INSTITUTE of HYDROLOGY

Woolhampton Gravel Pit, Berkshire

Water Inflows and Buffer Zone Stability

May, 1989

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WOOLHAMPTON GRAVEL PIT, BERKSHIRE.
WATER INFLOWS AND BUFFER ZONE STABILITY

Report for Steetley Construction Materials Ltd.

Prepared by: Institute of Hydrology and
Hydraulics Research Ltd.

May, 1989

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List of Contents

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1. Background information

1.1 Introduction

Steetley Construction Materials (SCM) are working gravel from a site near Woolhampton in Berkshire. The River Kennet traverses the site from west to east. Extraction is almost complete on the southern side of the river and will begin in the near future on the northern side of the river. The Kennet and Avon Canal forms the northern boundary of the site.

Due to a limited sand content the pit is being worked dry as far as possible in order to maximise sand production. However, dewatering of the southern pit has required high and continuous abstraction rates (up to 750000 gph during the initial stages) in order to work the pit dry. Even so, it has not been possible or economic to completely dewater the southern pit.

An unworked zone about 10m wide is being left either side of the river. A trench was excavated in this zone between the river and the southern pit and infilled with overburden material to stop the flow of water into the pit. This was successful in reducing inflow in the western part of the pit but attempts to seal the face adjacent to the river in the eastern part of the pit have been restricted by a particularly thick sequence of gravels.

A similar bund is to be installed along the northern side of the river. At present it is intended that the southern pit will be left to flood whilst excavating the northern pit.

In view of the rather unusual conditions of this particular site, SMC commissioned a study of the following aspects of particular concern, which could affect the costs and safety of the northern pit:

- whether the abstraction rates proposed for dewatering the northern pit will be sufficient

- whether the width of unworked zone adjacent to the river is sufficient to prevent collapse or breeching by the river

This study has been undertaken by the Institute of Hydrology (IH) in association with Hydraulics Research Limited (HRL). The method of approach adopted and the results of the study may also be applicable to sites with similar conditions elsewhere.

1.2 General Description of the Site

A description of the site is given in the Geological Report prepared by SCM in August 1987. The main features of the site relevant to the present study can be summarized as follows:

- The site covers an area of some 68 ha either side of the river Kennet just south west of the village of Woolhampton near Alder maston in Berkshire. The area has a flat relief ranging from 56 to 59m OD.

- The Kennet and Avon Canal (KAC) forms the northern boundary of the site and is connected to the Kennet via a sluice gate near the eastern edge of the site. This canal is not considered to be in hydraulic connection with the gravel deposits.

- The river Enborne joins the Kennet about one km downstream of the workings. The mean flow of the Kennet is about 10 cumecs and of the Enbourne about 1.3 cumecs. Both carry a major baseflow component, although the flow of the Enbourne is more variable.

- Water from the site is transferred from silt lagoons into the Kennet at the western end of the southern pit and into a major drainage ditch which runs east just south of the pit.

- The geology of the site was investigated prior to extraction by EM and resitivity surveys and 53 investigation boreholes.

- Alluvial silts with clays and peats underlie the floodplain bordering the river. These range in thickness from 0.3 to 3.4m.

- The valley sand and gravel deposits extend over a valley width of about 2 km. The thickness of these deposits, which form the main aquifer, range from about 1m to about 10m. The thickest part of the sequence occurs in the eastern part of the site in a north-west/south-east trending buried valley or scour hollow but the thickness is generally less than 3m over most of the site. Peat and silt lenses also occur within the sequence. Sieve analyses have been undertaken on 33 samples of the gravel deposits from 14 boreholes.

- Both the drift geological map of the area (Sheet 268) and the IMAU report for the Aldermaston area (Report 24, Sheets SU 56 and SU 66, 1:25000) identify the sequence underlying the gravel deposits as London Clay, although their appearance is more similar to the Reading Beds. Whichever, the underlying sequence is dominated by clays and silts with a low hydraulic conductivity which can be considered as an aquiclude hydraulically separating the gravel deposits from the deeper Chalk aquifer.

- The hydraulic connection between the river and the gravel sequence is likely to be better in the western part of the pit where the alluvium is thin. The river is relatively shallow but the depth of the river has not been measured. It is reported to be about 1m in depth.

- Water levels occur mainly at depths of about 1m across the site but relatively limited data are available to prepare ac curate water level contour maps. The area south of the pit, where only thin gravels occur, are unsaturated and the river stage is similar to the natural water table elevation. The water level response to dewatering of the southern pit has not been monitored.

- There is no site specific information on the hydraulic characteristics of the alluvium and gravel deposits. Estimates based on grain size data for heterogeneous sand and gravel deposits are usually rather unreliable. The highest transmissivities will be associated with the buried channel in the eastern part of the site.

Additional details are included in each section of the report.

1.3 Method of Approach

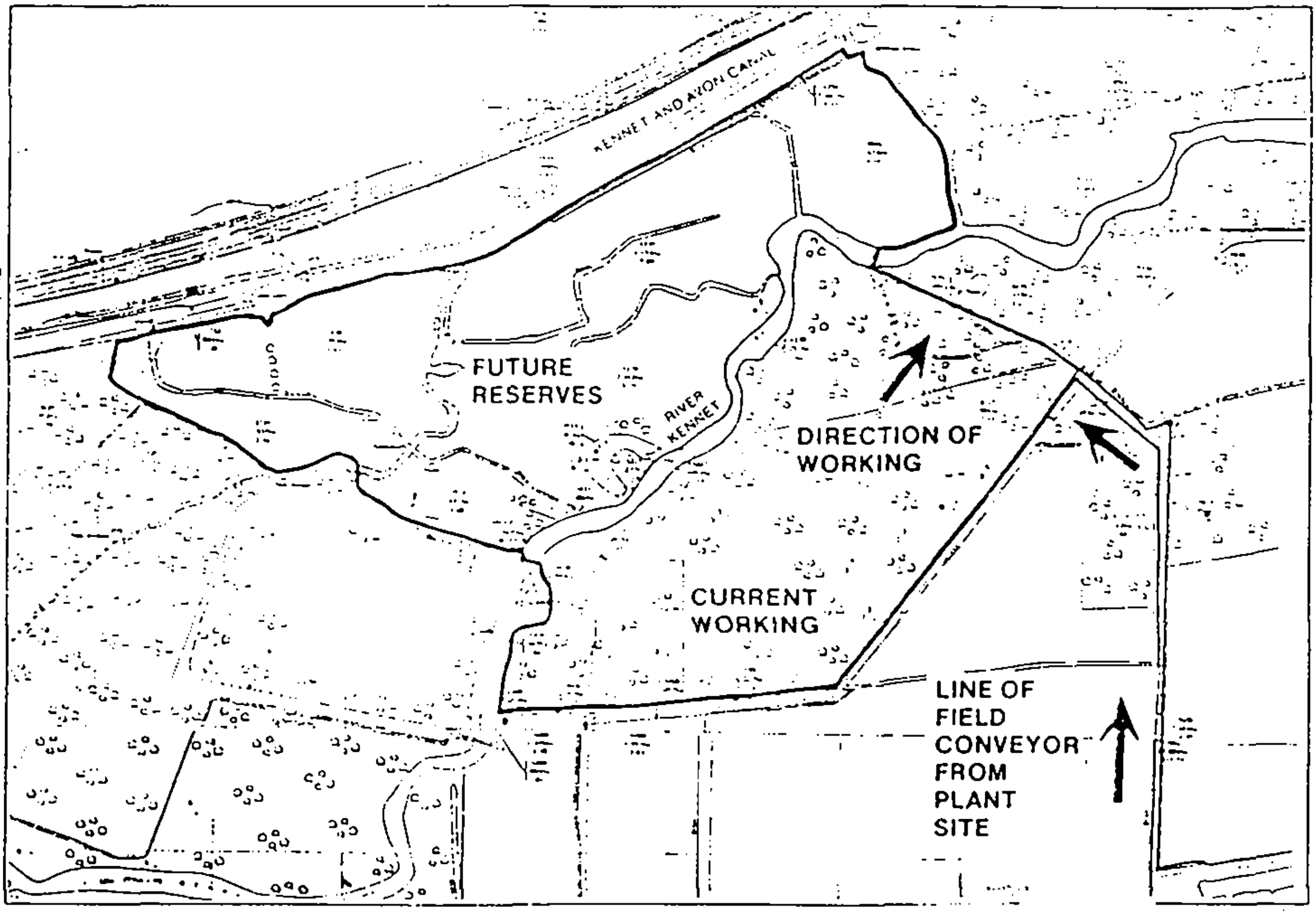
Staff from IH and HRL visited the site on the 4 April 1989 for discussions with SMC site staff. A general inspection of the site was undertaken accompanied by a geologist from SMC.

