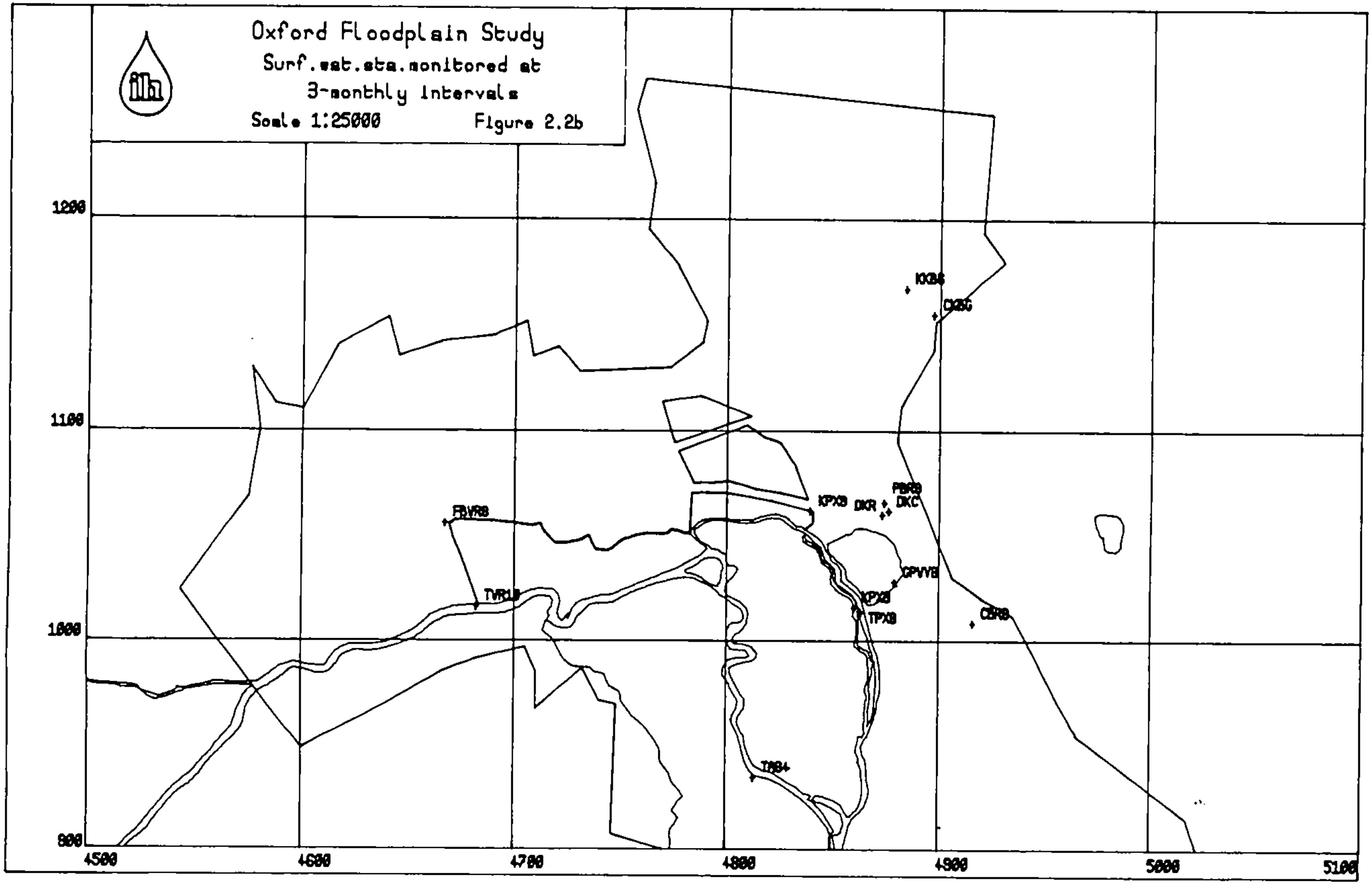

Oxford Floodplain Study
Surf.wat.sta.monitored at
3-monthly intervals
Scale 1:25000
Figure 2.2b
1200
1100
1000
900
4500
4600
4700
4800
4900
5000
5100
DKR
DKC

Fig.3.1.a

Cassington Pit Stage 1.

Measured groundwater levels-02.06.89.

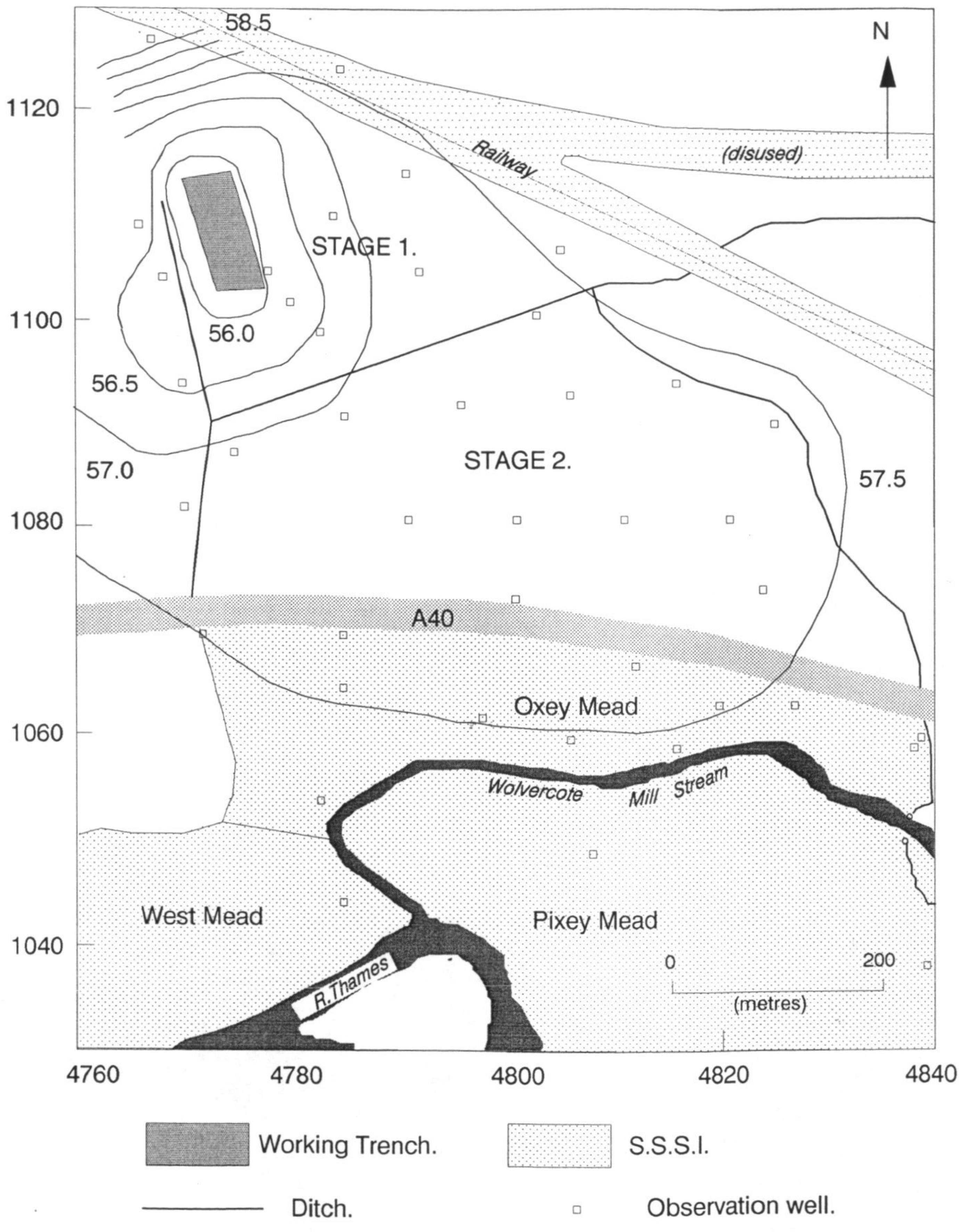


Fig.3.1.b

Cassington Pit Stage 1.

Measured groundwater levels-20.06.89.

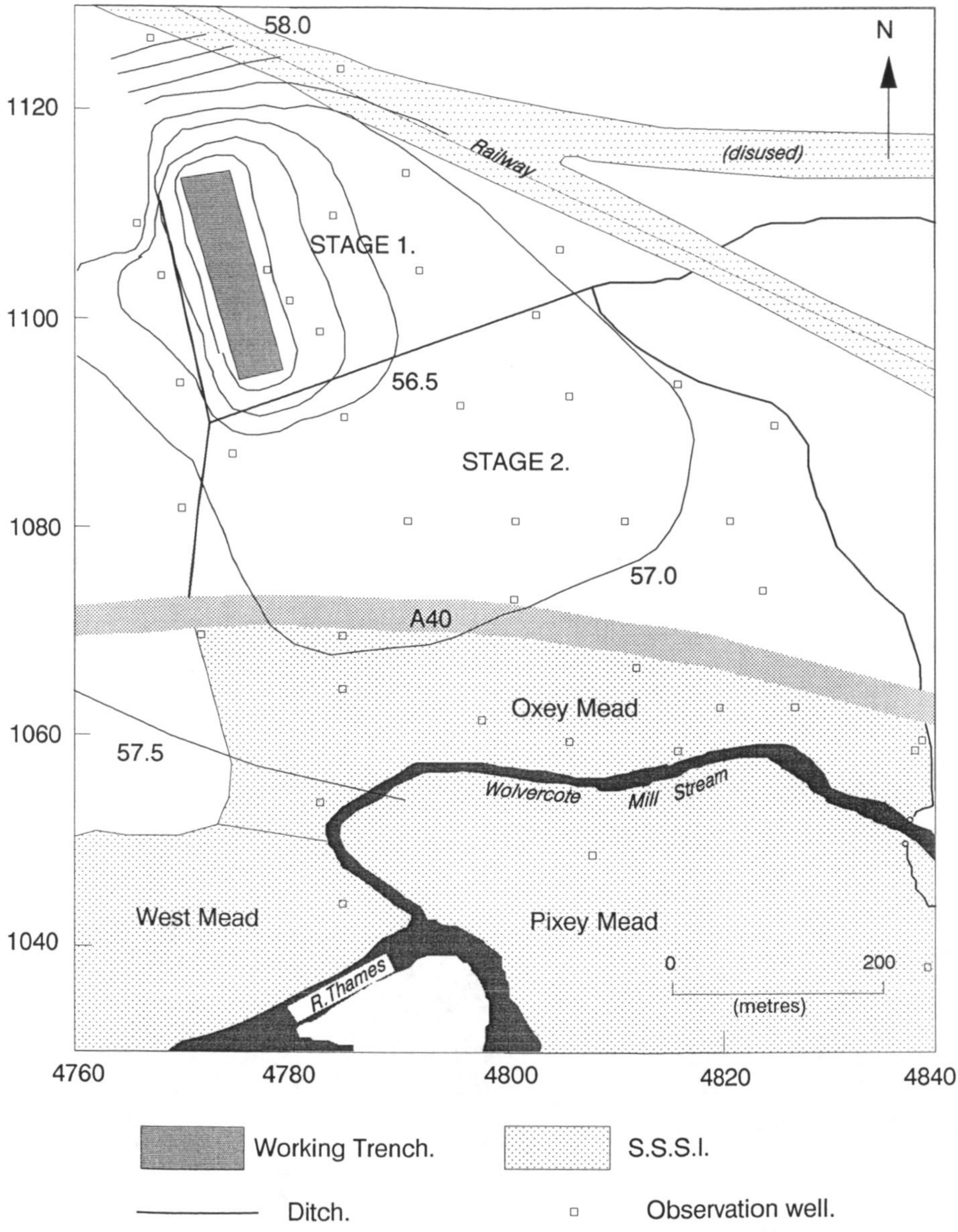


Fig.3.1.c Cassington Pit Stage 1.

Measured groundwater levels-27.06.89

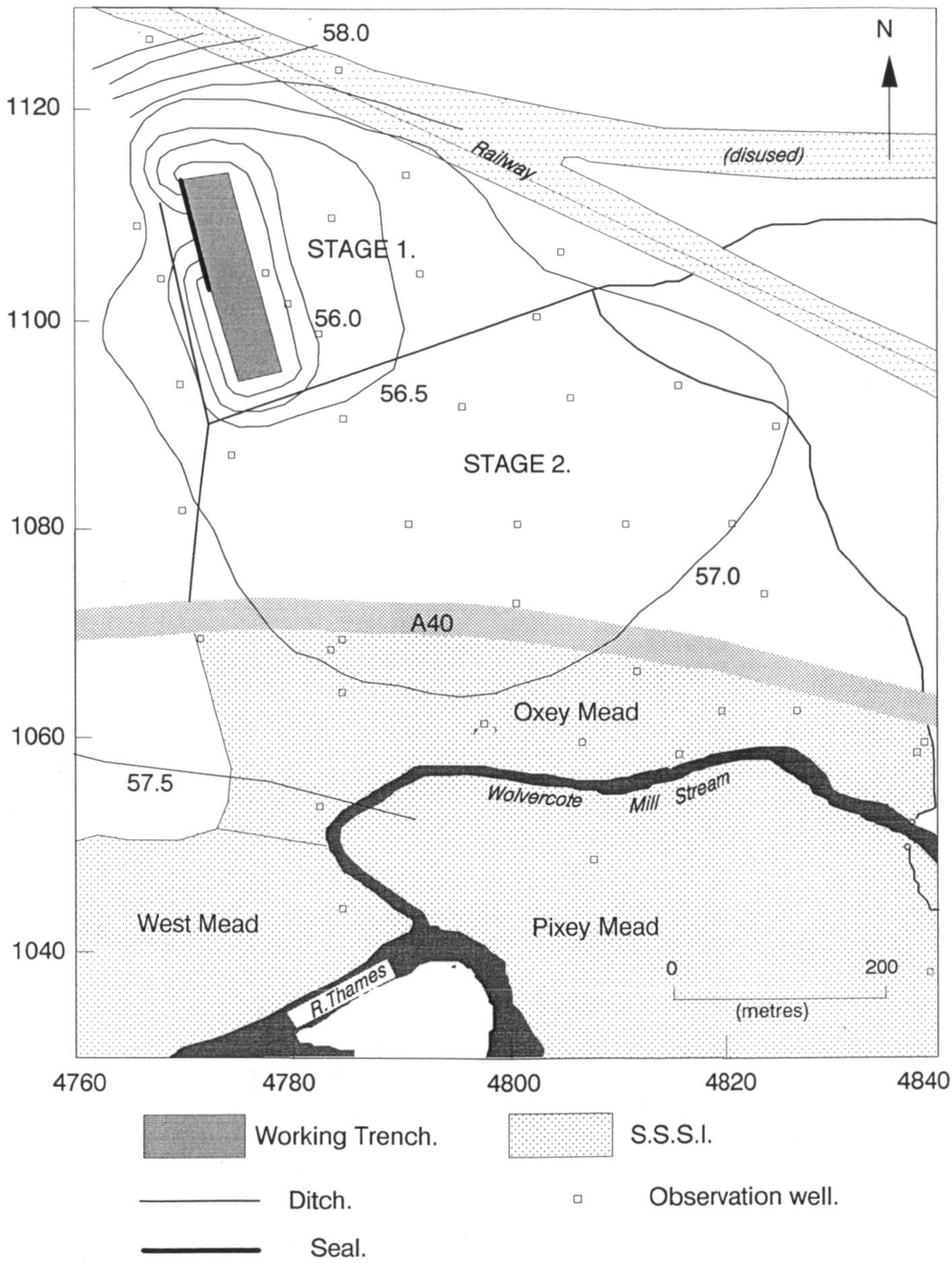


Fig.3.1.d

Cassington Pit Stage 1.

Measured groundwater levels-04.07.89.

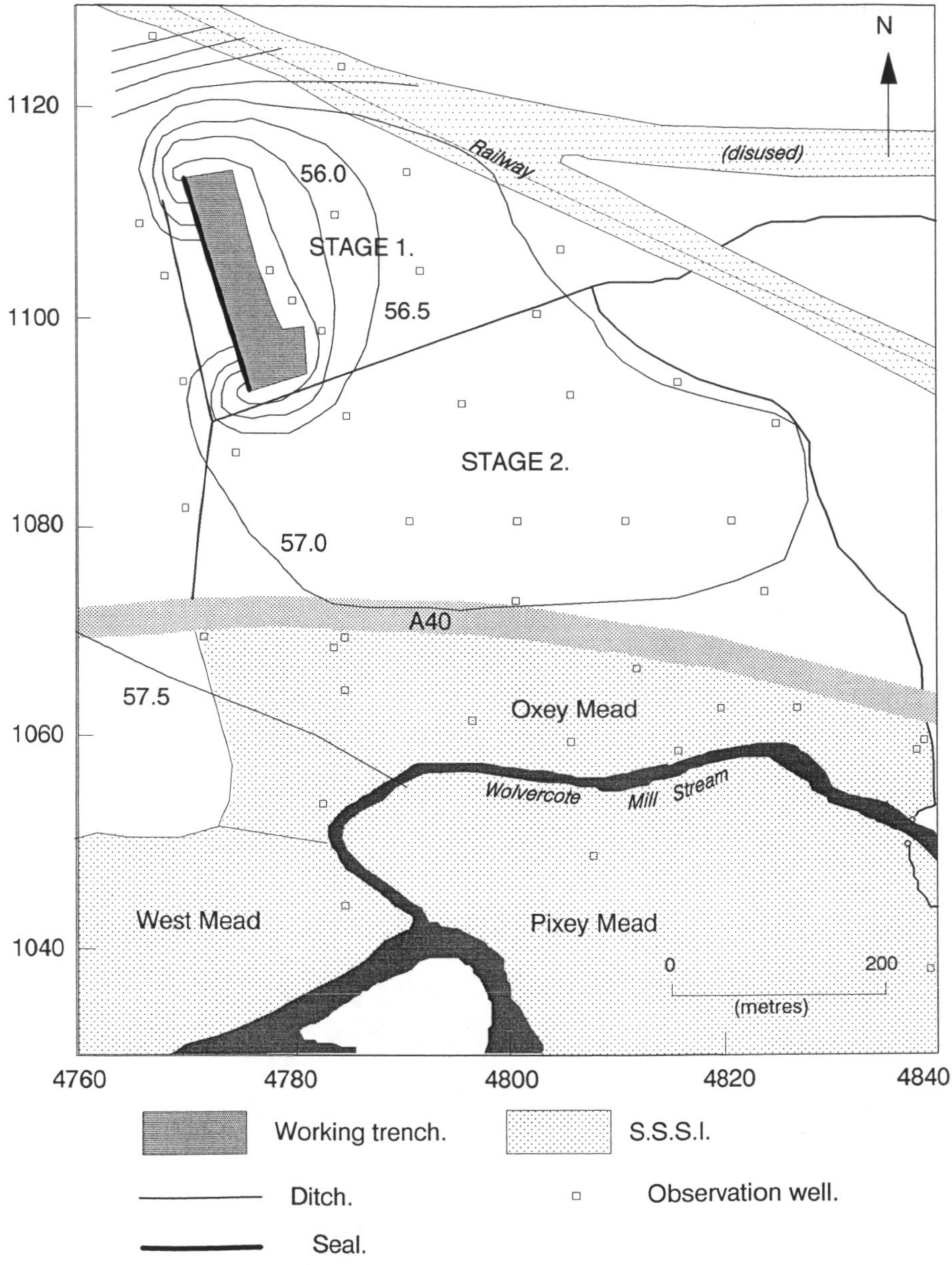


Fig.3.1.e Cassington Pit Stage 1.