Given the limited information available on the hydrogeology of the area, it was considered that numerical modelling techniques offered the only practical means of estimating inflows. A simple model was selected as a sophisticated model would not be justified without detailed investigations.

The model was used to test various assumptions regarding connection between the river and the pit and to estimate permeability. It was then used to predict the likely drawdowns in the northern pit for various rates of pumping and different degrees of sealing of the southern pit.

Computing techniques were also applied to examine the influence on pit inflows of installing an overburden bund along the river to varying depths and to examine the safety of the border zone with several slope configurations.

This desk study has been undertaken with limited hydraulic and geotechnical information. Various general recommendations are made for further data collection.



Woolhampton site

2. Pit inflows

2.1. Introduction

In this chapter an estimate of the impact of the proposed working procedure for the gravel to the North of the river Kennet on groundwater levels is made. This is achieved by utilising a numerical model of groundwater flow. This model was calibrated by using observations made during working of the gravel to the South of the river Kennet. The calibration of the model is also described in this report.

2.2. Model description

The numerical model used to carry out the work described in this report was AQ10 which was developed by Dr Arnold Verruijt of the University of Delft, Delft, The Netherlands.

AQ10 simulates two-dimensional horizontal flow in a single aquifer system. The equations governing this flow are solved using the finite element method with quadrilateral elements and linear basis functions. The numerical solution is found using the conjugate gradient method.

AQ10 can be used to simulate either steady state or transient groundwater flow. In this study steady state conditions were assumed. This assumption was made for two reasons ,

1) lack of data against which to calibrate a transient model.

2) following discussions with the Quarry Manager there are indications that steady state conditions were reached.

Since a steady state is only reached when the same conditions persist for a long period of time a steady state model simulation will give greater drawdowns than a transient model simulation of the same conditions. Hence if the steady state assumption is incorrect for the Woolhampton Pit the model will overestimate drawdowns.

2.2.1 Spatial discretisation

The grid used by the numerical model is illustrated in Figure 1.

The grid consists of 13 elements in the East-West direction and 10 elements in the North-South direction. In both directions the grid spacing is 100m. The total area covered by the model is 1,300,000 m^2. The model grid is based on the Ordnance Survey grid.

In the East-West direction the model terminates at the limits of gravel working. In the North-South direction the model extends from the Southern limit of gravel working to North of the A4.

2.2.2 Boundary Conditions

At the points indicated on Figure 1 fixed head boundary conditions were imposed. At these locations the gravel is thin (< 1m), but , it extends far beyond the limits of the model. Under these conditions the heads at these locations will controlled by conditions outside the model domain and thus can be treated as fixed.

No boundary conditions were imposed at the other boundary nodes; at these nodes the model is free to adjust both the head and the flow.

2.2.3 Aquifer properties

Since steady state conditions were assumed the only aquifer property required is the transmissivity. This was calculated at each node as the product of saturated thickness and hydraulic conductivity. The saturated thicknesses used are shown in Figure 1. The are based on logs from boreholes drilled as part of the mineral assessment procedure.

2.2.4 Groundwater abstraction and recharge

It was assumed that there was no groundwater abstraction or recharge other than that from the gravel pits and the river.

2.2.4.1 Gravel pits

Two areas of abstraction were used to represent dewatering from the gravel pits. These areas, which are shown in Figure 1, represent dewatering during working of the gravel to the South and North of the river Kennet.

During model calibration groundwater was abstracted from the area to the South of the river only.

During the predictive simulations water was abstracted from the area to the North of the river only. The area to the South of the river was assumed to be either open water, leaky or sealed.

2.2.4.2 River

The nodes which were used to represent the river are indicated in Figure 1.

The river is not represented in the NE part of the modelled area since in this zone it is joined by the canal and is therefore likely to be sealed and thus not in hydraulic connection with the aquifer.

In the SW part of the modelled area the alluvial overburden is thin ; under these conditions it is likely that the river will be in good hydraulic connection with the aquifer.

Elsewhere the alluvium in thicker and thus there may or may not be good connection between the river and the aquifer.

2.3. Model calibration

Observations by either Steetley or Hydraulics Research gave the following data against which the model could be calibrated.

a) at an abstraction rate from the Southern pit of 500,000 gallons/hour there was between 5 and 6 m of drawdown at the Southern pit.

b) at an abstraction rate of 500,000 gallons/hour from the Southern pit there was a drawdown of approximately 3m 10m to the North of the river Kennet.

c) when the abstraction rate from the Southern pit was increased to 750,000 gallons/hour the drawdown at the Southern pit increased by 1-2m.

d) when the abstraction rate from the Southern pit was decreased to 250,000 gallons/hour the drawdown at the Southern pit was decreased by 2-3m.

The two unknowns which were varied in order to calibrate the model were the hydraulic conductivity and the degree of hydraulic connection between the river Kennet and the aquifer.

2.3.1 Hydraulic Conductivity

The only information available from which hydraulic conductivity estimates could be obtained were sediment gradings of material collected during the mineral assessment program. These gradings showed a wide range of sediment sizes and subsequently gave a wide range of possible hydraulic conductivity values.

When groundwater is abstracted from an aquifer system the maximum drawdown and extent of the resulting cone of depression depend on the transmissivity and thus the hydraulic conductivity. As the hydraulic conductivity increases the maximum drawdown decreases and the cone of depression extends over a greater areal area. This dependence on hydraulic conductivity is illustrated by Figures 2 and 3 which show the cones of depression resulting from abstraction at a rate of 500,000 gallons/hour from the Southern pit with hydraulic conductivities of 500m/day and 1000m/day respectively. In both cases it is assumed that there is no hydraulic connection between the river and the aquifer.

2.3.2 River-aquifer connection

No information exists on the degree of hydraulic connection between the river Kennet and the aquifer.

As the degree of connection between the river and the aquifer increases the groundwater levels, at a given abstraction rate and a given hydraulic conductivity will increase. This is illustrated by Figures 4 and 5 which show,respectively, the cones of depression resulting from abstraction at 500,000 gallons/hour from the Southern pit with no and perfect hydraulic connection between the river and the aquifer. In both cases an hydraulic conductivity of 750 m/day is assumed.

As described in section 2.4.2 there is an indication that the degree of hydraulic connection between the river and the aquifer varies along the river. In the SW part of the modelled domain it is almost certainly very good. Figure 6 illustrates the cone of depression which occurs for an abstraction rate of 500,000 gallons/hour from the Southern pit with perfect hydraulic connection along the Western part of the river and no hydraulic connection elsewhere. The hydraulic conductivity with this simulation was 750 m/d. Comparison of Figures 4 and 6 shows that good hydraulic connection in the western part of the river only has limited effect on the overall cone of depression.

2.3.3 Results of model calibration

A number of numerical experiments were carried out with hydraulic conductivities ranging from 500m/d to 1000m/d and degrees of hydraulic connection between the river and the aquifer ranging from none to perfect. All these experiments had an abstraction rate of 500,000 gallons/hour from the Southern pit. These numerical experiments resulted in drawdowns at the Southern pit which ranged from 1.5m to 12.5m.

The best calibration against criteria a) and b) given above was achieved with the following conditions,

* hydraulic conductivity 750m/d

* perfect connection between the river and aquifer in the SW part of the modelled domain.

* elsewhere the river is leaky. At each river node the recharge rate is 40% of that which occurred with perfect hydraulic connection.

The results of the best model calibration are shown in Figure 7.

2.3.3.1 Pit abstraction rate = 750,000 gallons/hour

In order to see if condition c) was satisfied by the calibrated model described above the abstraction rate from the Southern pit was increased to 750,000 gallons/hour. The leakage from the river nodes was also increased by 50%. This numerical experiment gave increases in drawdown at the Southern pit of more than 3m. The groundwater heads calculated in this experiment implied a increase in hydraulic gradient in the vicinity of the river relative to the model calibrated at an abstraction rate of 500,000 gallons/hour. This indicates a greater potential for leakage from the river. In order to satisfy this potential the recharge from the river was increased further to twice that in the model calibrated at an abstraction rate of 500,000 gallons/hour. The resulting numerical experiment gave good calibration against calibration criterion c). The results of this experiment are shown in Figure 8.