Measured gronudwater levels-18.08.89.

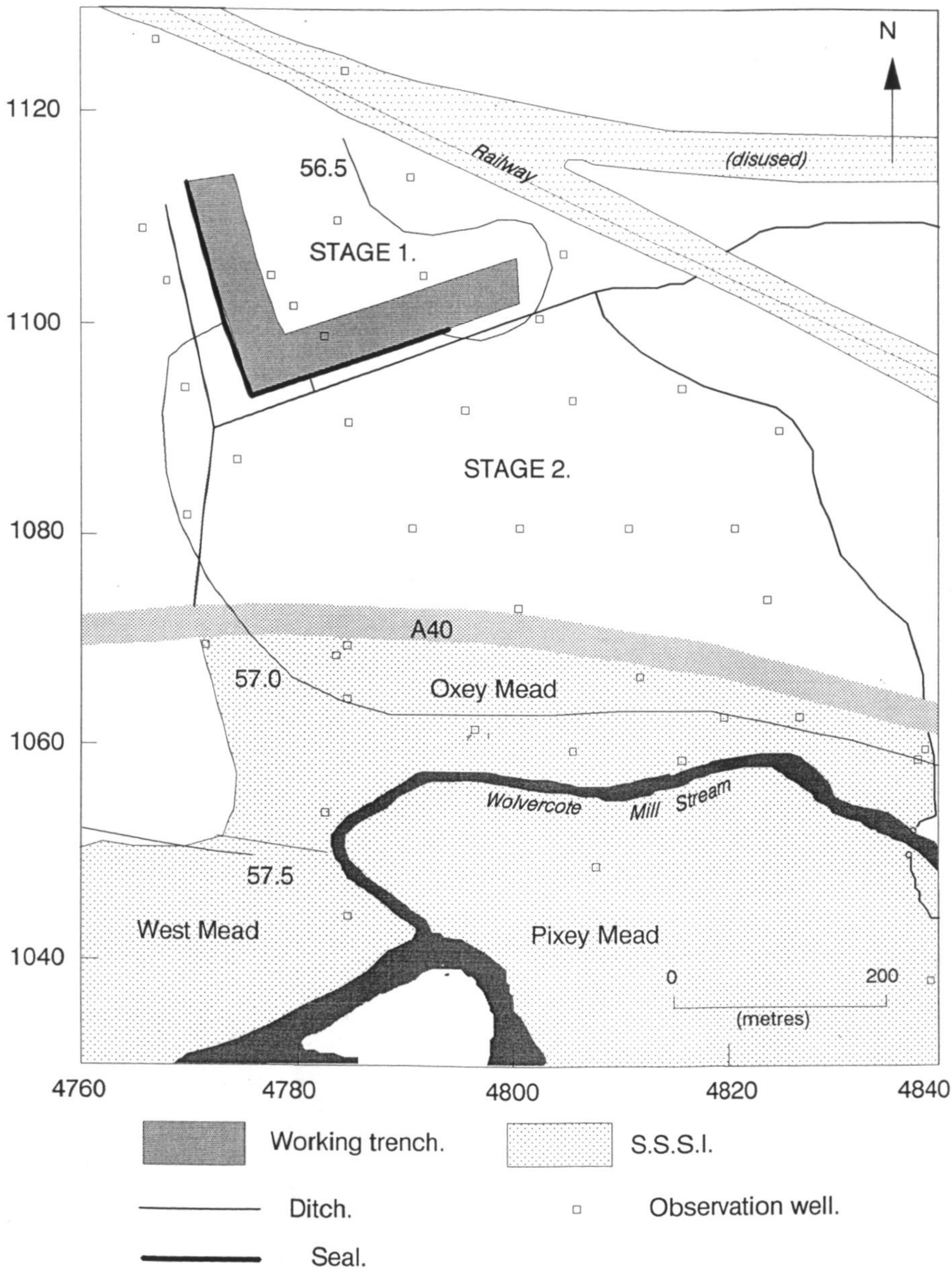


Fig.3.1.f Cassington Pit Stage 1.

Measured groundwater levels-03.10.89.

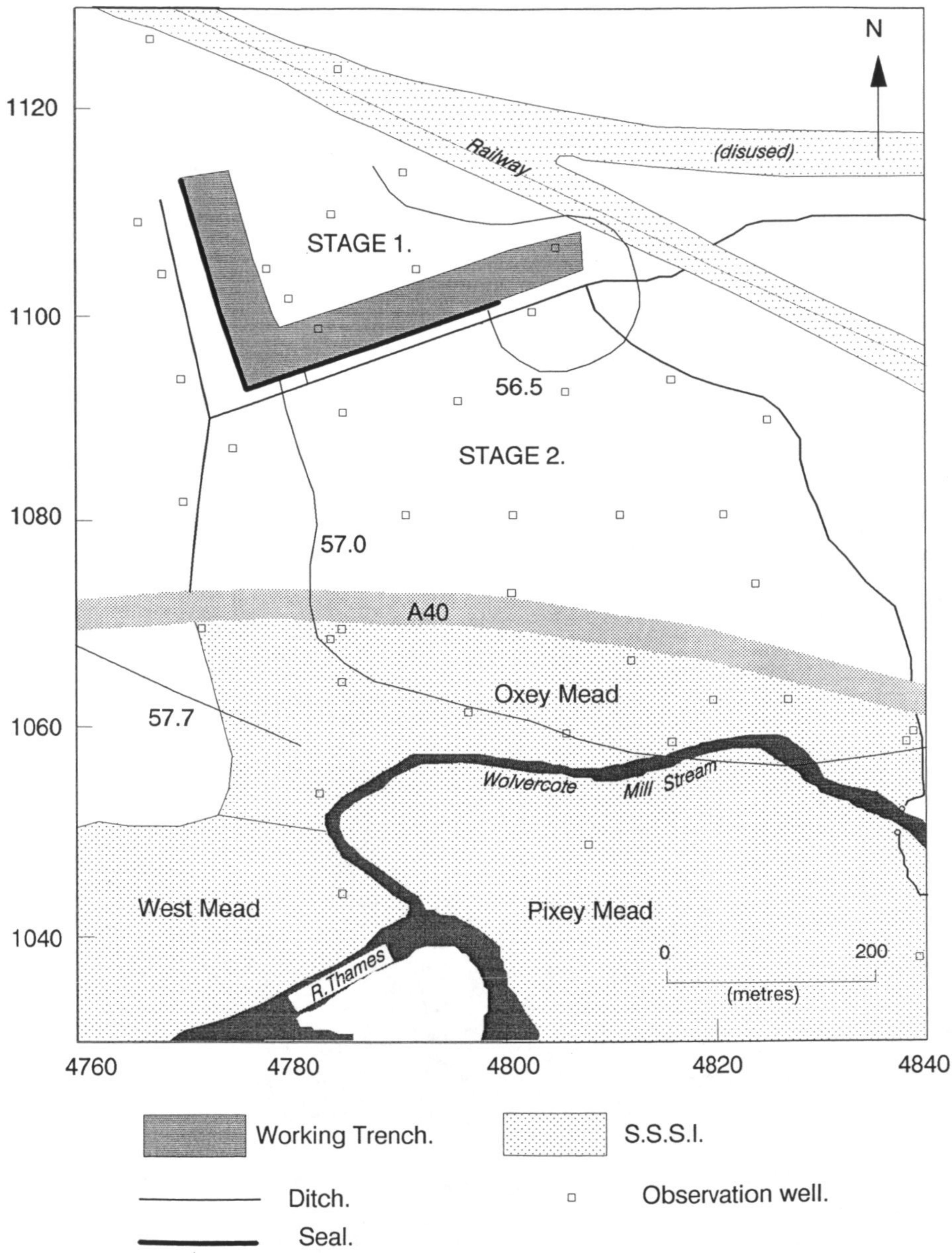
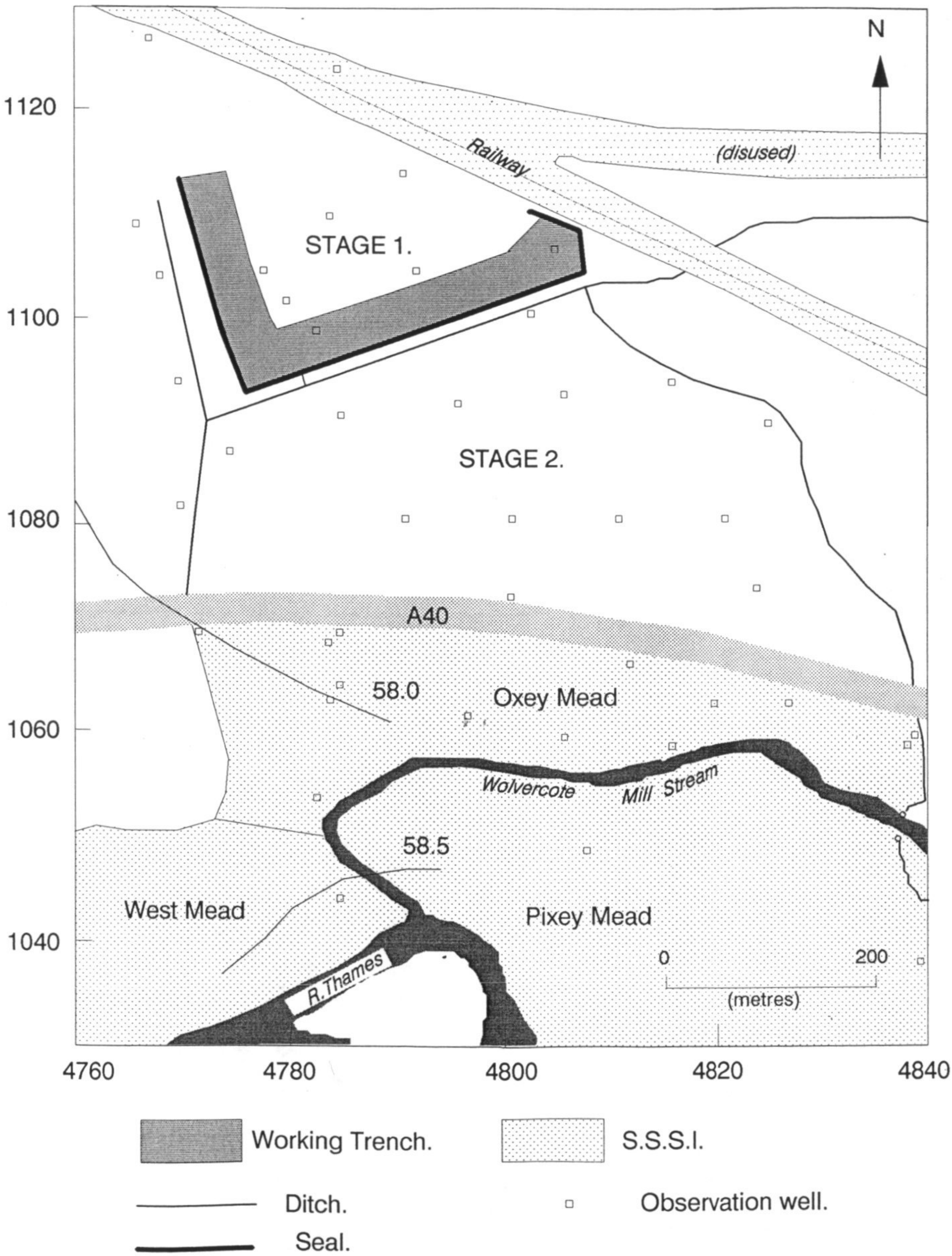
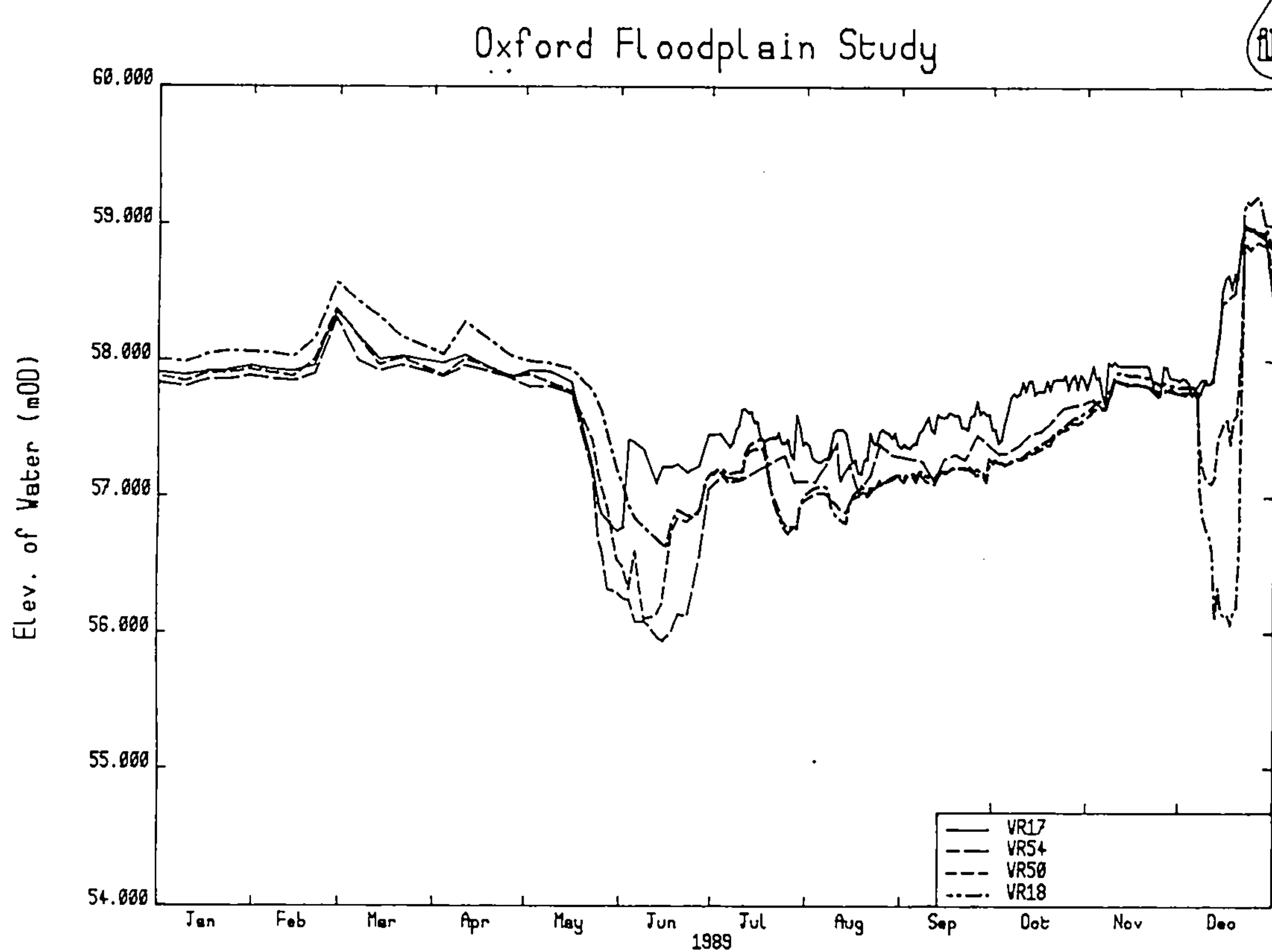


Fig.3.1.g

Cassington Pit Stage 1.

Measured groundwater levels-17.11.89.

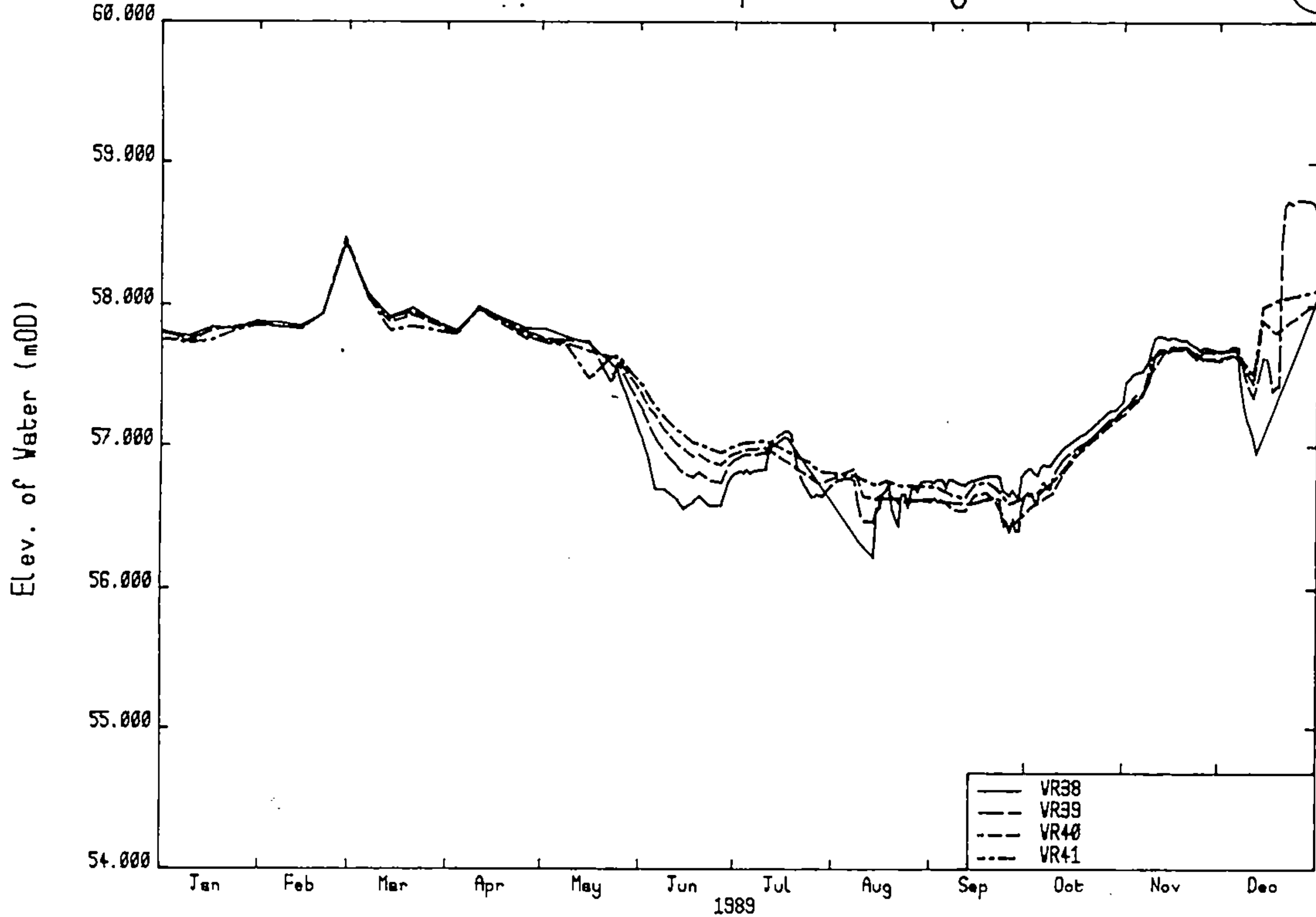




Hydrograph

Fig. 3.1h

Oxford Floodplain Study



Hydrograph

Fig. 3.11

Fig.3.2.a

Cassington Pit Stage 2.