2.3.3.2 Pit abstraction rate = 250,000 gallons/hour

The abstraction rate from the Southern pit was now reduced to 250,000 gallons/hour. The leakage from the river was decreased , relative to the 500,000 gallons/hour calibrated model, by proportionally the same amount as it was increased in the final numerical experiment described in section 3.3.1; the resulting proportion was 0.375.

The results of this numerical experiment, which gave good agreement with calibration criterion d) are shown in Figure 9.

Table 1 gives, for the calibrated model at each of the abstraction rates, the amount of the abstracted water coming from direct river recharge. Table 1 also sub-divides the river recharge into that coming from the Western part which is in good hydraulic connection and the rest of the river which is leaky.

2.4. Predictive simulations - gravel working to the North of the river Kennet.

Once gravel working to the South of the river Kennet has been completed it is planned to landscape the edges of the pit using impermeable clay where the pit is shallow and overburden where the pit is deep. This landscaping will form a partial but not perfect seal. To the North of the river Kennet it is planned to dewater using two submersible pumps with a total capacity of 250,000 gallons/hour. As far as is possible it is hoped to work the gravel to the North of the river Kennet dry.

These planned working procedures were simulated using the calibrated numerical model described in section 3.3.2. In these simulations there are three possible ways of representing the Southern pit - unsealed, partially sealed and totally sealed. When the Southern pit was represented as partially sealed the same proportional leakage rate as from the river was assumed.

The results of the numerical simulations with abstraction from the Northern pit at a rate of 250,000 gallons/hour and the three different Southern pit sealing conditions are shown in Figure 10. These results show that even under the best possible scenario viz. Southern pit sealed, only between 3 and 4m of drawdown are achieved at the Northern pit. At the other extreme a drawdown of only between 1 and 2m could be achieved if the Southern pit were unsealed. The most realistic scenario of a leaky Southern pit gives a maximum drawdown at the Northern pit of between 2 and 3m.

In order to increase the drawdown at the Northern pit the pumping rate could be increased. Figure 11 and 12 respectively illustrate, for the three types of Southern pit sealing, the cones of depression with abstraction rates at the Northern pit of 500,000 gallons/hour and 750,000 gallons/hour. For the most realistic scenario of a partially sealed Southern pit the maximum drawdown at the Northern pit is between 5 and 6m for an abstraction rate of 500,000 gallons/hour and between 6 and 7 m for an abstraction rate of 750,000 gallons/hour.

The quantities of the abstracted water coming from the river and southern pit for the most realistic scenario of a leaky Southern pit with Northern pit abstraction rates of 250,000 500,000 and 750,000 gallons/hour are given in Table 2.

2.5. Conclusions

Based on the results of the numerical model the following conclusions can be drawn,

1. The average hydraulic conductivity of the aquifer under study is approximately 750 m/d.

2. Over most of its length the river Kennet is not in perfect hydraulic connection with the aquifer. At an abstraction rate of 500,000 gallons/hour from the Southern pit the best calibration is achieved with leakage at 40% of that which would occur if hydraulic connection were perfect.

3. As the abstraction rate from the Southern pit either increases or decreases the proportional increase or decrease in river leakage must be greater than that of abstraction in order to achieve calibration.

4. With the best possible scenario of a sealed Southern pit the maximum drawdown that could be achieved at the Northern pit with an abstraction rate of 250,000 gallons/hour is less than 4m. With the worst possible scenario of an unsealed Southern pit the corresponding maximum drawdown is less than 2m.

5. Under the most realistic scenario of a partially sealed Southern pit the maximum drawdown which could be achieved at the Northern pit with an abstraction rate of 250,000 gallons/hour is between 2 and 3m. If the abstraction rate from the Northern pit was increased to 500,000 or 750,000 gallons/hour the corresponding maximum drawdowns would, respectively, be between 5 and 6m and between 6 and 7m.

TABLE 1

Sources of recharge for southern pit abstraction

Southern pit abstraction
River · perfect hydraulic connection in West
Leaky elsewhere
K = 750 m/day

Abstraction rate (gallons/hr)	Leaky river recharge m^3 (percentage of total river recharge)	Other river recharge m^3 (percentage of total river recharge)	Total river recharge m^3 (percentage of pit abstraction)
250,000	7266(58)	5298(42)	12564(46)
500,000	19377(68)	9170(32)	28547(52)
750,000	38754(78)	10970(22)	49724(61)

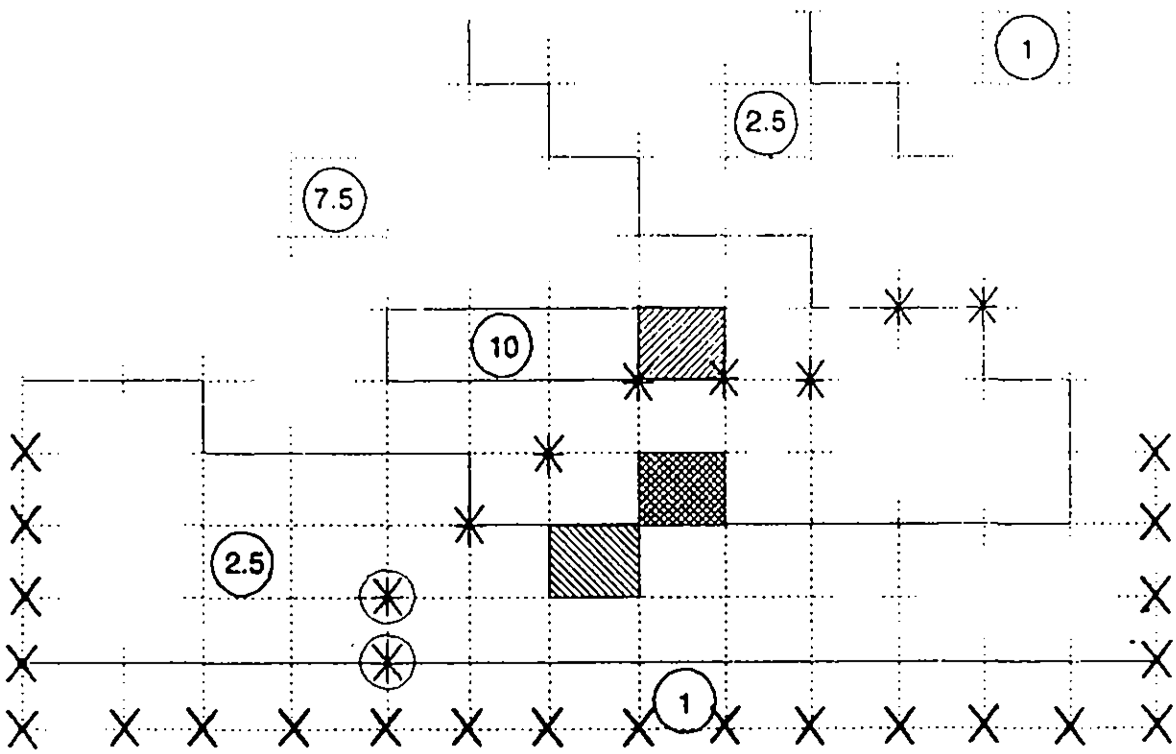
TABLE 2

Sources of recharge for Northern pit

Northern pit abstraction
River · perfect hydraulic connection in west
leaky elsewhere
Southern pit leaky
K = 750 m/day

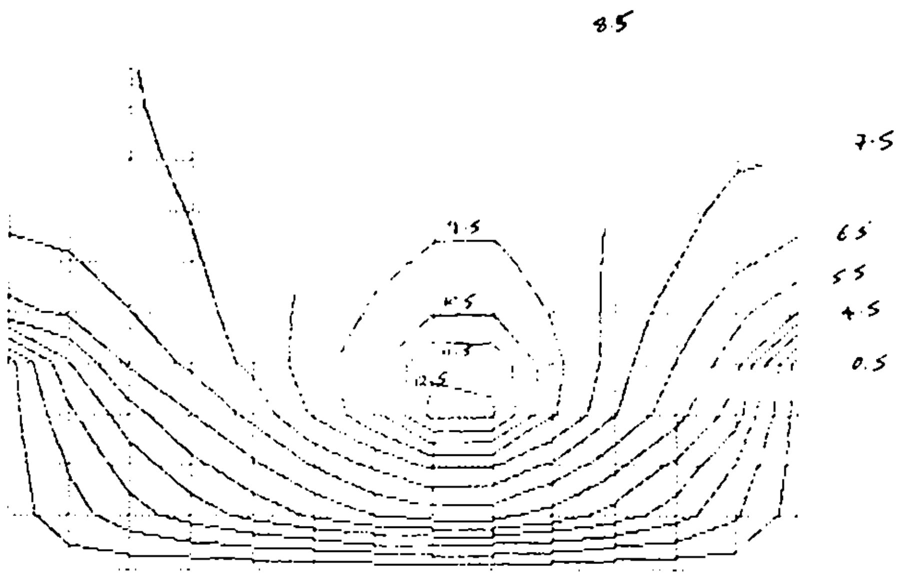
Abstraction rate (galls/hr)	Leaky river recharge m^3 (percentage of total river and southern pit recharge)	Other river recharge m^3 (percentage of total river and southern pit recharge)	Southern pit recharge m^3 (percentage of total river and southern pit recharge)	Total river and southern pit recharge m^3 (percentage of total northern pit abstraction)
250,000	3930(28)	4801(34)	5438(38)	14169(52)
500,000	10479(32)	7887(24)	14502(44)	32868(60)
750,000	20958(36)	8364(14)	29004(50)	58326(71)

Model Grid

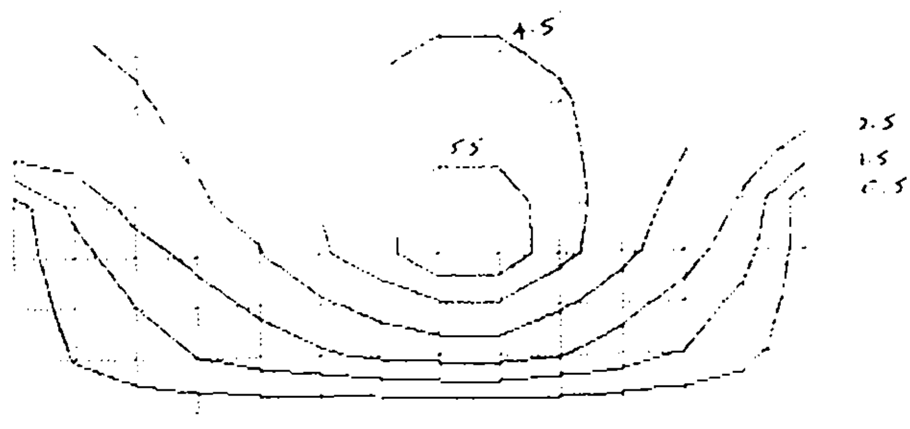


× Fixed head boundaries
⊛ Perfect hydraulic connection river nodes
* Leaky or perfect hydraulic connection river nodes
▨ Northern pit abstraction
▩ Southern pit abstraction
▧ and ▩ Southern pit restoration : unsealed, partially sealed, or sealed
— Saturated thickness boundaries
(2.5) Saturated thickness values (m)

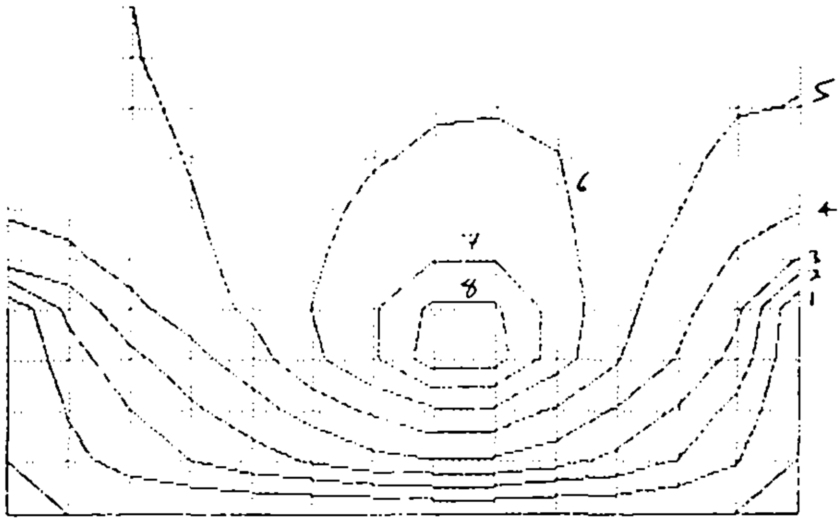
Figure 1



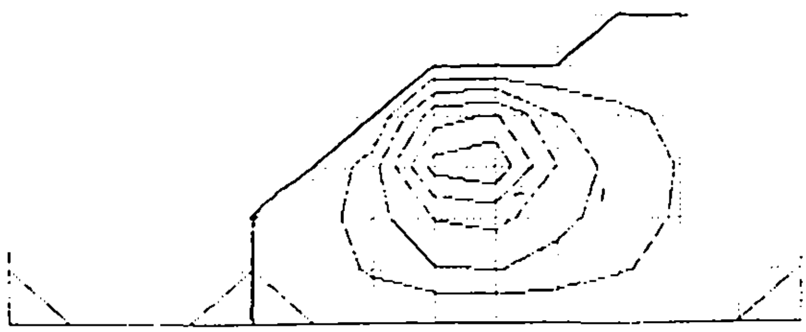
2. Southern pit. Abstraction 500000gph, K=500m/d No river recharge



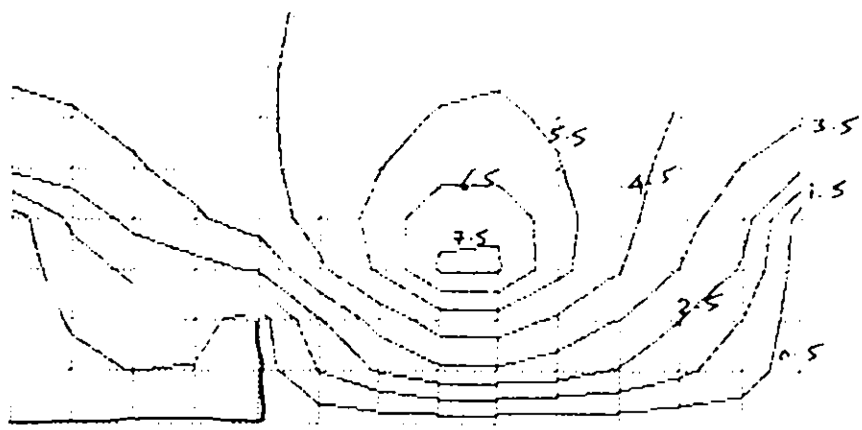
3. Southern Pit. Abstraction 500000gph, K=100m/d No river recharge



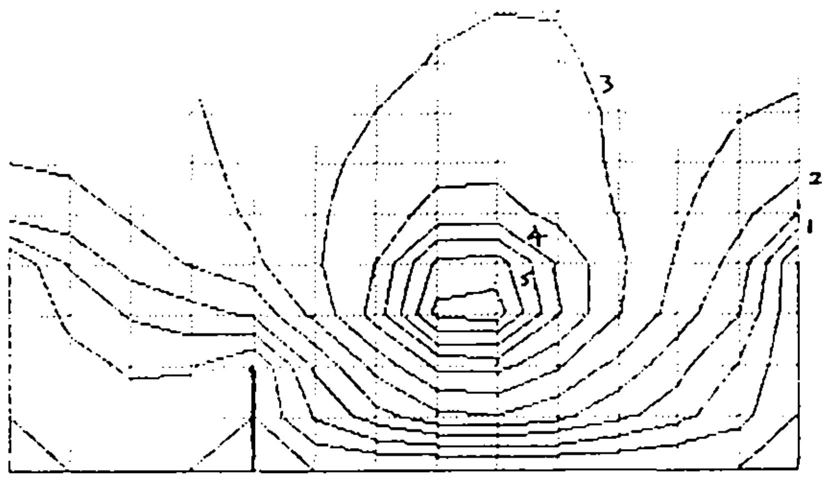
4. Southern Pit. Abstraction 500000gph, K=750m/d No river recharge