Measured groundwater levels-20.06.90.

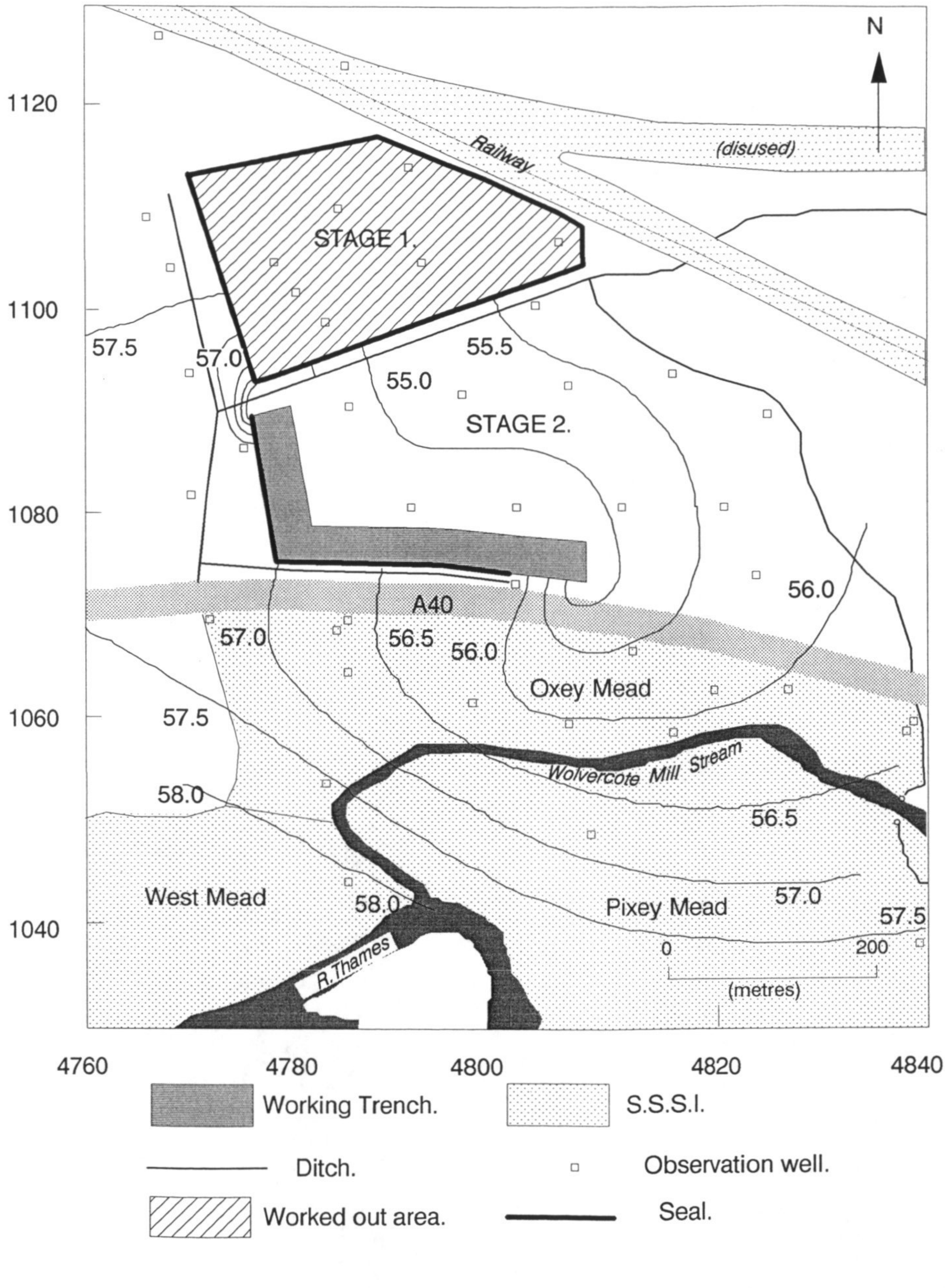


Fig.3.2.b

Cassington Pit Stage 2.

Measured groundwater levels-03.07.90.

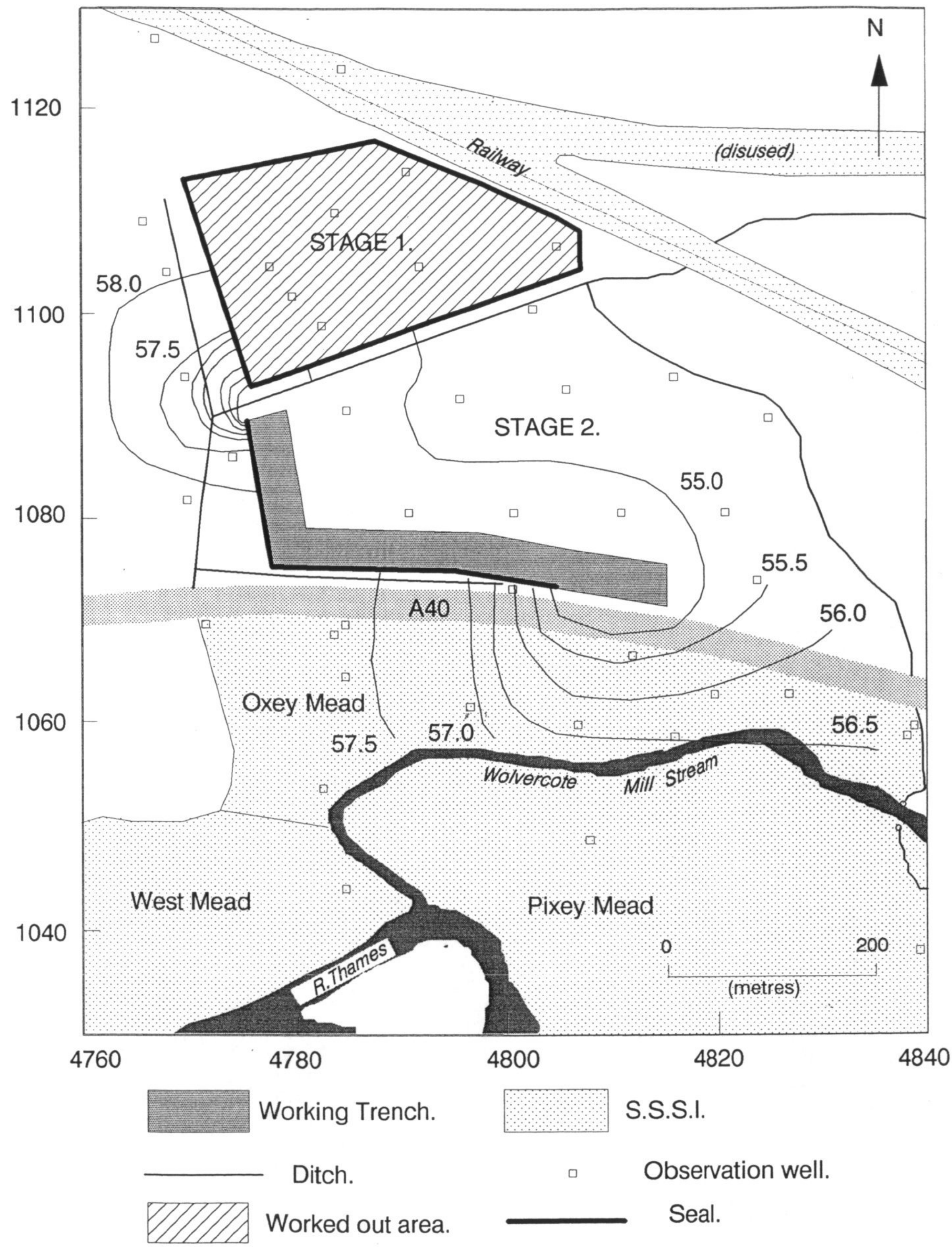


Fig.3.2.c

Cassington Pit Stage 2.

Measured groundwater levels-27.07.90.

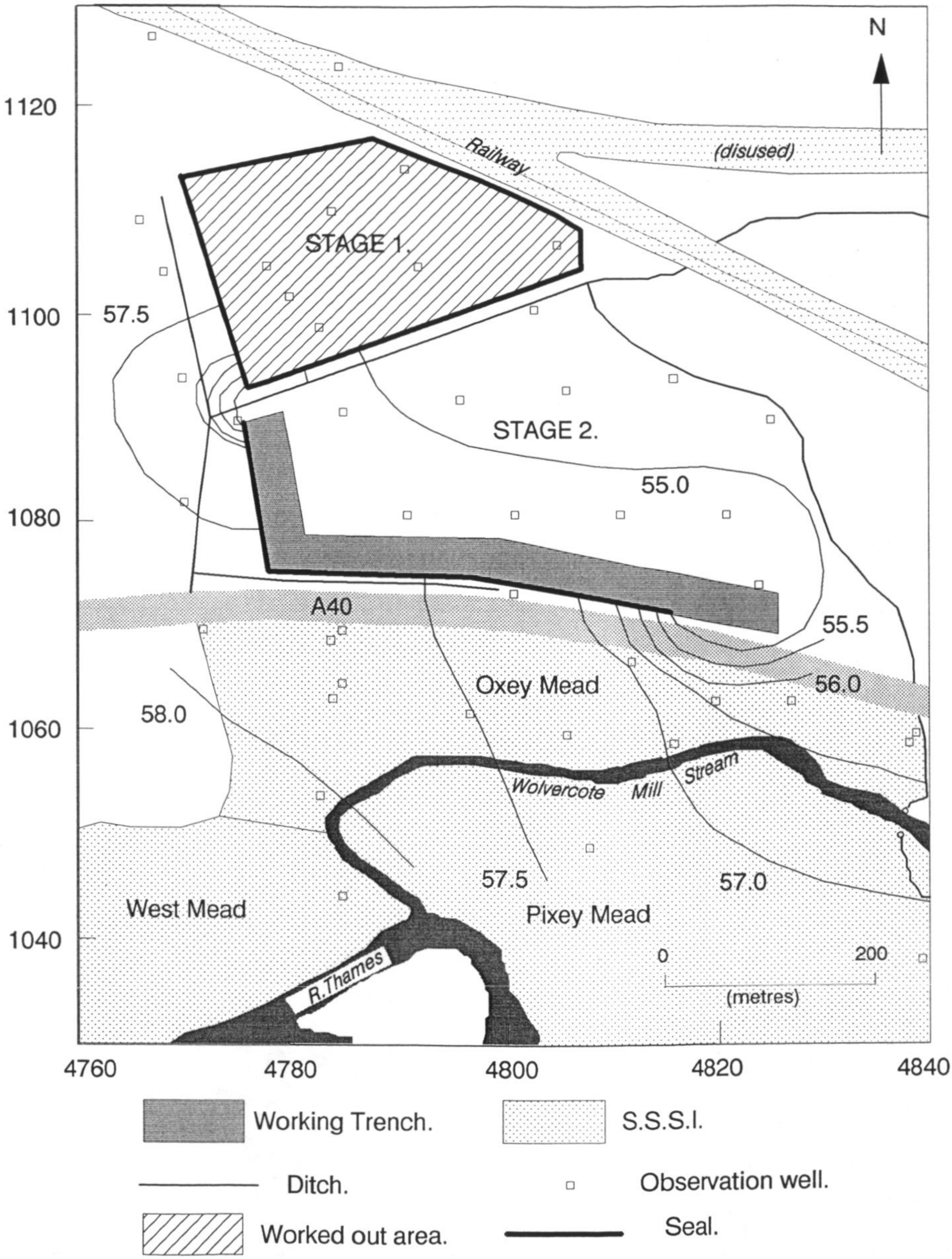


Fig.3.2.d

Cassington Pit Stage 2.

Measured groundwater levels-03.08.90.

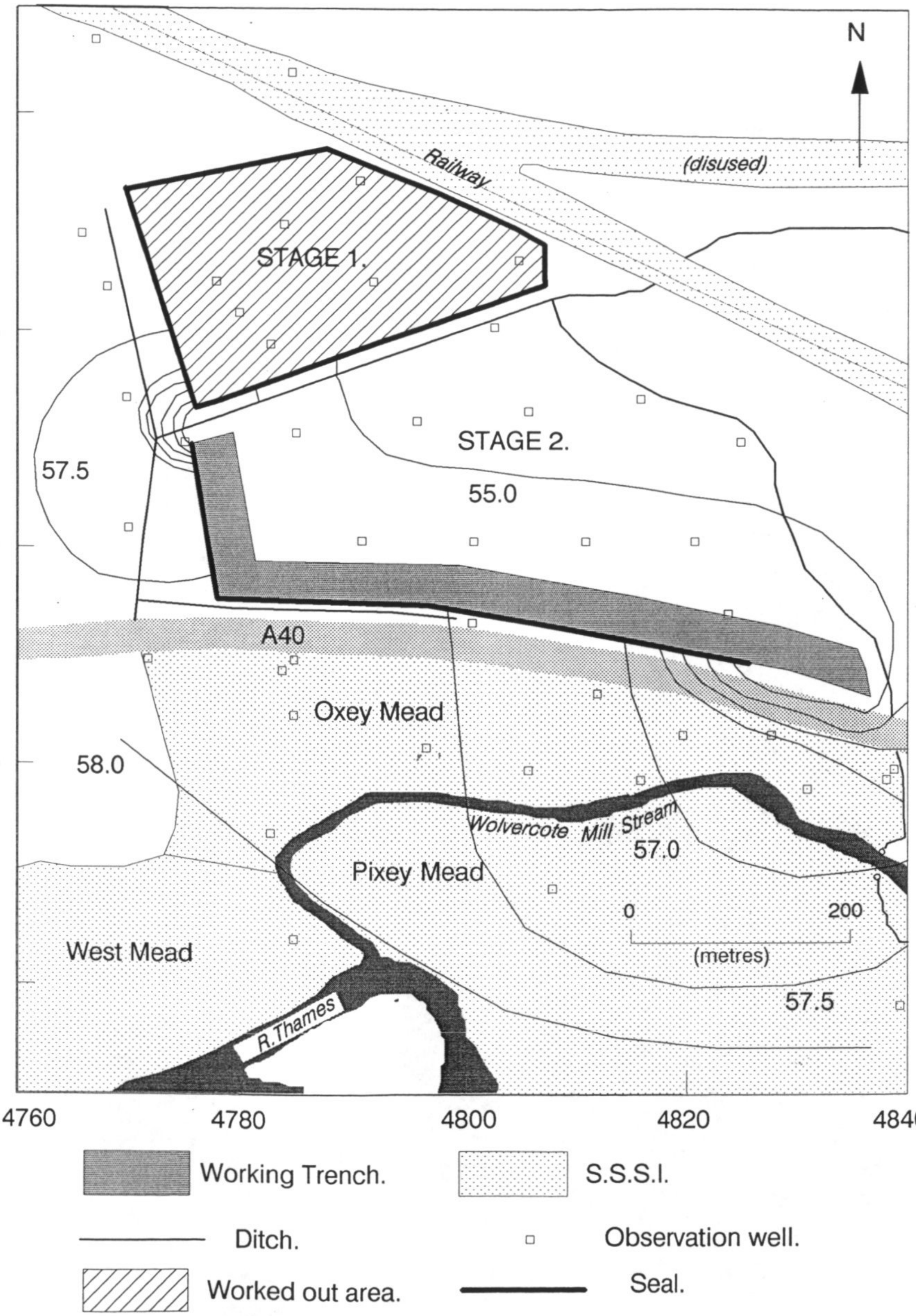


Fig.3.2.e

Cassington Pit Stage 2.

Measured groundwater levels-10.08.90.