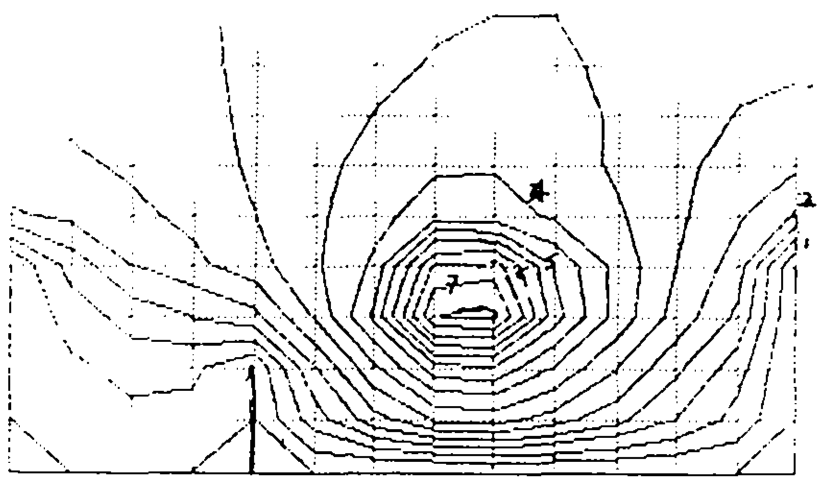
5. Southern Pit. Abstraction 500000gph, K=750m/d With river recharge and full hydraulic connection



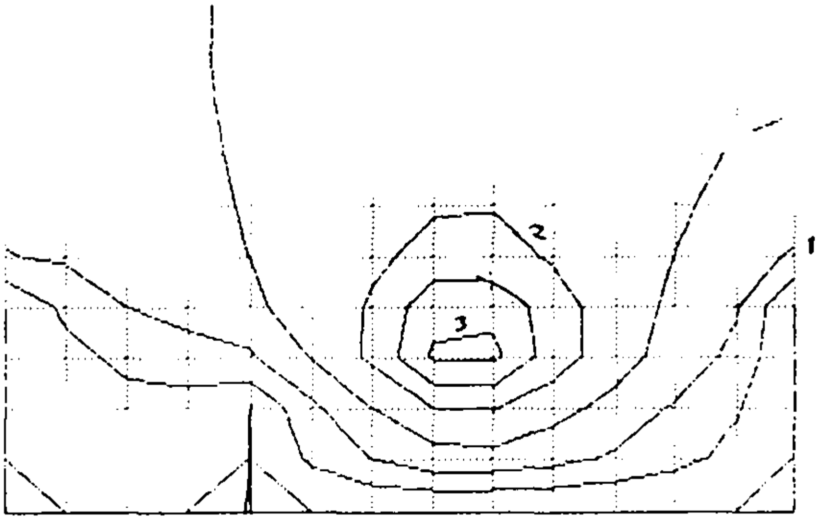
6. Southern Pit. Abstraction 500000gph, K=750m/d With river recharge but full hyraulic connection only to west of pit



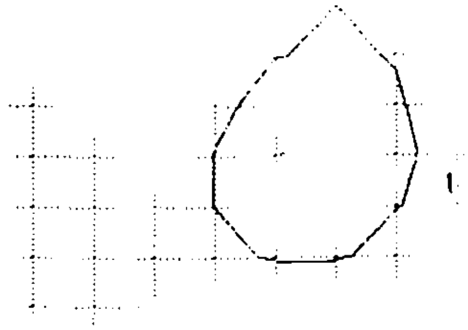
7. Southern Pit. Abstraction 500000gph, K=750m/d With river recharge but full hydraulic connection to west of pit and imperfect connection adjacent to pit

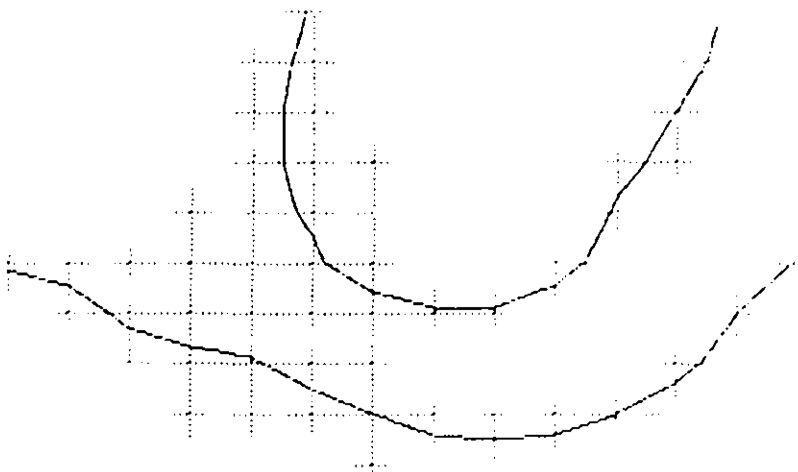


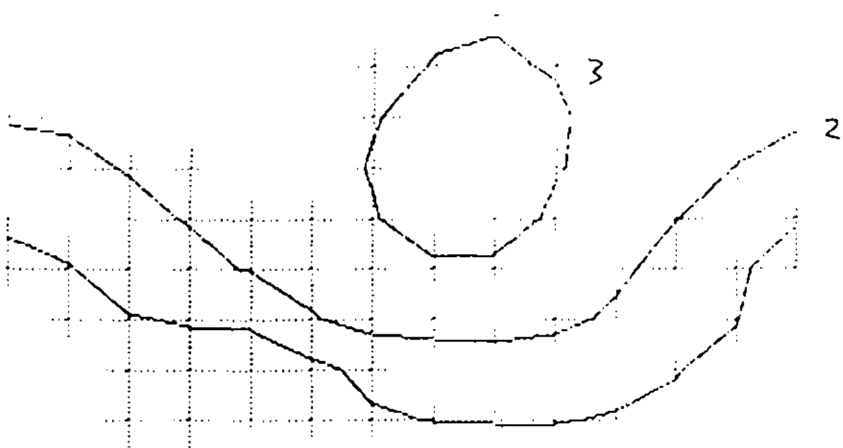
8. Southern Pit. Abstraction 750000gph, K=750m/d With river recahrge but full hydraulic connection to west of pit and imperfect connection adjacent to pit



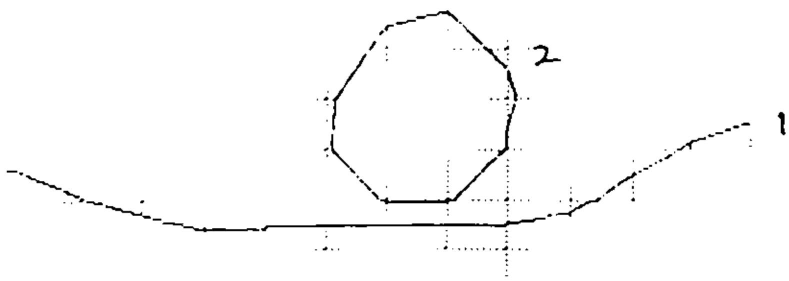
9. Southern Pit. Abstraction 250000gph, K=750m/d With river recharge but full hydraulic connection to west of pit and imperfect connection adjacent to pit