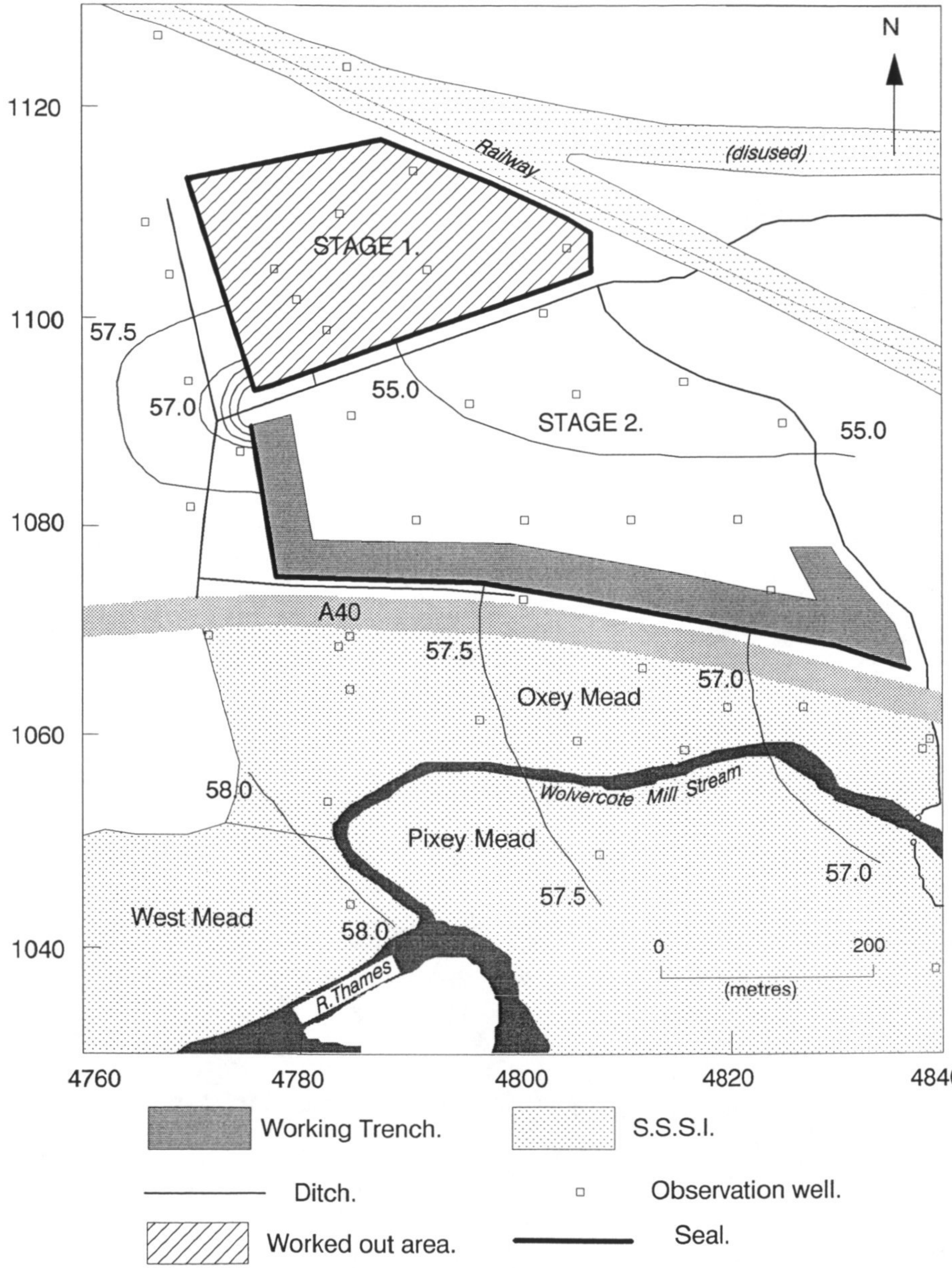
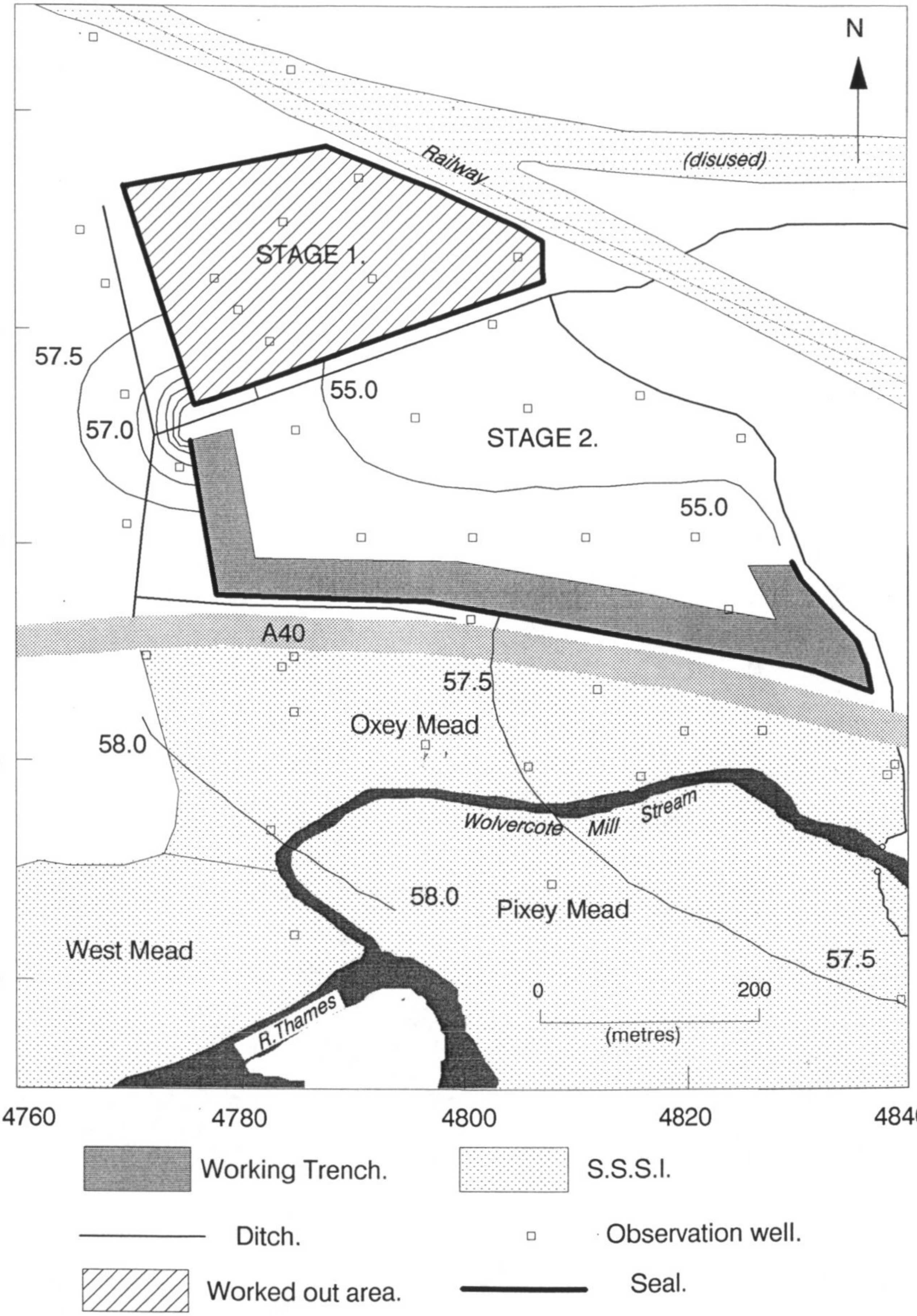


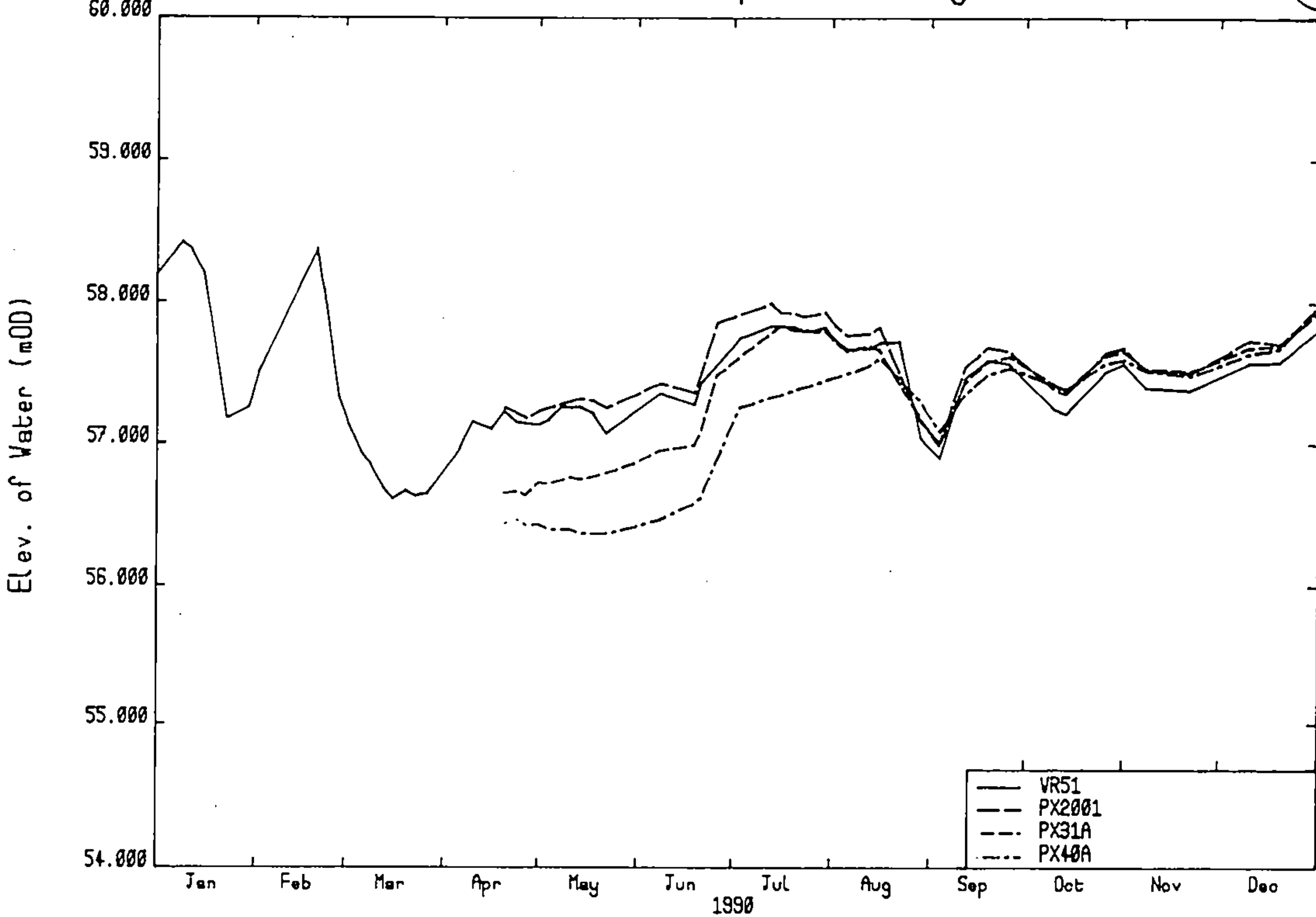
Fig.3.2.f

Cassington Pit Stage 2.

Measured groundwater levels-20.08.90.

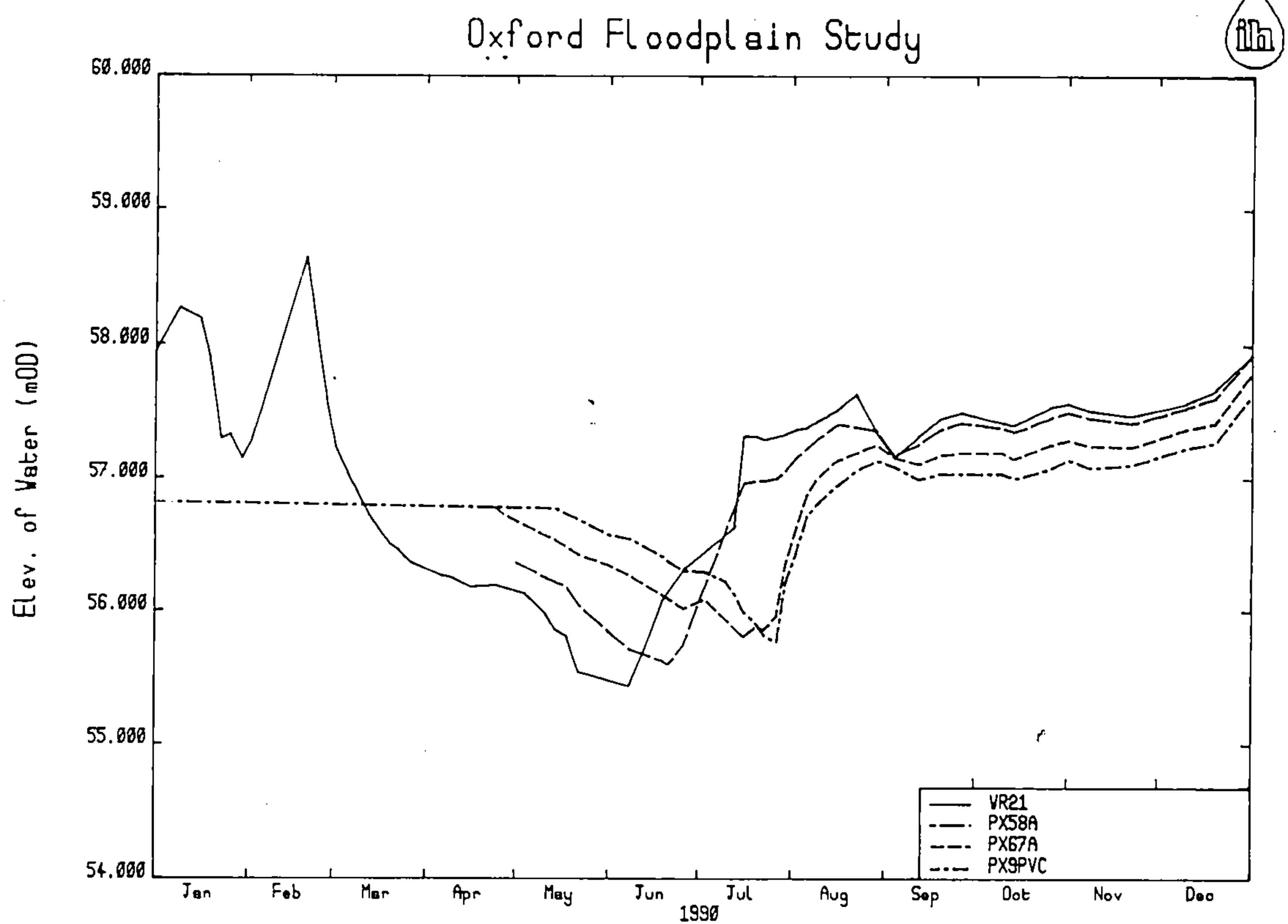


Oxford Floodplain Study



Hydrograph

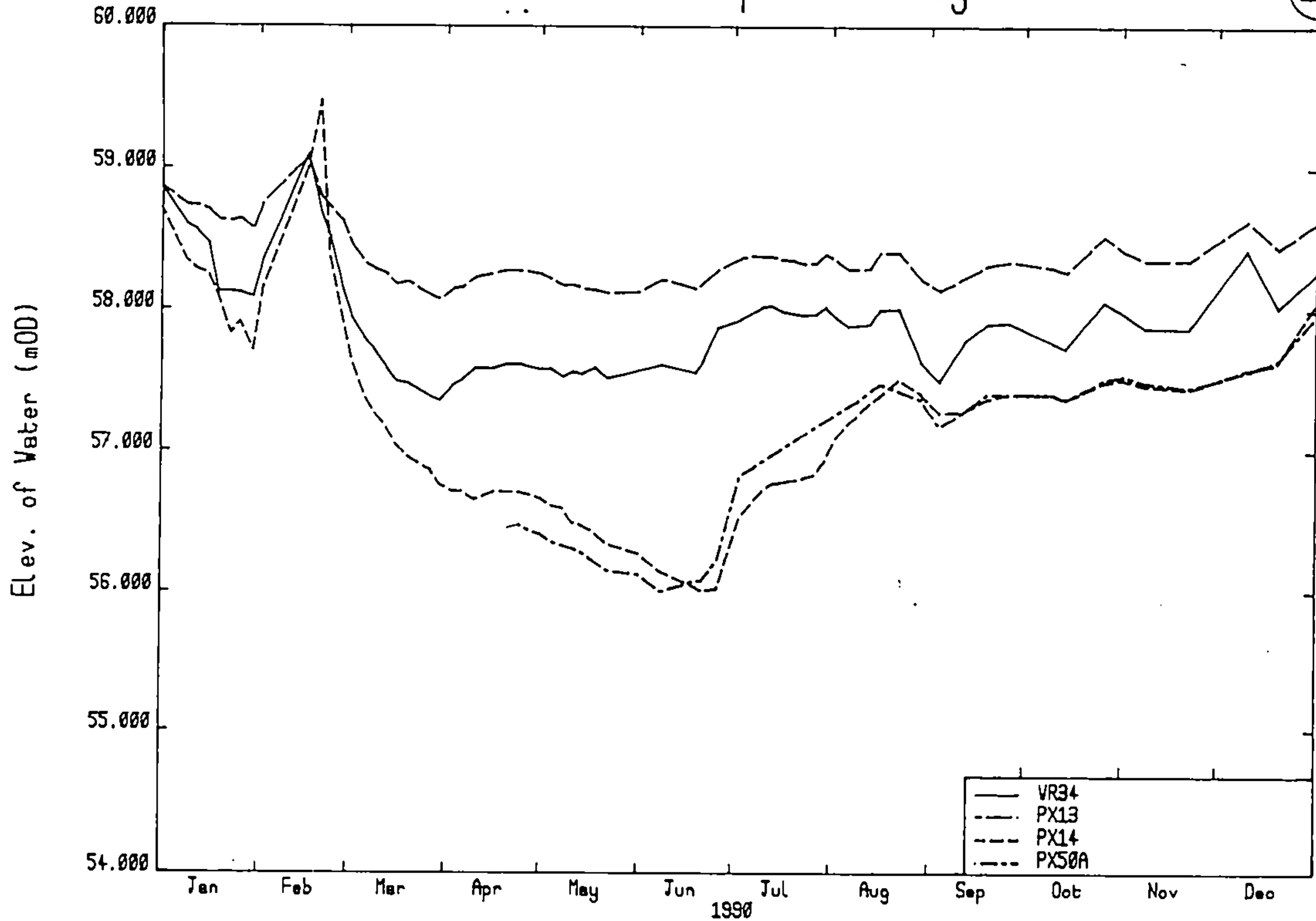
Fig. 3.2g



Hydrograph

Fig. 3.2h

Oxford Floodplain Study



Hydrograph

Fig. 3.21

Fig.3.3.a

Cassington Pit Stage 1.

Simulated groundwater levels-02.06.89.

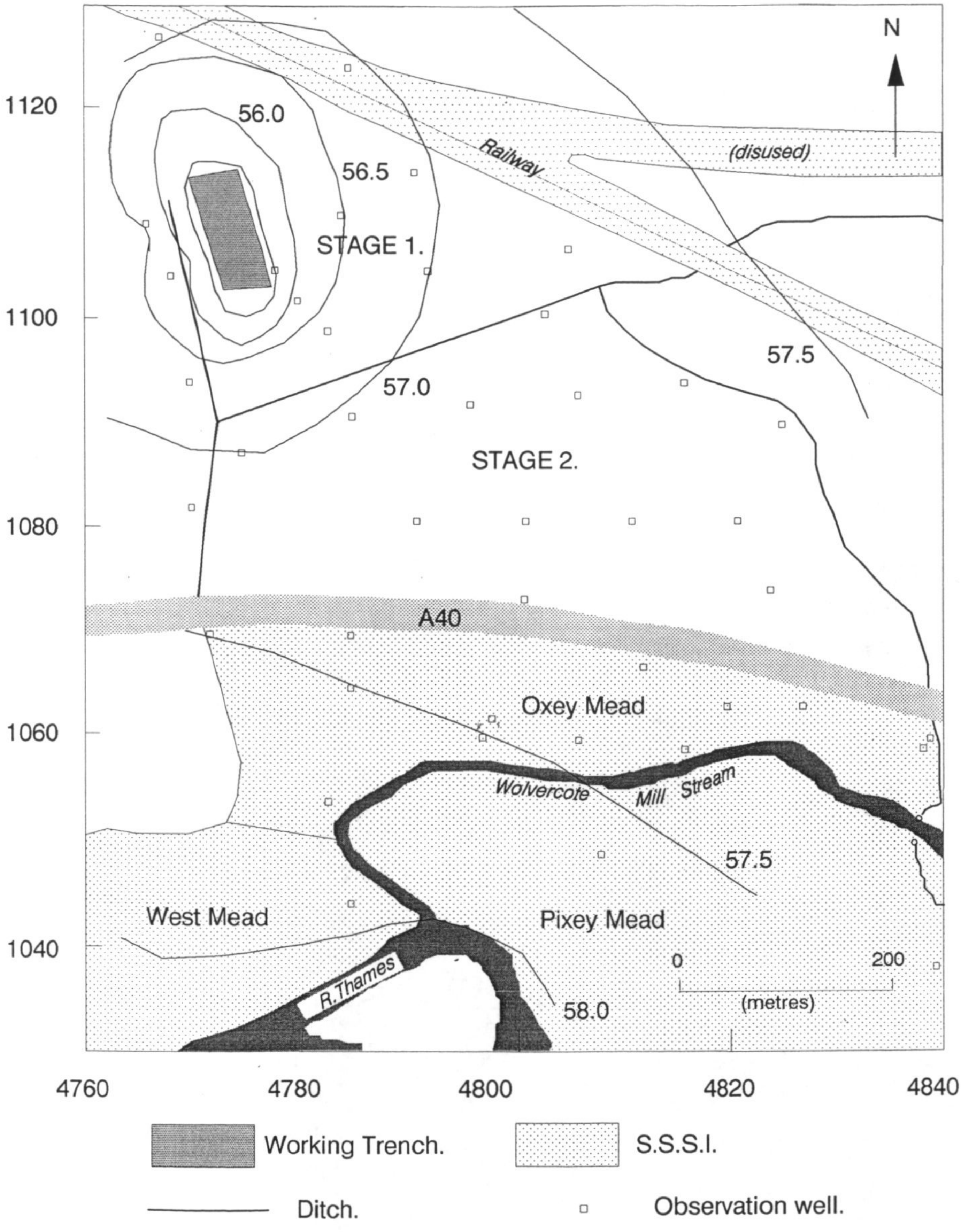
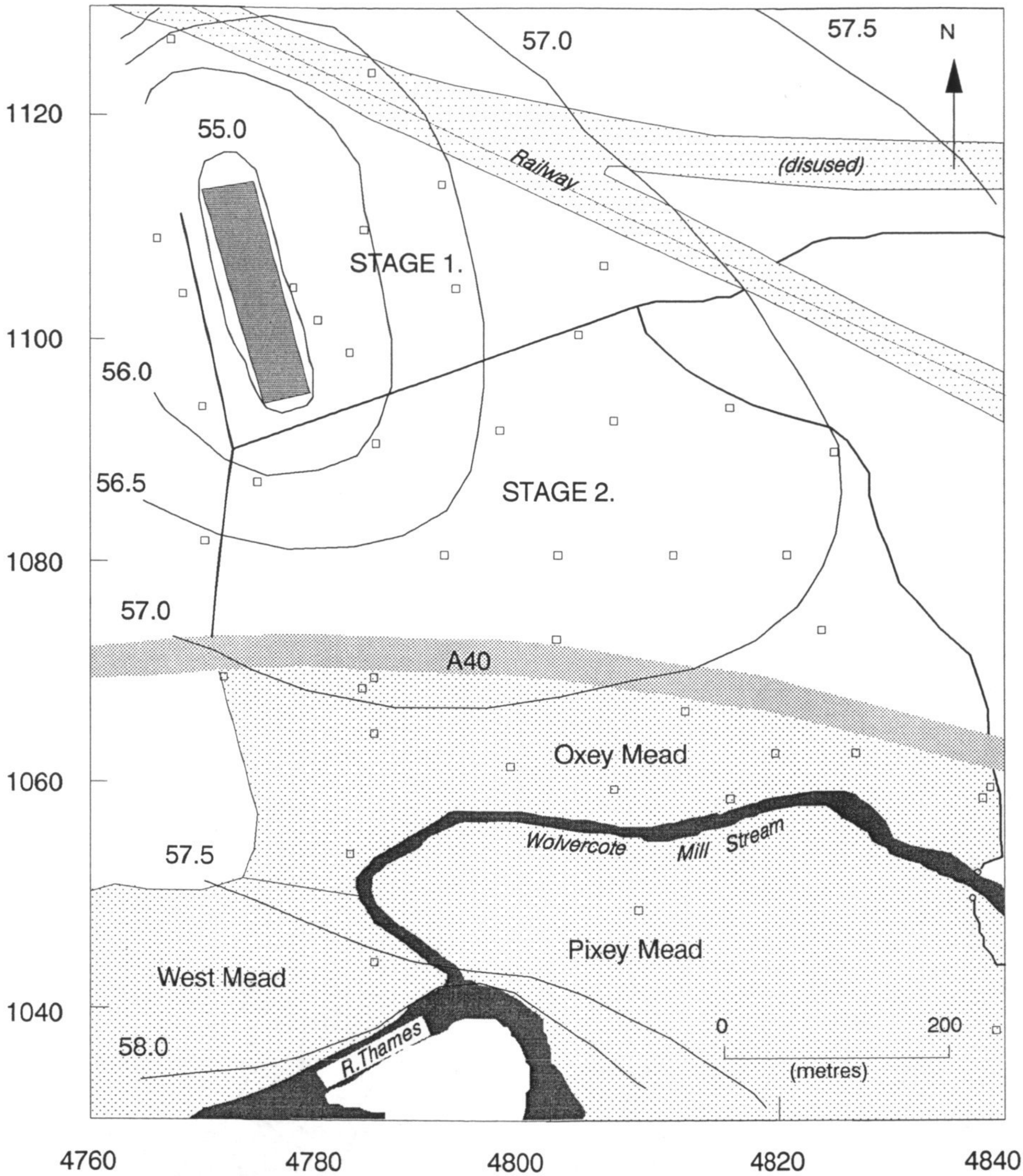


Fig.3.3.b

Cassington Pit Stage 1.

Simulated groundwater levels-20.06.89.



Working Trench. S.S.S.I.

Ditch. Observation well.

Fig.3.3.c

Cassington Pit Stage 1.

Simulated groundwater levels-27.06.89.

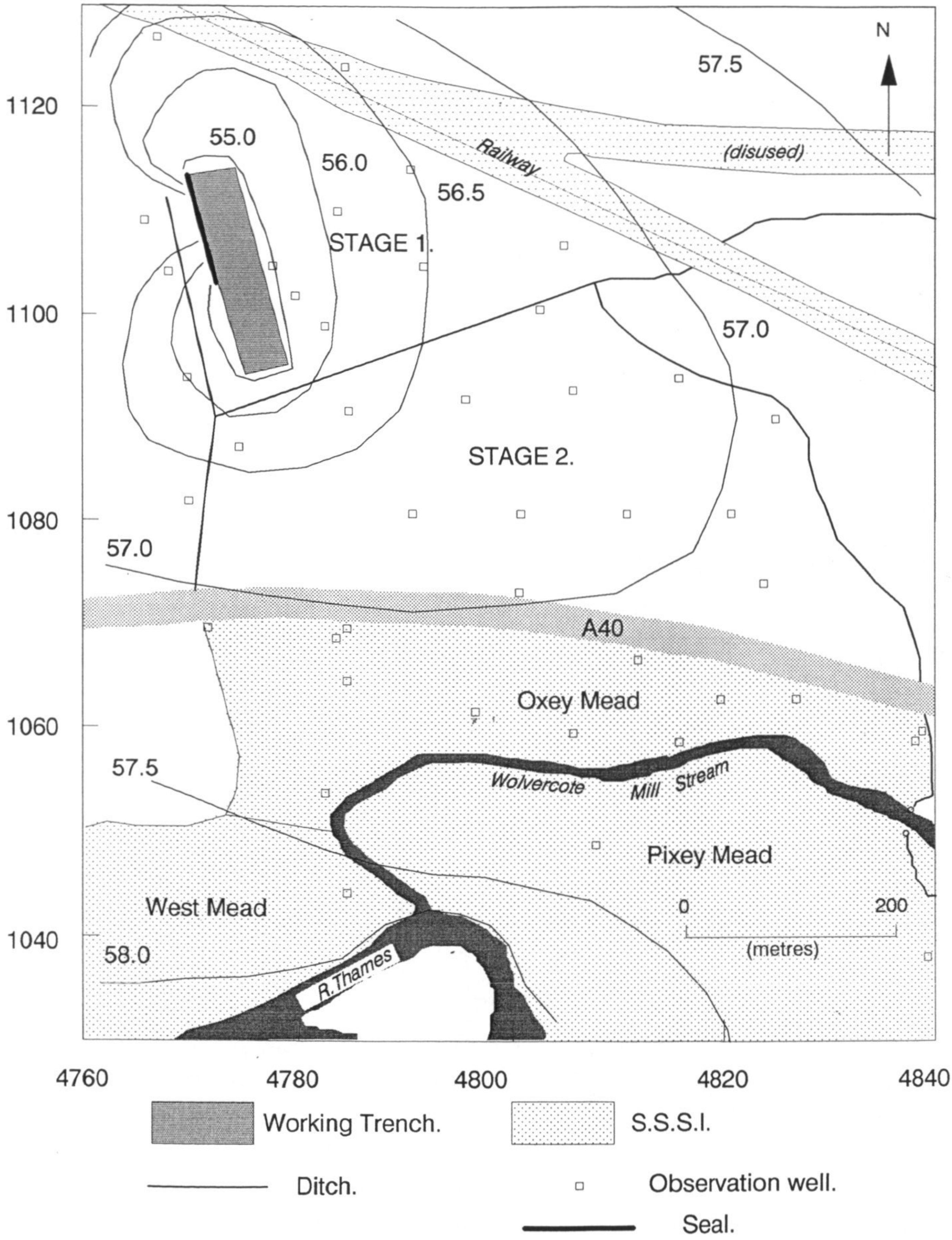


Fig.3.3.d

Cassington Pit Stage 1.

Simulated groundwater levels-04.07.89.

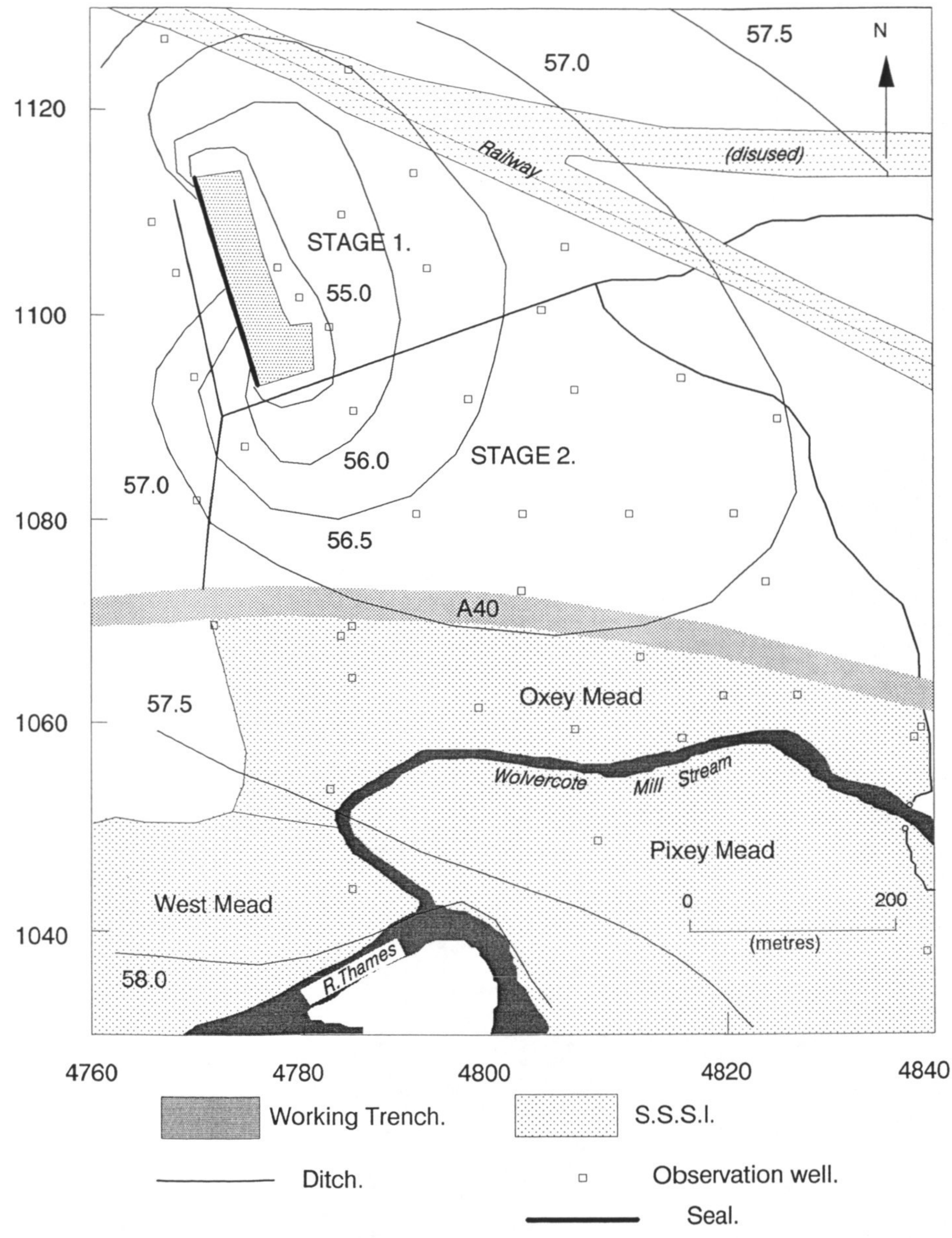


Fig.3.3.e

Cassington Pit Stage 1.

Simulated groundwater levels-18.08.89.

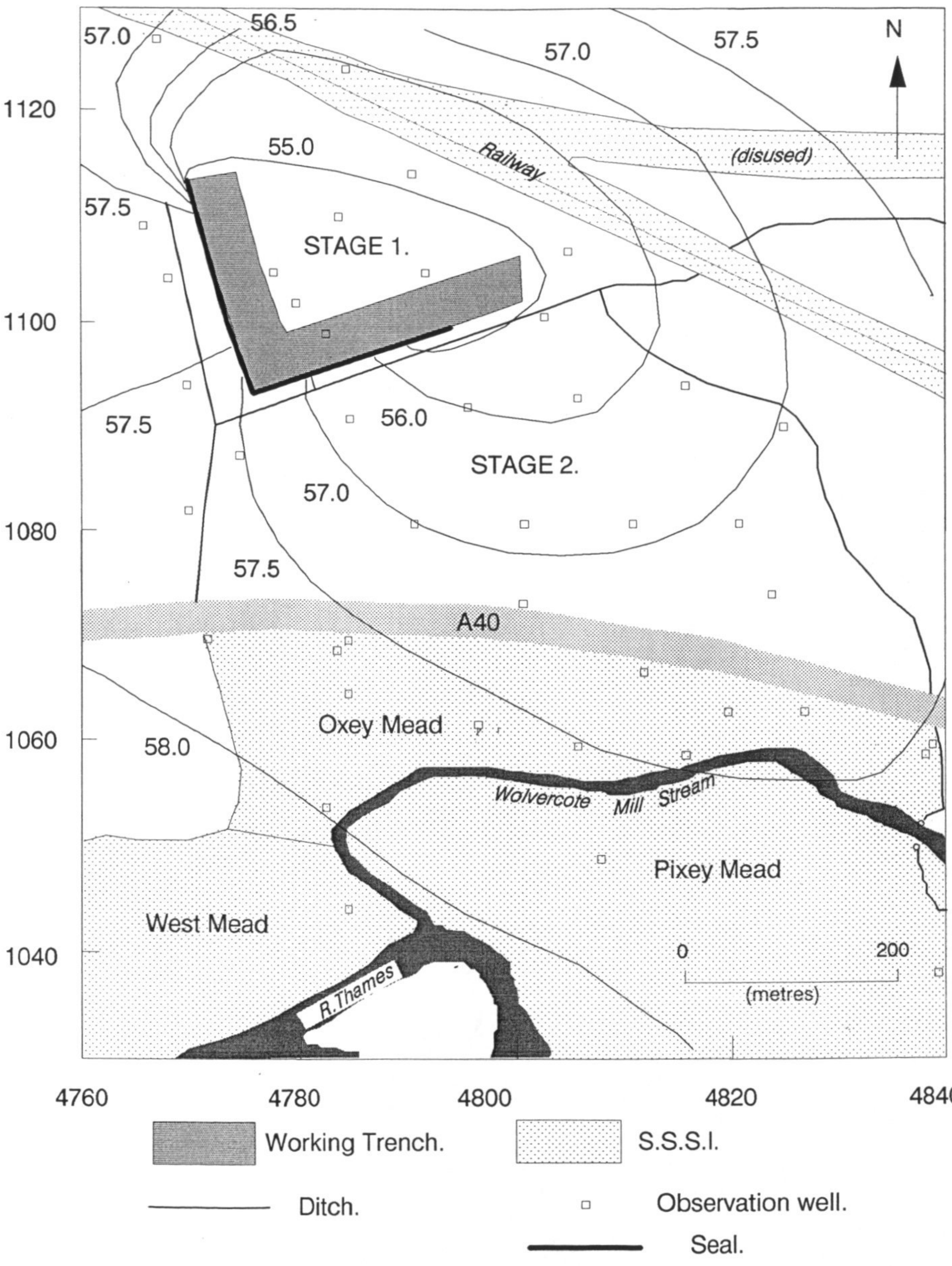


Fig.3.3.f

Cassington Pit Stage 1.

Simulated groundwater levels-03.10.89.

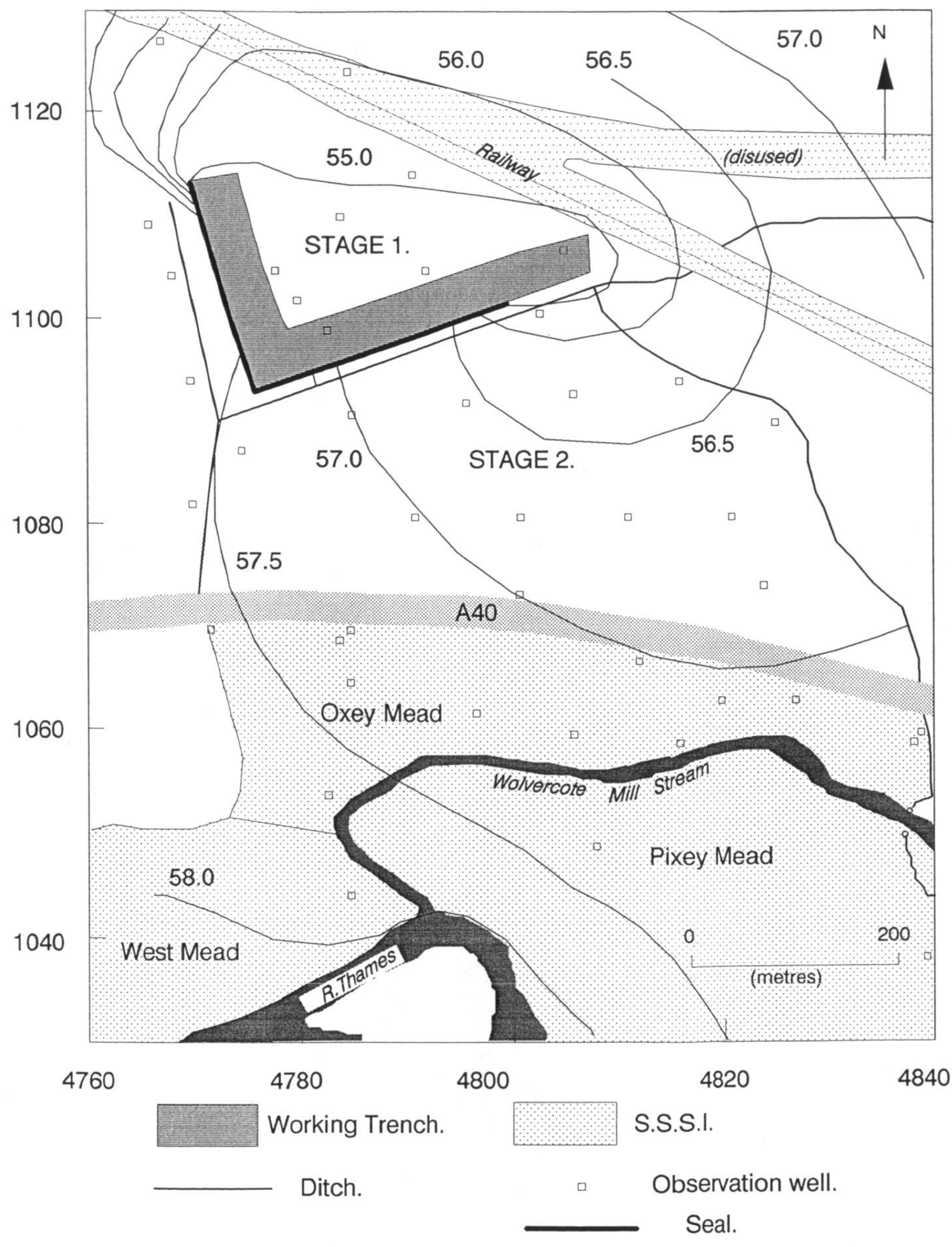


Fig.3.3.g

Cassington Pit Stage 1.