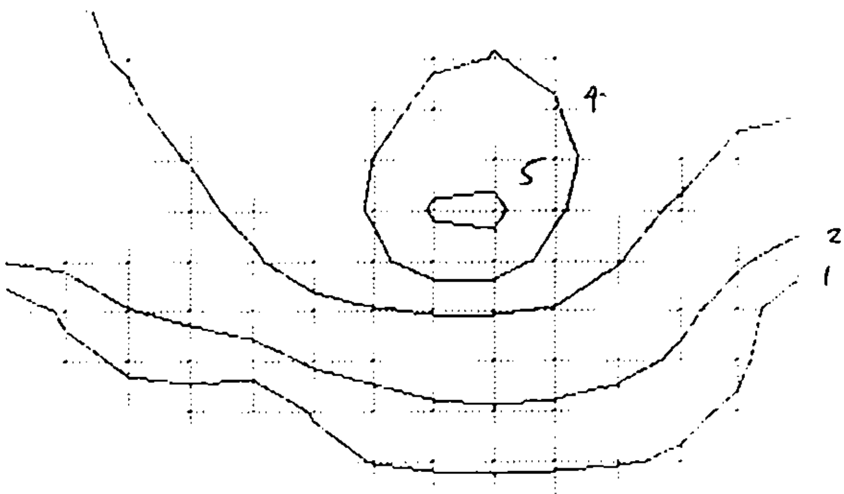


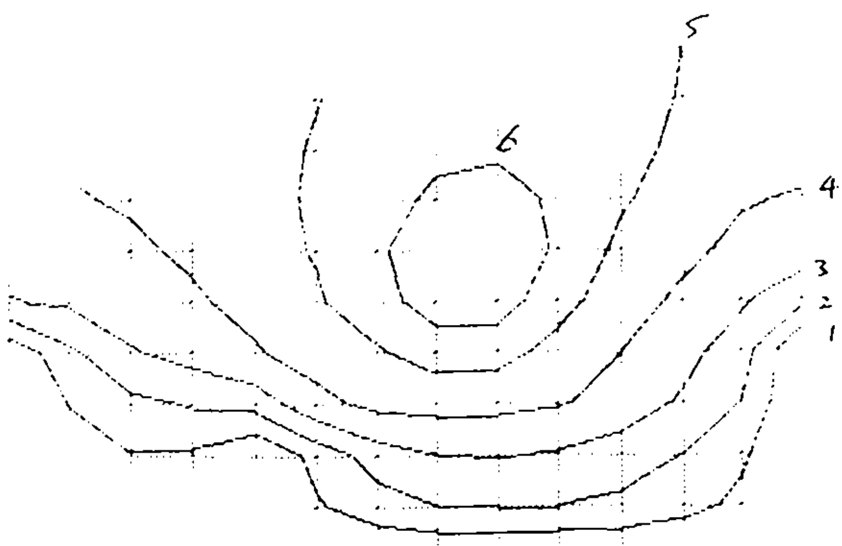




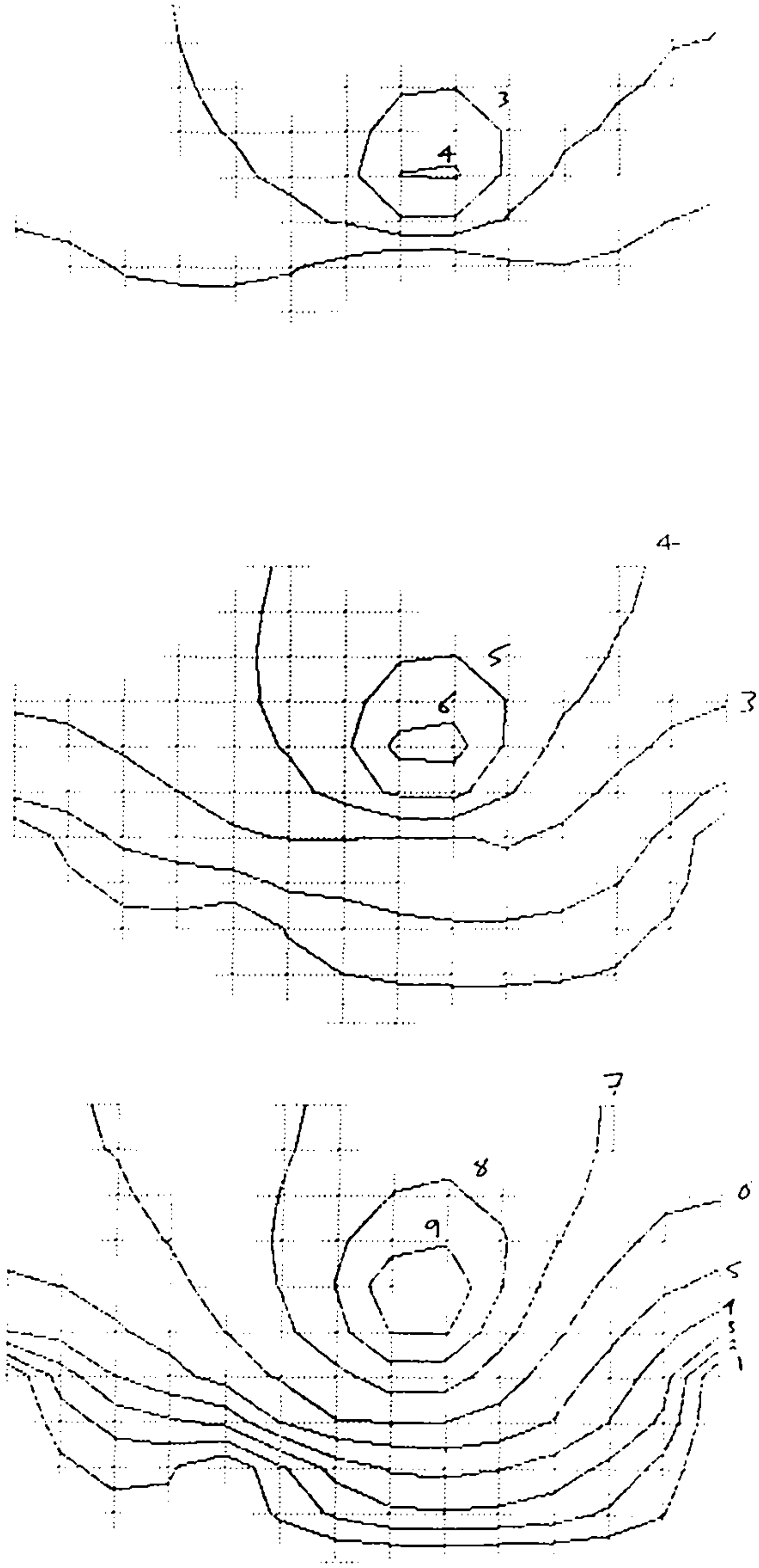
10. Northern pit. Abstraction 250000gph, K=750m/d With river recharge but full hydraulic connection to west of pit and imperfect connection adjacent to pit
    (a) Southern Pit unsealed
    (b) Southern pit partially sealed
    (c) Southern pit sealed







11. Northern pit. Abstraction 500000gph, K=750m/d With river recharge but full hydraulic connection to west of pit and imperfect connection adjacent to pit
    (a) Southern pit unsealed
    (b) Southern pit partially sealed
    (c) Southern pit sealed



12. Northern pit. Abstraction 750000gph, K=750m/d With river recharge but full hydraulic connection to west of pit and imperfect connection adjacent to pit
(a) Southern pit sealed
(b) Southern pit partially sealed
(c) Southern pit sealed

3. Impact of overburden bund on pit inflows

3.1 Introduction

The major objective of placing an overburden bund between the river Kennet and the gravel workings to the North of the river is to reduce pit inflows. In this chapter a flow net model is used to investigate the effect of different bund configurations on the pit inflows.

3.2 Bund configurations investigated

Three configurations were investigated;

(a) no overburden bund,

(b) overburden bund to a depth 4 m above the base of the gravels,

(c) overburden bund to a depth 1 m above the base of the gravels.

These configurations are illustrated in Figure 13.

For each configuration a linear phreatic surface with a phreatic level of 12 m at the river and 4 m at the pit was assumed.

3.3 Results for different configurations

The results for the different configurations are presented in Table 3. These show that the emplacement of an overburden bund reduces the pit inflow. The amount of reduction depends on the depth of the bund; for a bund to a depth of 4 m above the gravel base the reduction is 13% whilst for a bund to a depth of 1 m above the gravel base the reduction is 16%.

3.4 Discussion

The placing of an overburden bund between the River Kennet and the gravel workings to the North of the river will reduce pit inflows. This reduction is , however , relatively small and depends on the depth of the bund relative to the base of the gravels.

The emplacement of a bund will also affect slope stability; this is discussed in the next chapter.

3.5 Recommendations for further work

Flow into the gravel pit to the North of the River Kennet is dependent on both hydraulic gradient and aquifer properties. In order to carry out the work described in this chapter values have been assumed for each of these parameters ; the conclusions drawn are to some extent dependent on the assumed values. In order to improve estimates of the impact of a overburden bund on pit inflows field measurements of hydraulic gradient and hydraulic conductivity are required.

TABLE 3

Pit inflows for different configurations simulated with flow net model

Configuration	Pit Inflow ($m^2/m/day$)	Pit inflow (As percentage of configuration 1 pit inflow)
[illegible]	407	100
[illegible]	355	87
3	340	83

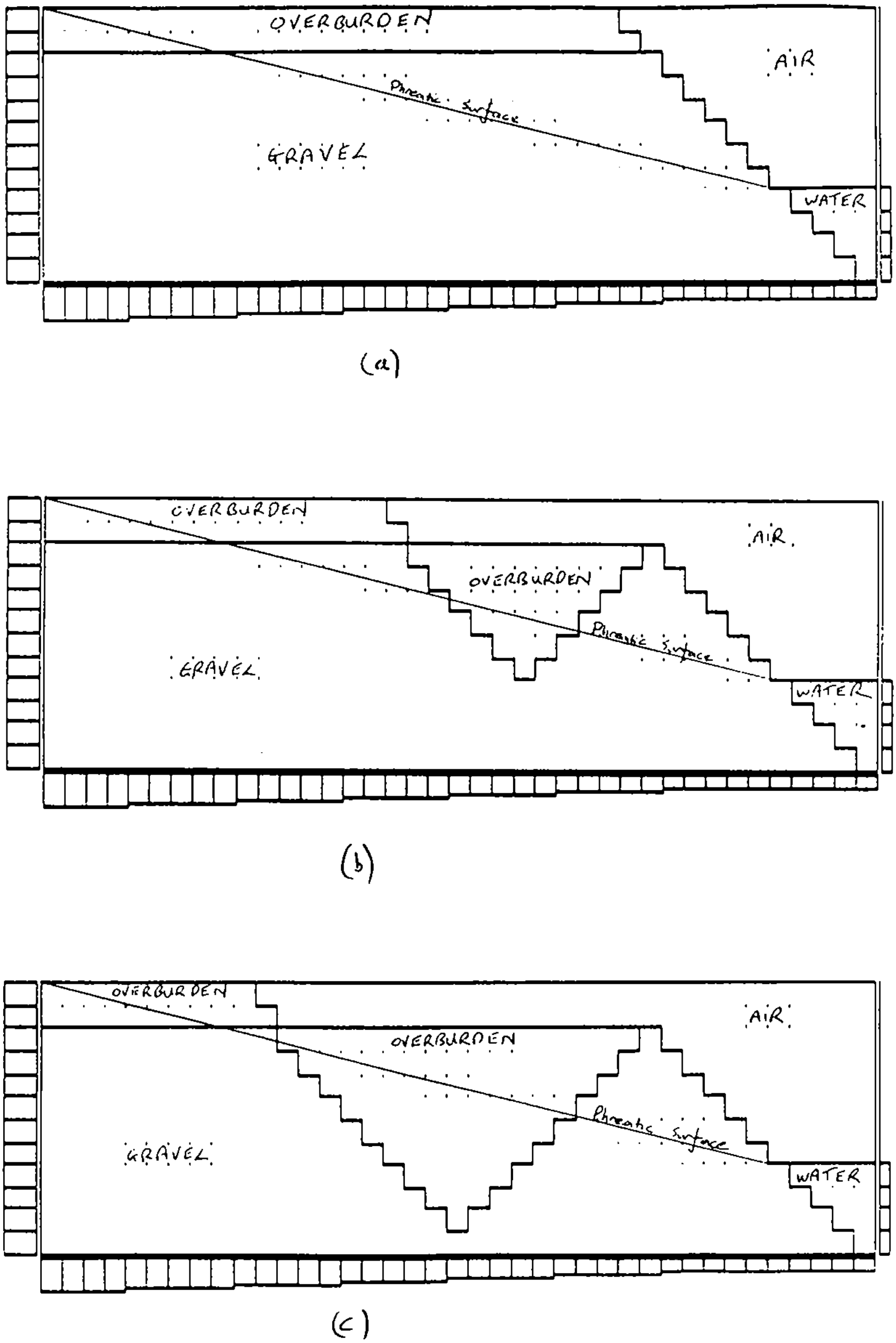


FIGURE 13 Configurations investigated with flow net model

Slope stability analysis

4.1 Introduction

The proposed procedure for excavating gravel from the Woolhampton Pit comprises a number of stages. Each of these stages give rise to a potential slope stability problem. An analysis of the likely slope stabilities has been undertaken based on limited geotechnical information. Three configurations of excavations were assessed for slope stability, each with either two or three assumed phreatic water level profiles (Fig 14).

The final phase of the excavation in which soil is placed at a shallower angle on the exposed gravel cut was not analysed. It was not reasonable to estimate soil strength parameters in this case as the stability of the final slope would depend so greatly on the estimated parameters.

4.2 Soil properties and methodology

The overall assumed soil profile was a 10m thick fluvial gravel lying on a firm stratum. Overlying the gravel was 2m of a sandy soil. The phreatic water level was not known, and therefore, different assumed phreatic water levels were investigated (Fig 14). Each phreatic water level emerged at 4m above the firm stratum. Estimates of the bulk density of the two soils were made · $1.8Mgm^{-3}$ for the sandy overburden and $1.7Mgm^{-3}$ for the fluvial gravel. However, little information was available on the strength characteristics of the soils. The angle of repose of the gravel at minimum density, i.e. in a spoil heap after being excavated, was estimated to be 35°. Accordingly, a value of 45° was assumed for the angle of shearing resistance of the in-situ gravel. An angle of shearing resistance of 30° was assumed for the sandy overburden.

It can immediately be appreciated that the surface of such excavations will be unstable as the cut slope angle of 45° is equal to the angle of internal shearing resistance.

The slope stability analysis was performed using the computer program

SLOPE v5 from Geosolve. Bishop's method with parallel inclined interslice forces was selected. Circular slip circles were used with a common tangent at the interface between the gravel and the firm stratum beneath.

Analyses of the stability of deep circular slips in the excavation were undertaken to determine the factor of safety, i.e. the factor by which the strength of the soil can be reduced before failure occurs.

4.3 Results for configurations

The first configuration represents the stable cut which has already been used in the excavation of the gravel pit to the south of the river. It comprises a 10m deep gravel bed cut at an angle of 45 degrees to within 1m of the firm underlying stratum. The worst case (and somewhat unrealistic) assumption of a high phreatic water level (W.L.(1) on Fig 14) gave a factor of safety (FS) slightly less than unity. This means that such a slope would fail. The FS for the low phreatic water level (3) and the intermediate phreatic water level (2) was a little above unity, i.e. on the point of failure. These findings indicate that the assumptions made as to the soil parameters are to some extent justified in that the existing configuration of excavation, which is known to be stable, was predicted to be just stable.

The second configuration investigated related to the excavation of the trench in the fluvial gravel prior to filling with more impermeable soil. Again, the stability of deep circular slips was studied (Fig 14). The results indicated that the factor of safety was close to unity, hence, the slope was on the point of failure. A sensitivity analysis was conducted by reducing the assumed angles of internal shearing resistance to 40° for the fluvial gravel and 15° for the sandy overburden. The effect on the stability was to reduce the FS to significantly below unity, i.e. to a failure condition.

The third configuration considered (Fig 14) represented the phase when the trench had been backfilled and the gravel cut at 45° to the firm stratum. The stability in the bund of gravel was investigated for two phreatic water level conditions. The effect of the phreatic water level was minimum with the FS just greater than unity for a deep circular slip. The effect of upward seepage forces in the gravel just beneath the bottom of the trench on the stability of the slope were found not to be significant for the assumed soil profiles and phreatic water levels.

4.4 Discussion

The analyses of slope stability has shown that there is a predicted failure by deep circular slips in the first two configurations. The factor of safety for these configurations were similar. However, the first configuration is a representation of the existing stable excavation at the gravel pit to the south of the river. Therefore, it could be argued that as that excavation has been demonstrated as being stable the proposed new excavation (configuration II) would also be stable. What is not known though, is the closeness of the existing slopes at the southern site to failure.

It must be appreciated that a small general reduction in the shear strength of the fluvial gravel would result in a clear failure condition. In addition, any local variation in the soil properties could have a serious effect on the stability on that part of the excavation.

As the consequences of failure are catastrophic with the river only 10m from the top of the cut, it is advisable, even with a knowledge of the soil parameters, that the calculated factor of safety of the excavations does not fall below 1.5 at any stage. If the soil parameters are not determined through field and laboratory testing, it is advisable to ensure a minimum factor of safety of 2. As ~~this is by~~ the soil properties are not known in ~~no means~~ the present case it is considered necessary to investigate the stability of the slopes in more detail.