Simulated groundwater levels-17.11.89.

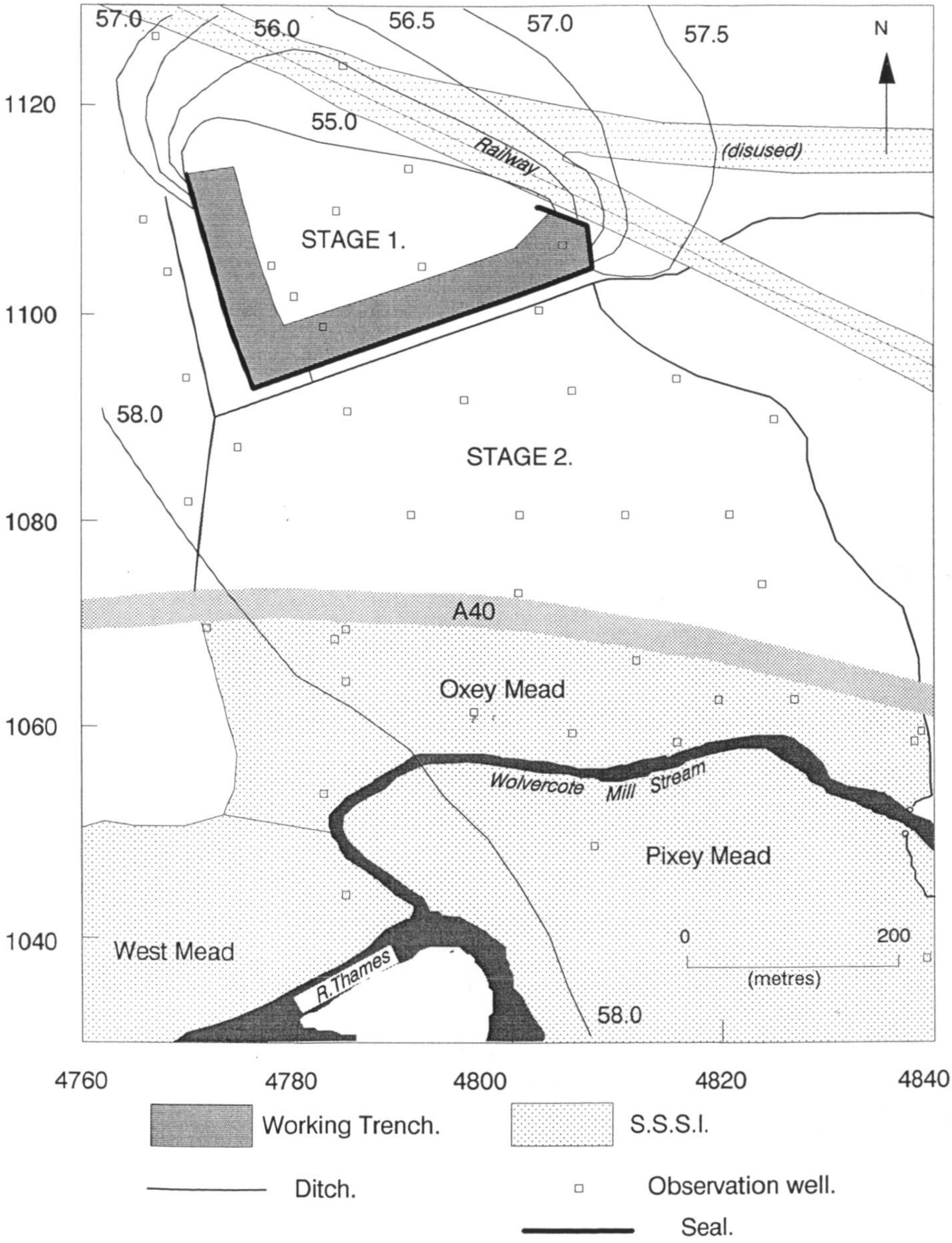


Fig.3.4.a

Cassington Pit Stage 2.

Simulated groundwater levels-20.06.90.

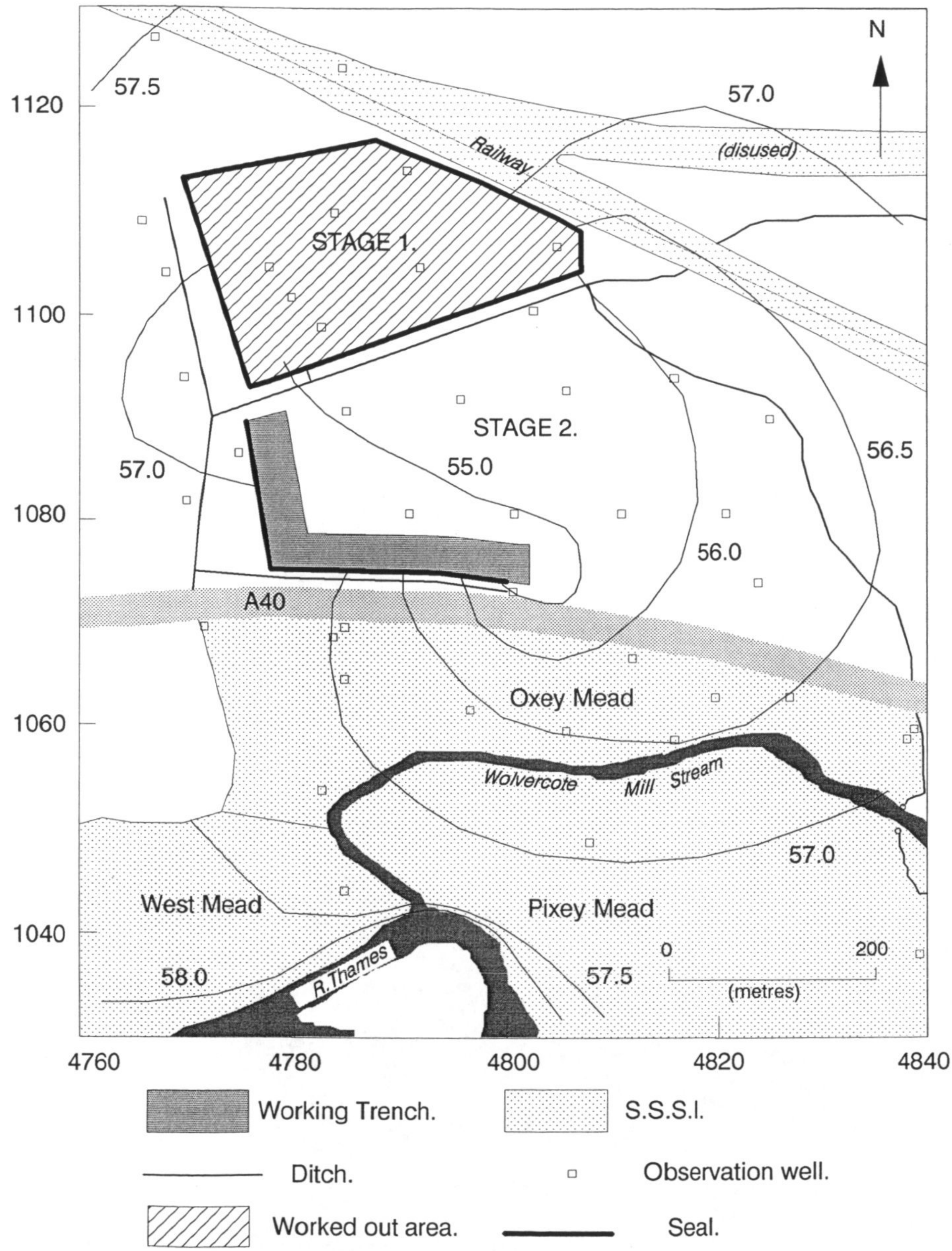


Fig.3.4.b

Cassington Pit Stage 2.

Simulated gronudwater levels-03.07.90.

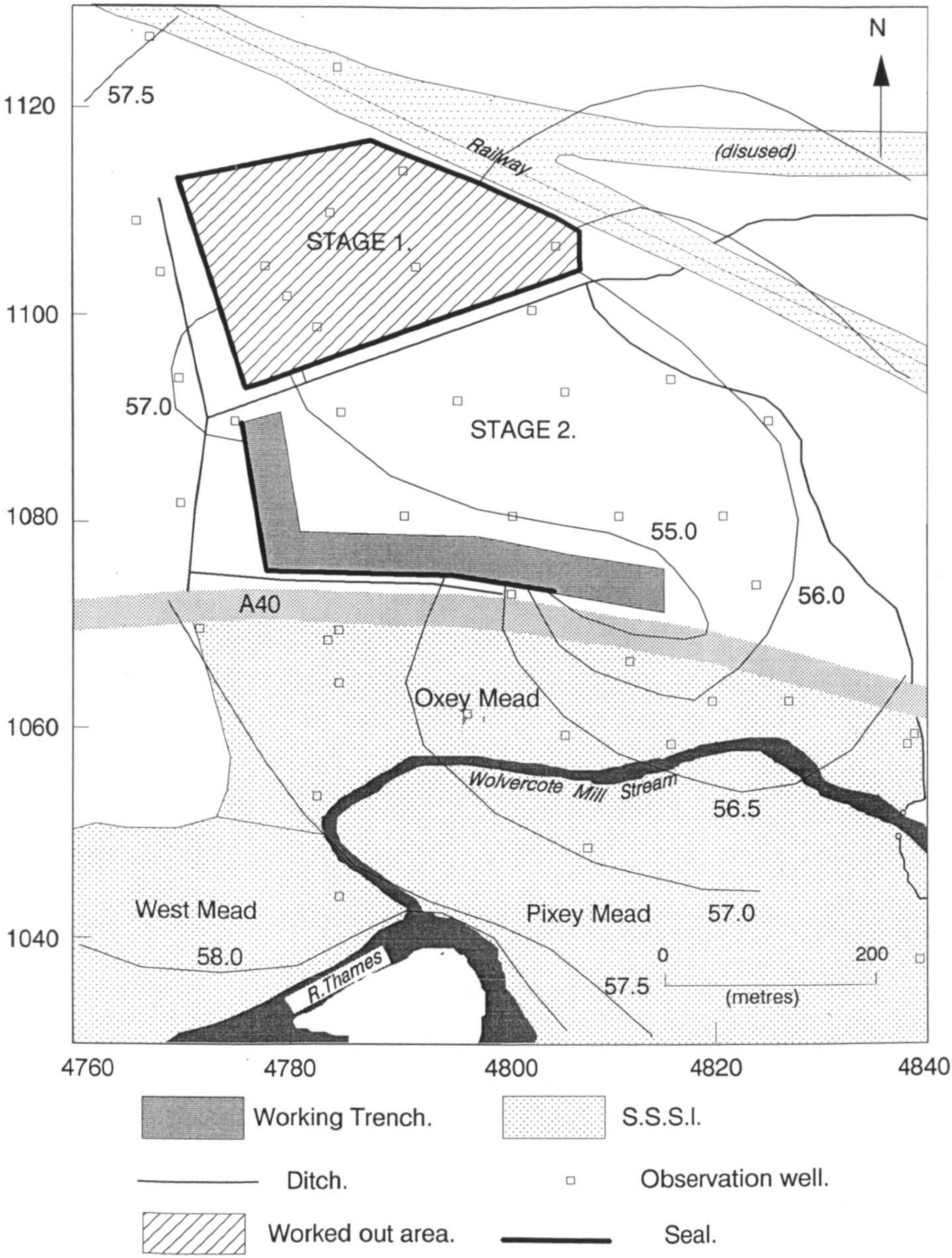


Fig.3.4.c

Cassington Pit Stage 2.

Simulated groundwater levels-27.07.90.

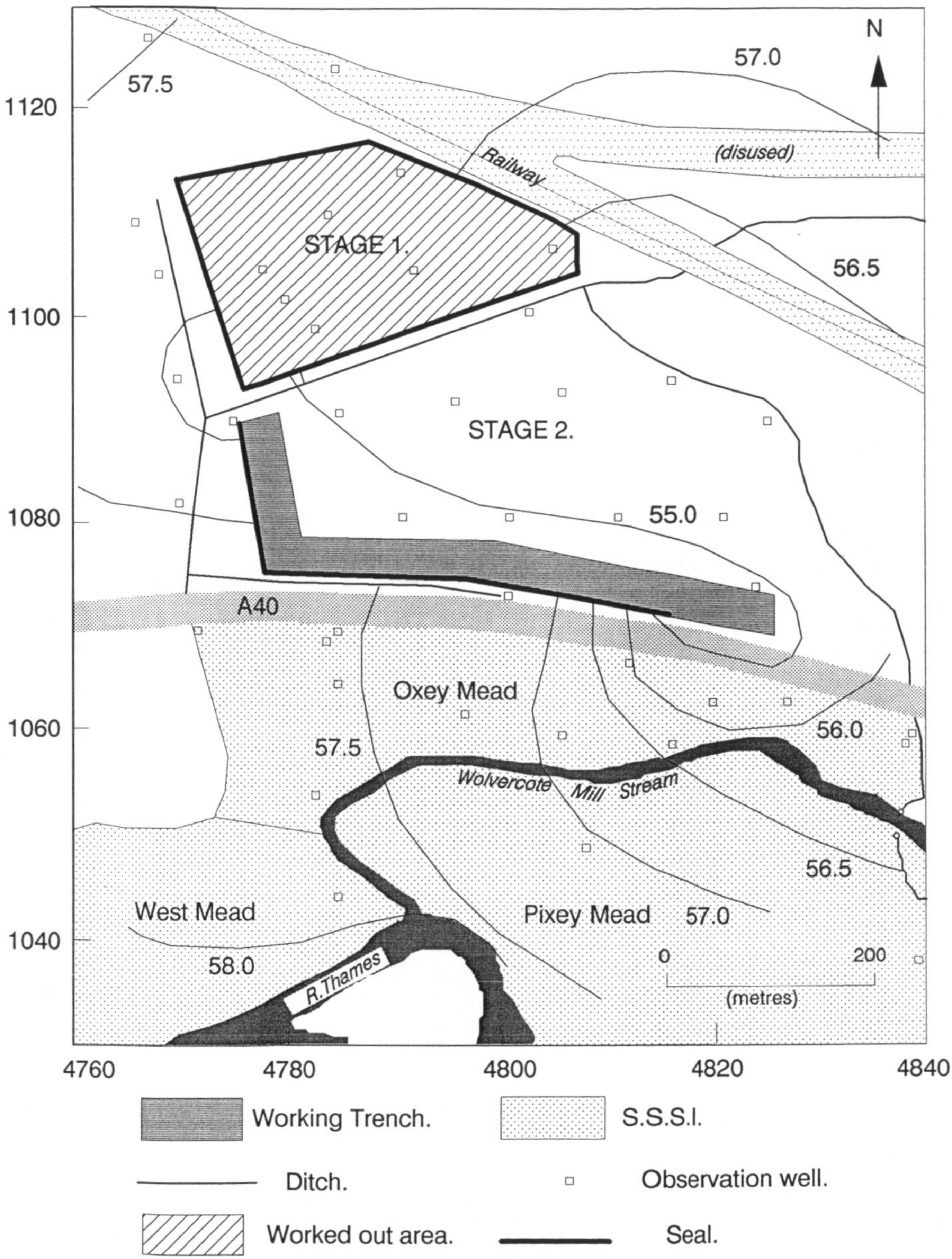


Fig.3.4.d

Cassington Pit Stage 2.

Simulated groundwater levels-03.08.90.

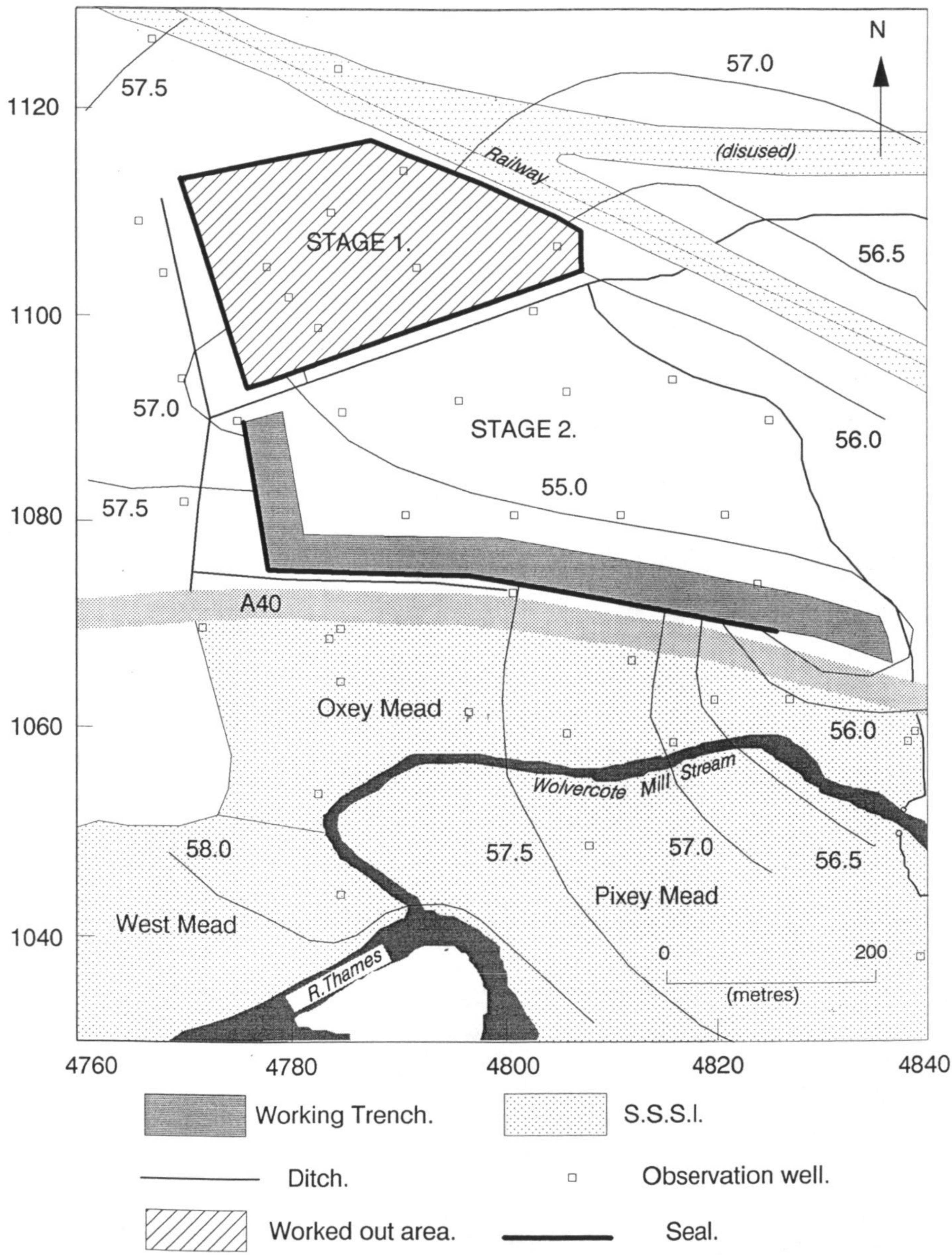


Fig.3.4.e

Cassington Pit Stage 2.

Simulated groundwater levels-10.08.90.

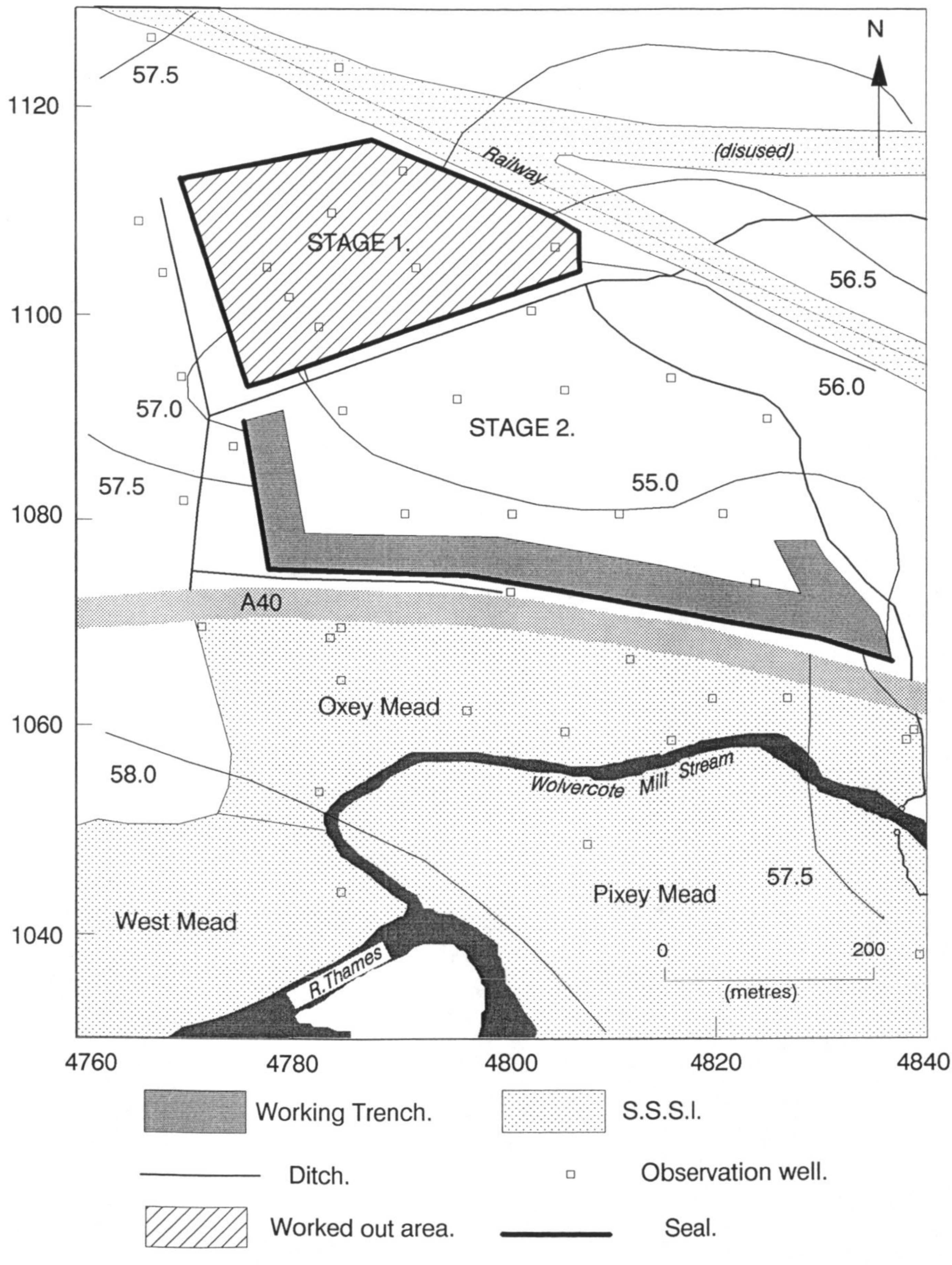


Fig.3.4.f

Cassington Pit Stage 2.

Simulated groundwater levels-20.08.90.

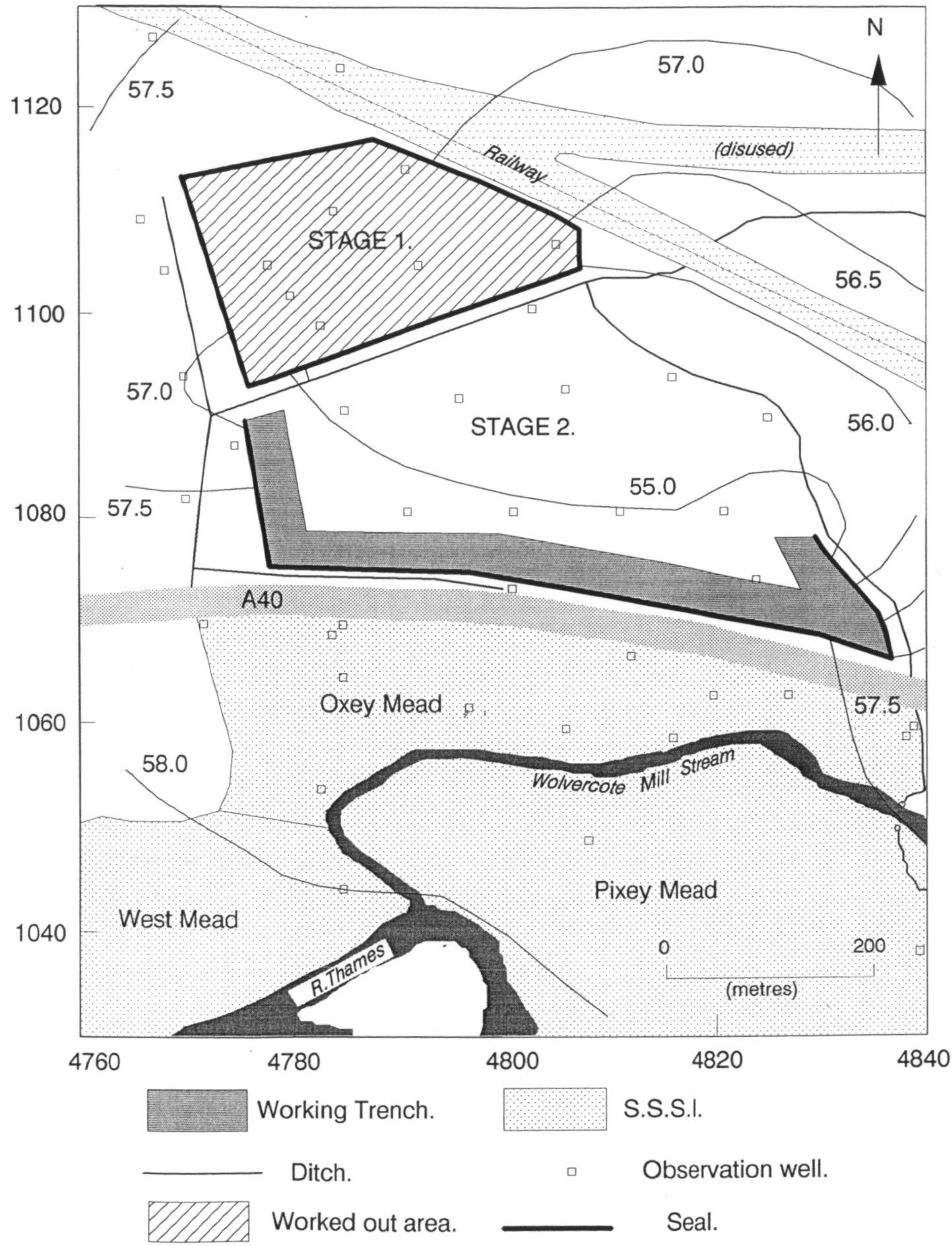


Fig.4.1.a

Cassington Pit Stage 2.

Simulated groundwater levels.

Eastern edge worked,without seal.

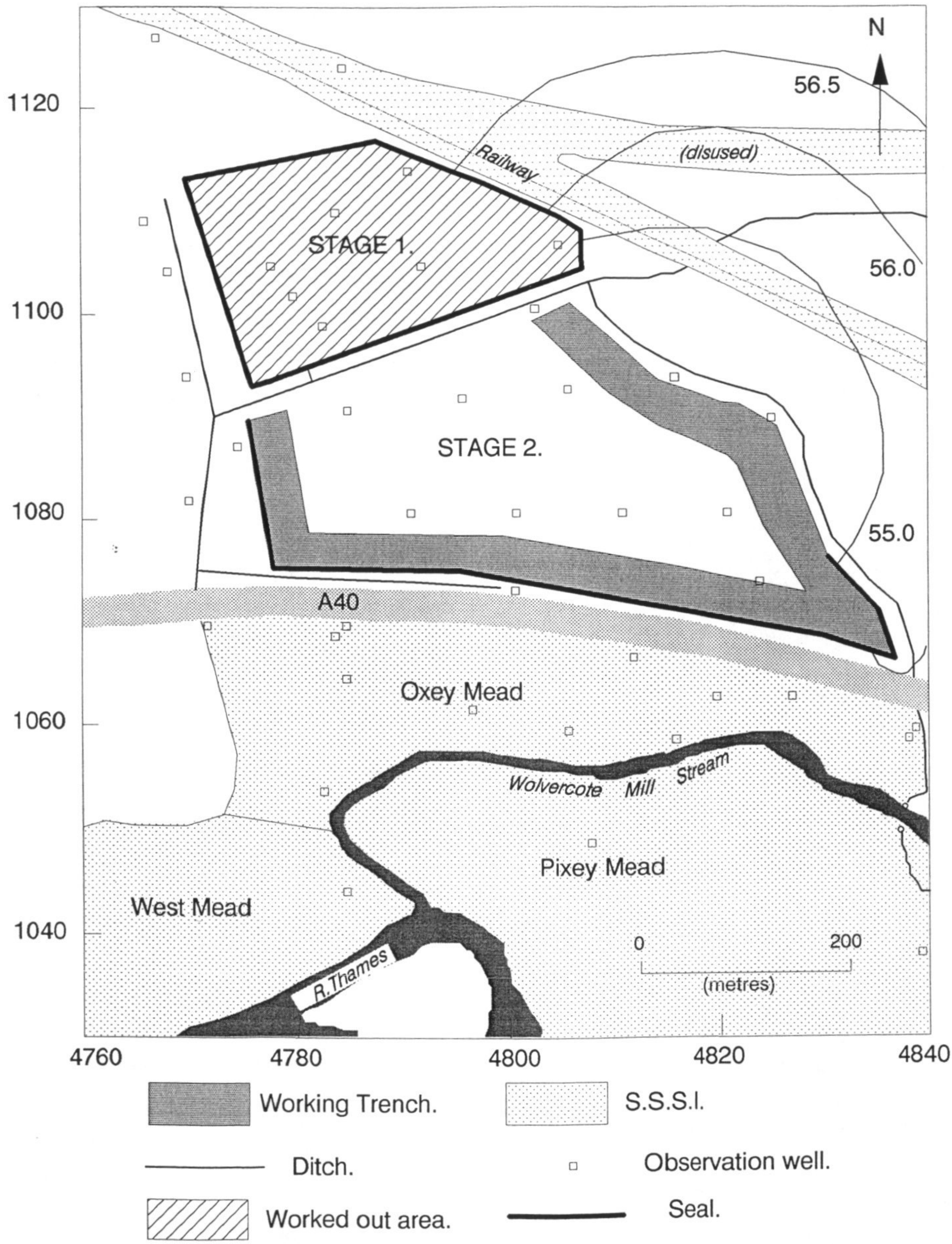


Fig.4.1.b

Cassington Pit Stage 2.

Simulated groundwater levels.

Eastern edge worked,with seal.

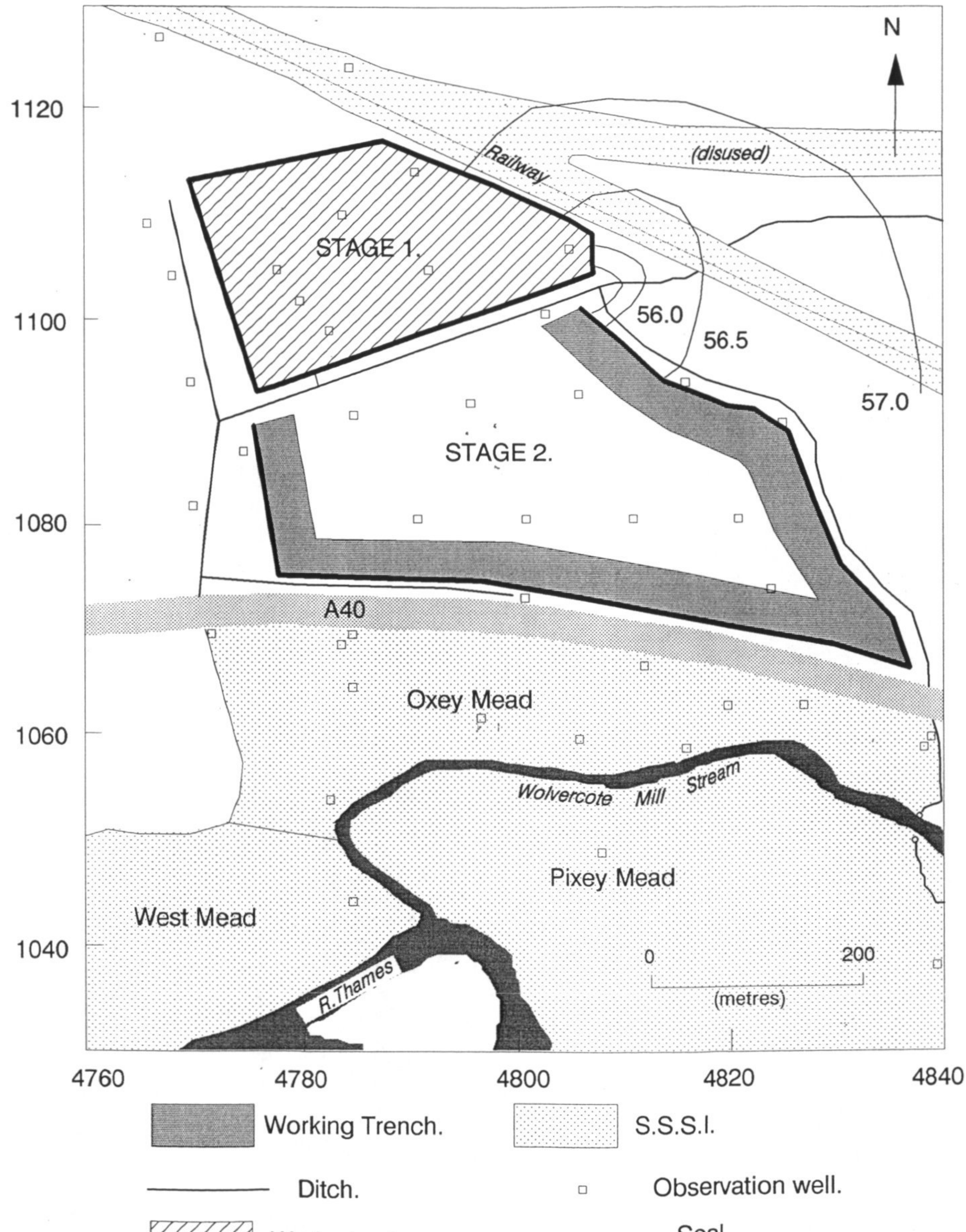


Fig.4.2.a

Cassington Pit Stage 2.

Simulated groundwater levels-20.06.90.

No seal or recharge ditch.

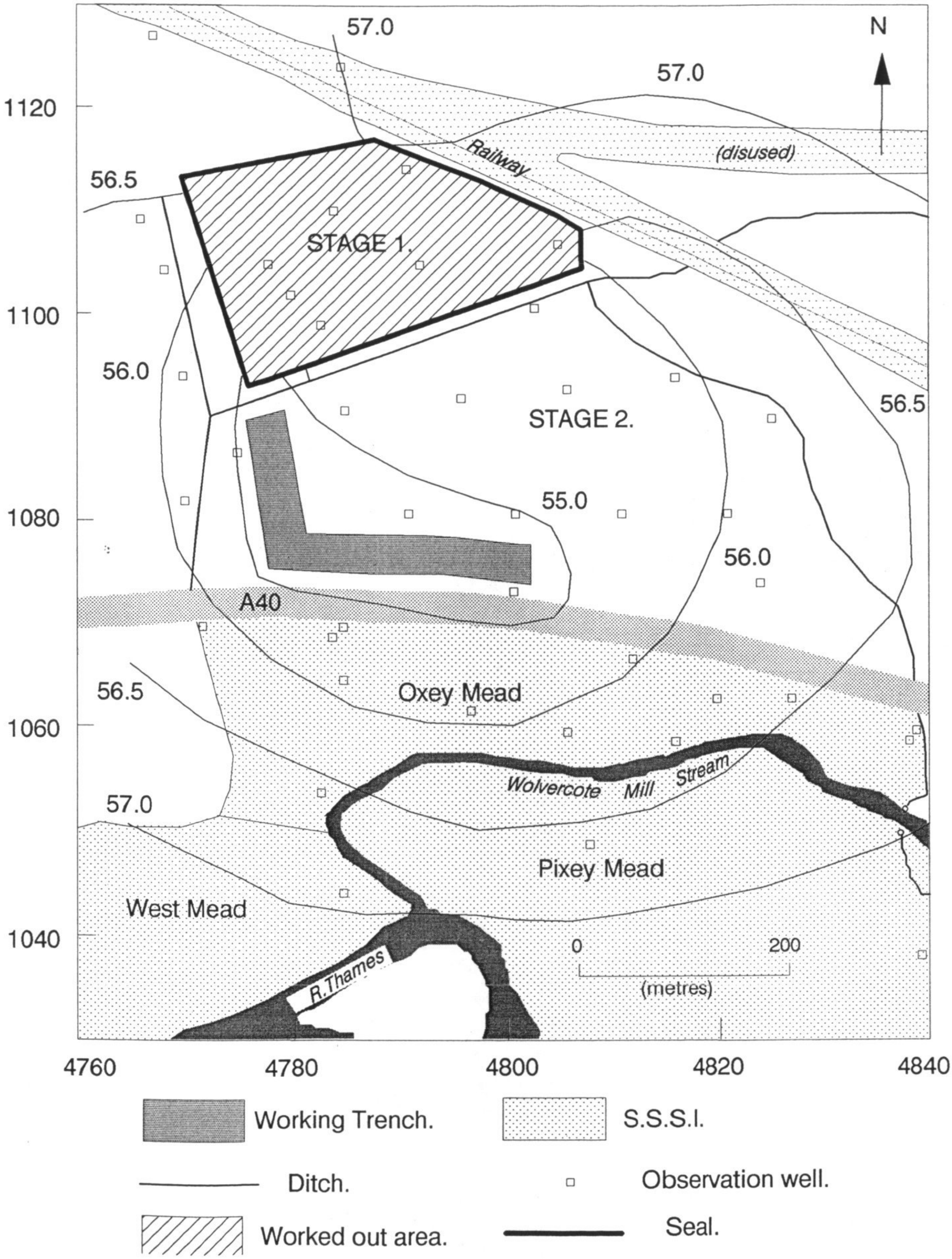


Fig.4.2.b

Cassington Pit Stage 2.

Simulated groundwater levels-03.07.90.

No seal or recharge ditch.

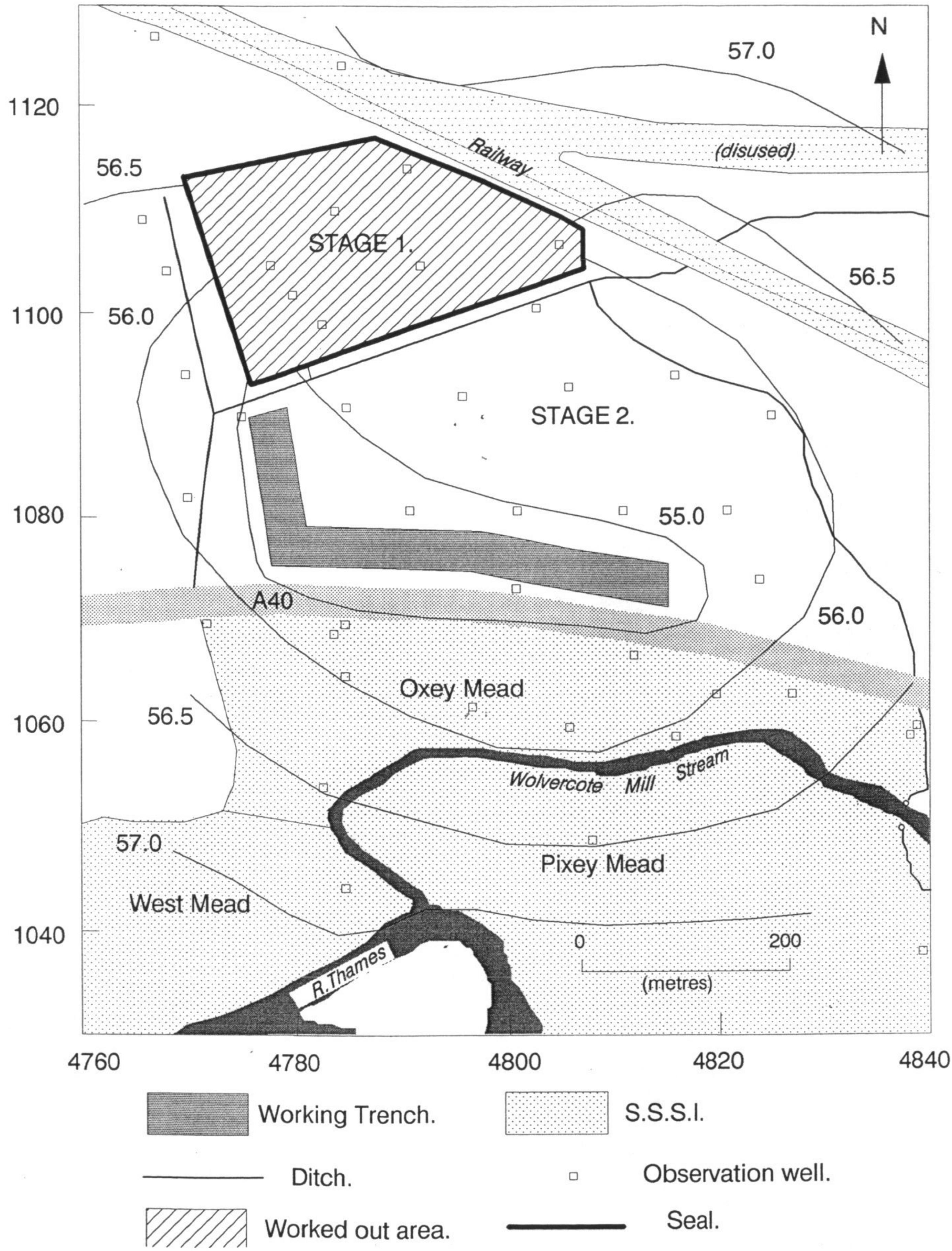


Fig.4.2.c

Cassington Pit Stage 2.

Simulated groundwater levels-27.07.90.

No seal or recharge ditch.

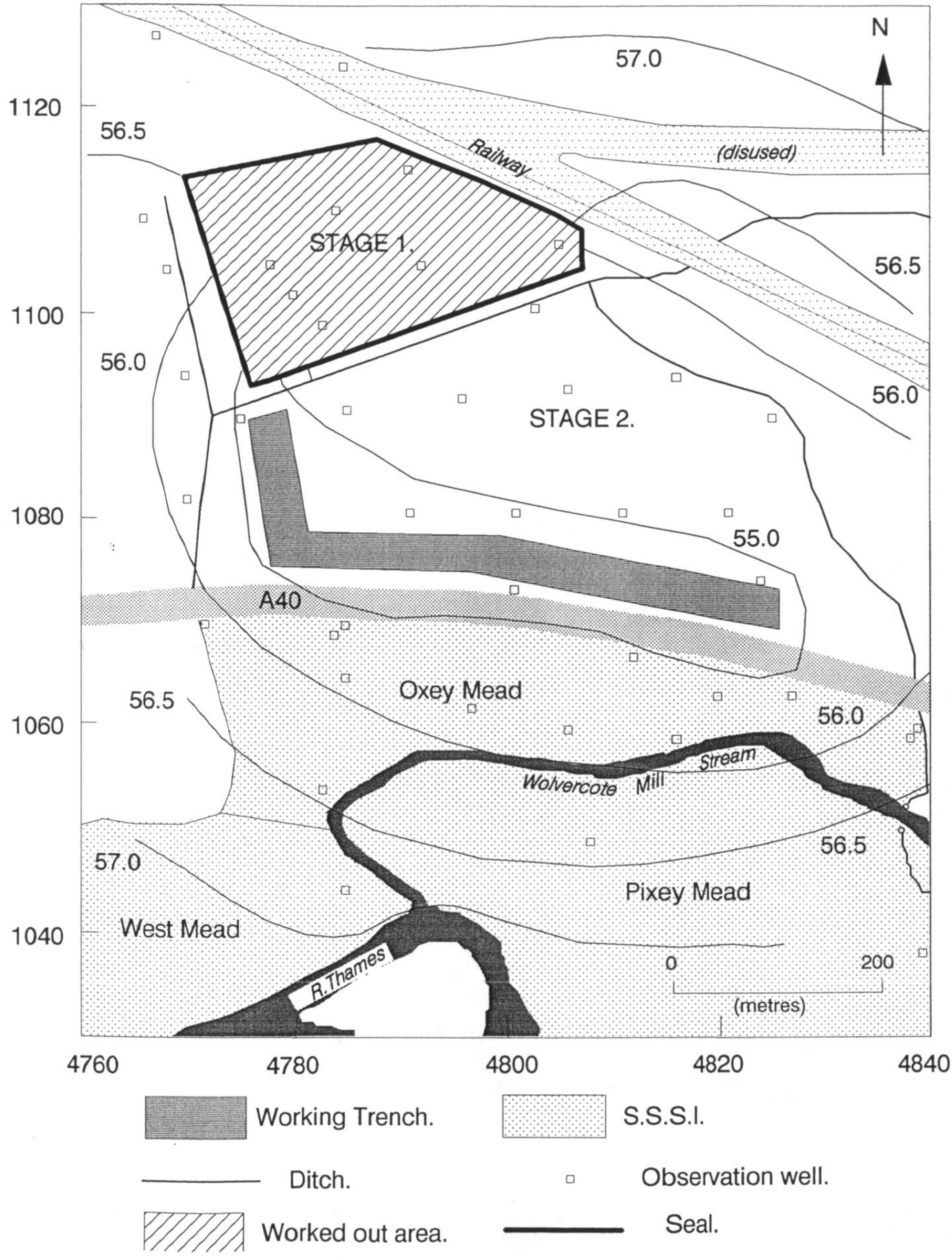


Fig.4.2.d

Cassington Pit Stage 2.

Simulated groundwater levels-03.08.90.

No seal or recharge ditch.

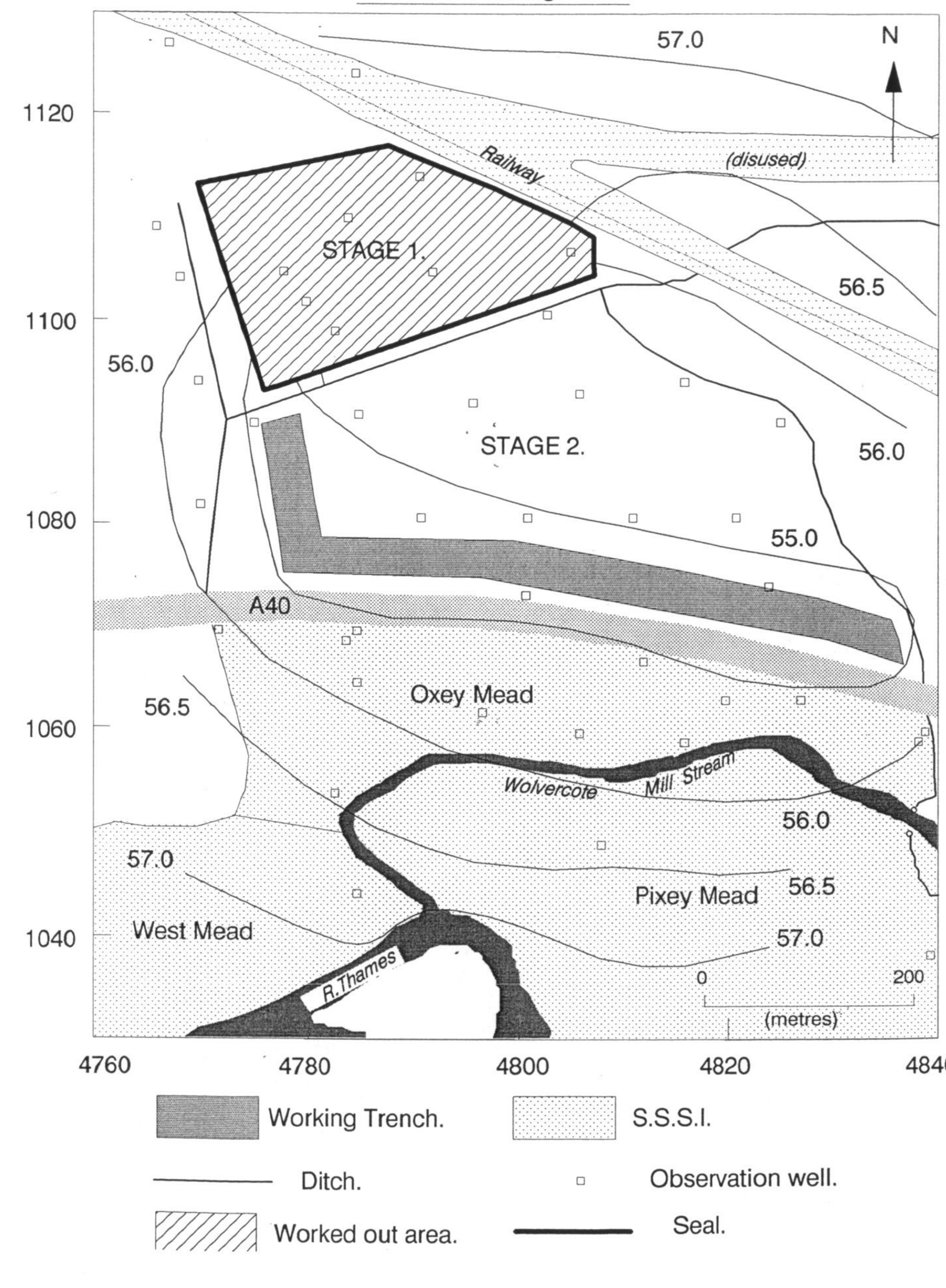


Fig.4.2.e

Cassington Pit Stage 2.

Simulated groundwater levels-10.08.90.

No seal or recharge ditch.

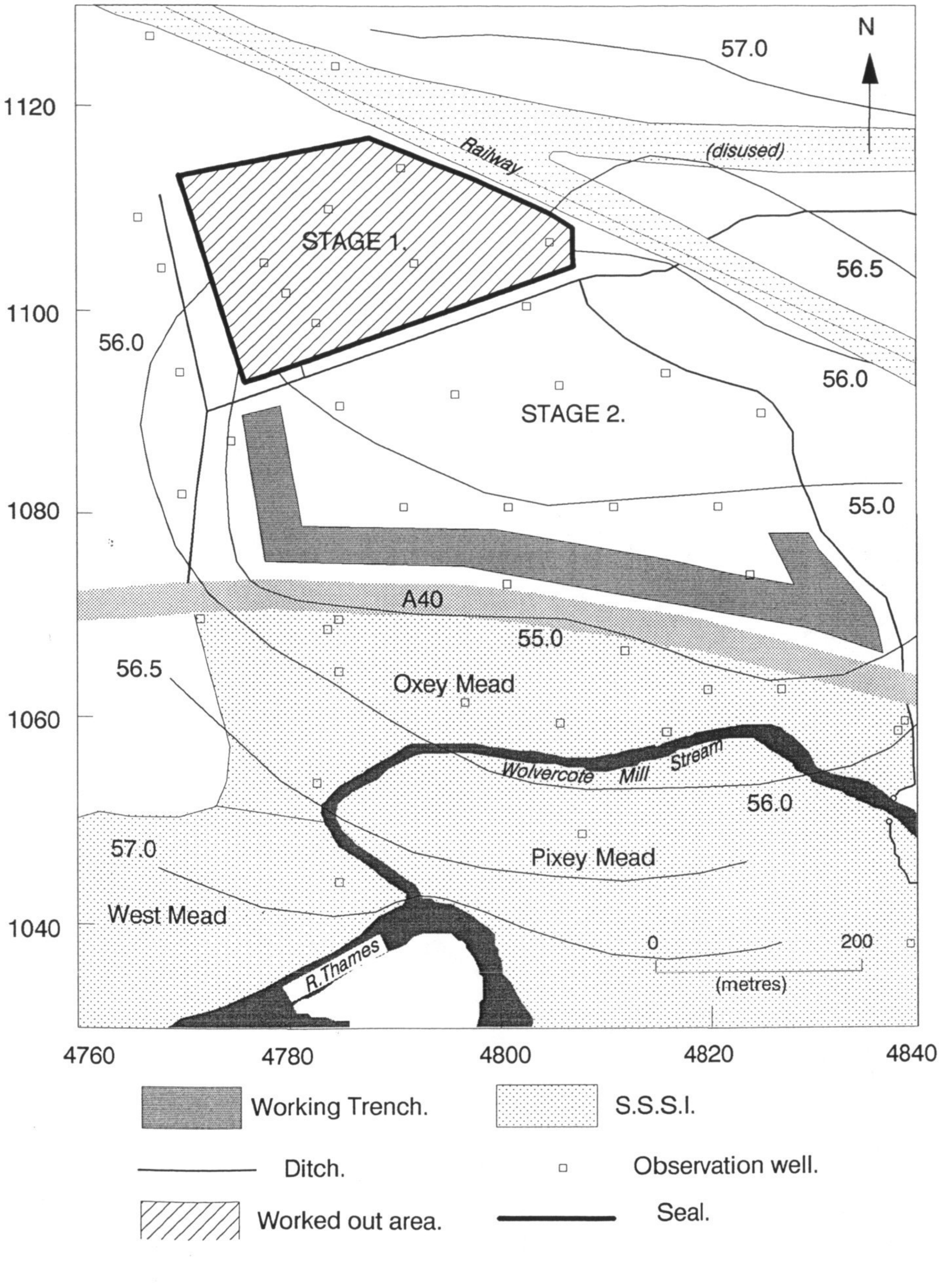
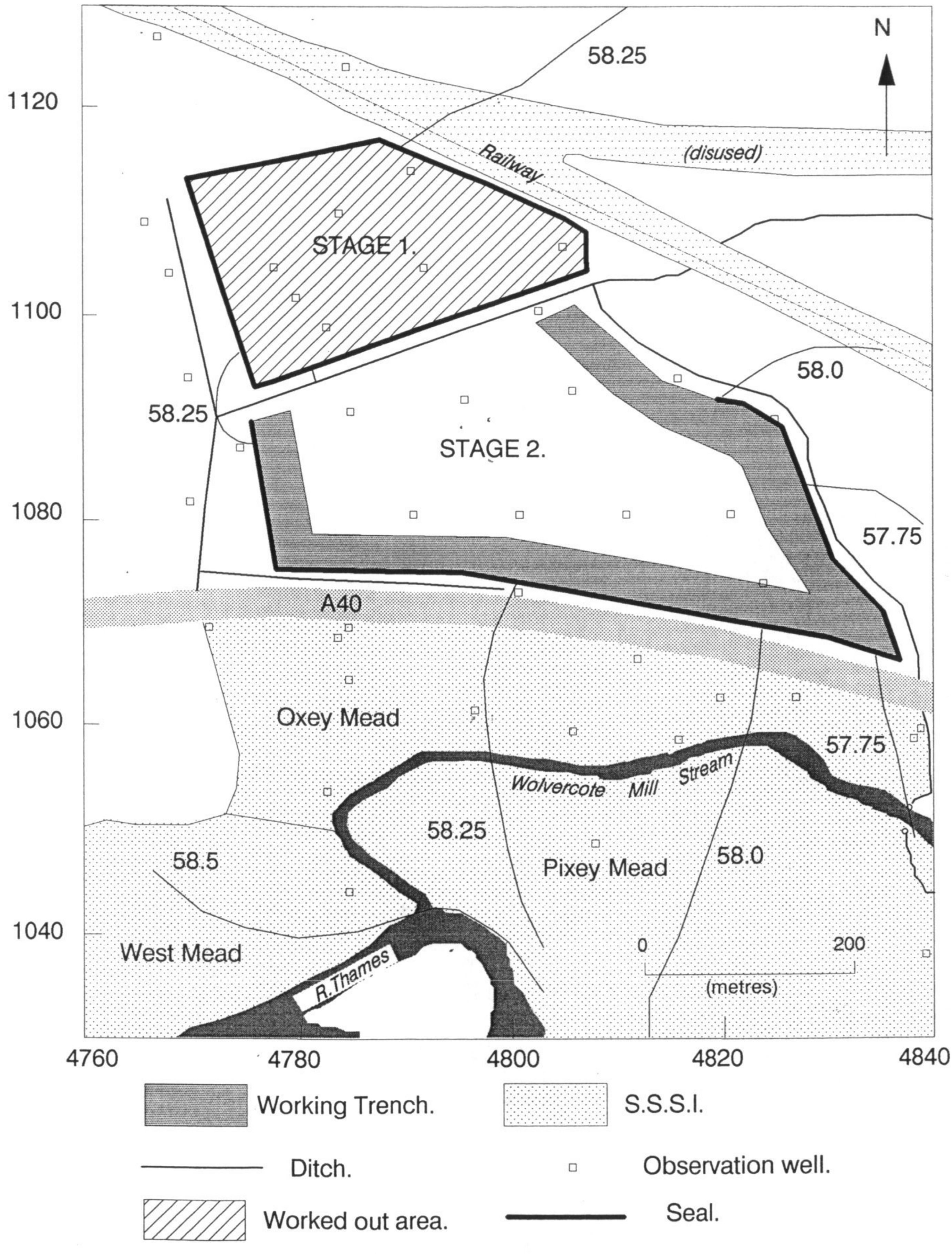


Fig.4.3

Cassington Pit Stage 2.

Simulated groundwater levels.

Equilibrium with recharge/discharge ditch.



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