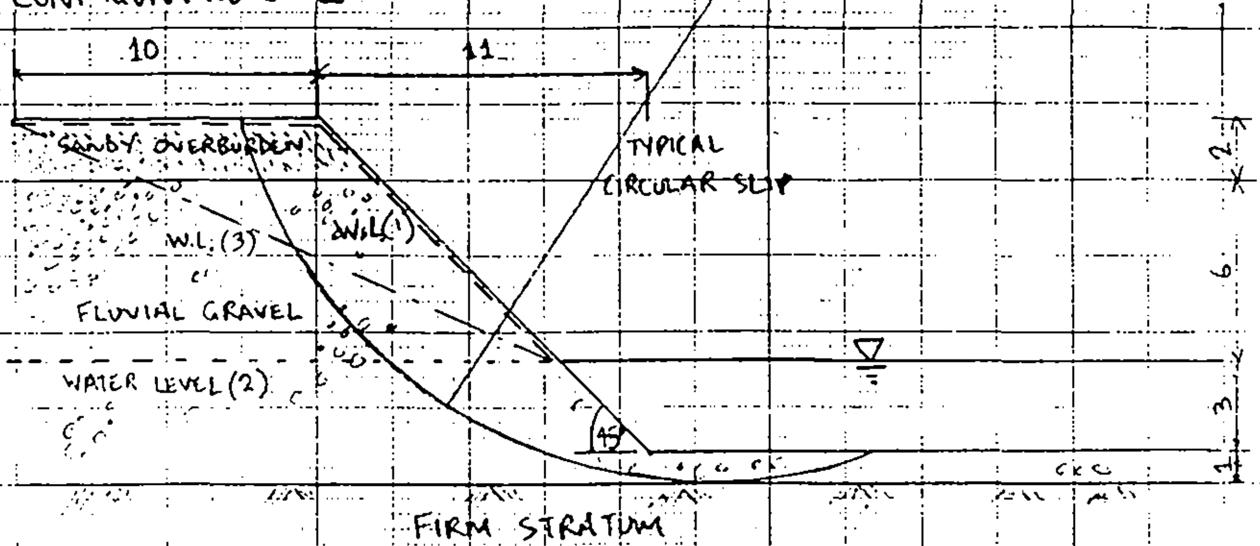
Recommendations for future work

Without undertaking some kind of field investigation, a further desk analysis of the slope stability would probably result in very conservative slope angles being advised. It is likely that slope angles in the region of 25° would be advised.

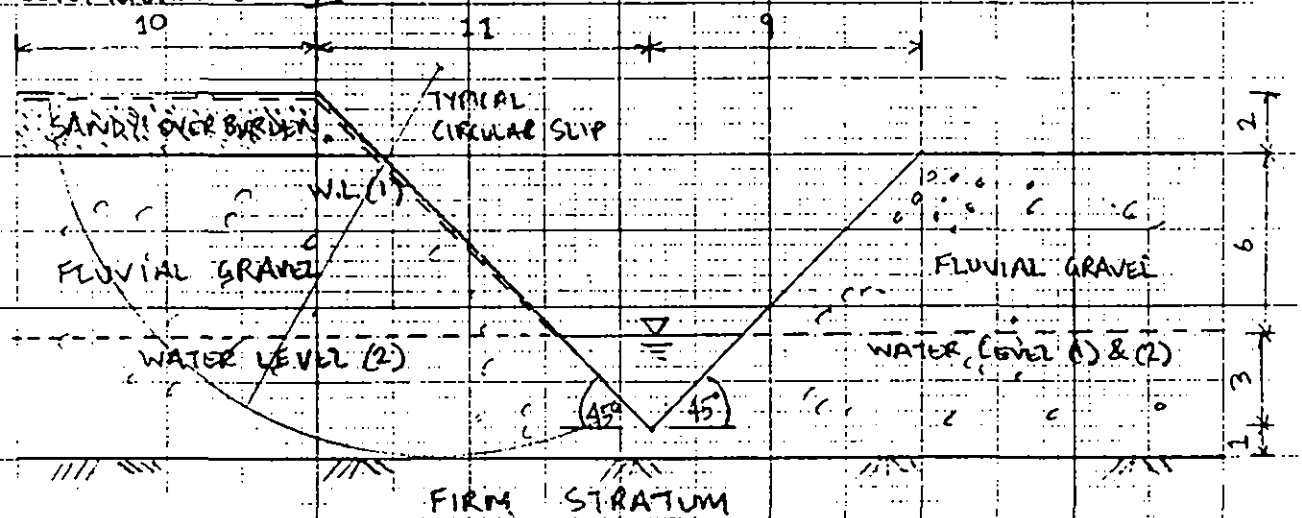
Accordingly, it is recommended that a field investigation with some laboratory analysis of samples is undertaken. This would be followed a mathematical model prediction of the phreatic water level and further analysis of the slope stability leading to recommendations of the optimum excavation configurations.

The field investigation would comprise excavation of a number of trial pits and slopes along the length of the proposed trench. This would enable a visual inspection of the soil strata and sampling of the soils and to take place. Quick undrained shear box laboratory tests would be performed on some of the samples. A series of specifically designed field tests on a number of trial slopes would also be conducted to assess the actual stability of slopes. Comparison with slope stability predictions would give an indication of the variability in soil properties and assumed failure mechanisms. The phreatic water level in the trial slopes could be estimated from standpipe measurements.

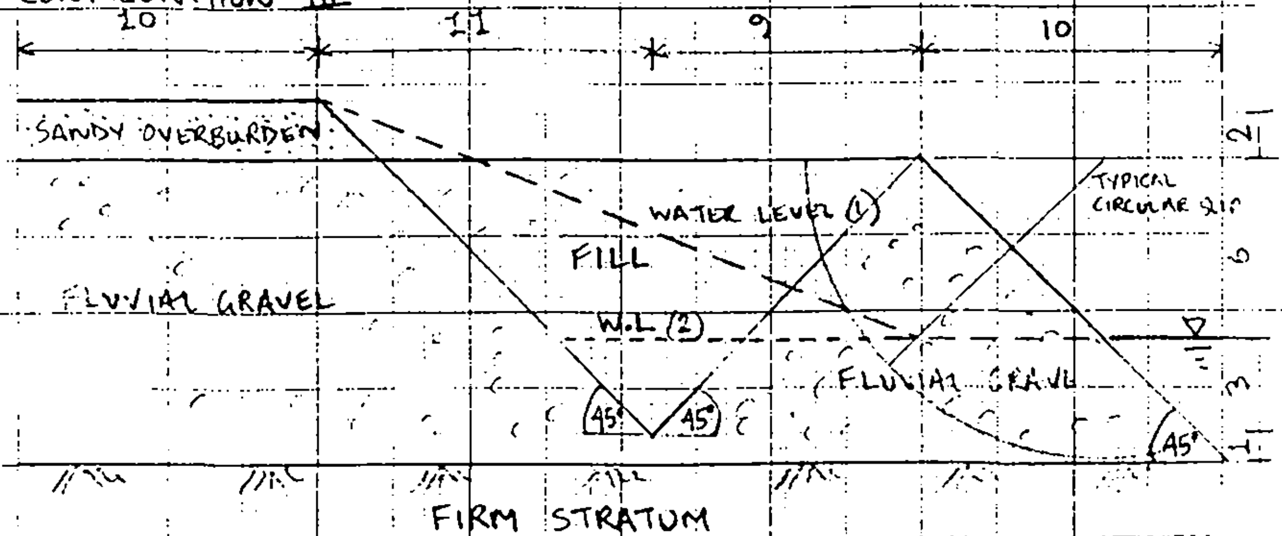
CONFIGURATION I



CONFIGURATION II



CONFIGURATION III



ALL DIMENSIONS IN METRES SCALE 1:250

FIG 1.4 CONFIGURATIONS OF SLOPES ASSESSED FOR STABILITY

5. Conclusions

The conclusions from this study can be summarised as follows:

1. The River Kennet must be in hydraulic connection with the gravel deposits to produce the drawdowns reported in the southern pit. The degree of connection is influenced by the thickness of the alluvium and is likely to vary along the river.

2. A bund placed adjacent to the river where the gravel is thin (< 3m) has been shown to reduce inflows to the southern pit. However, it is still possible for flow to move north from the river at the edge of the cone of depression (where the water table will still be in direct connection with the river) and then swing south beneath the partial bund at the eastern edge of the pit where the aquifer is thickest and then into the southern pit.

3. It is probably impractical to form a complete seal between the river and each pit in the area of thickest gravels at the eastern end of the workings. Consequently, the northern pit will remain in hydraulic connection with the southern pit.

4. When, as currently proposed, the southern pit is flooded whilst working the northern pit, water will move beneath the bund where the gravel is thickest and into the northern pit. However, the emplacement of a partial bund can reduce inflows by up to 20%.

5. The required drawdowns are unlikely to be achieved if the northern pit is worked in the way proposed. The implications of this are that:

(a) higher pumping rates than those proposed are likely to be needed to dewater the northern pit; or,

(b) an effective seal would have to be placed to the full depth of the gravel sequence along the river and around the eastern and southern edge of the southern pit; or,

(c) the southern pit will need to retained in a dry condition.

Any of these alternatives will incur additional costs.

6. If the northern pit is worked in the way proposed then the slopes will be close to ,if not at, the point of failure. A lower angle of slope, perhaps as low as 25 degrees, is indicated. This also has cost implications since this will reduce the area that can be worked.

Due to the lack of appropriate data, it should be noted that the results and conclusions from this study have been based on various assumptions. Further work would be required to undertake a more detailed analysis.

The demand for long-term scientific capabilities concerning the resources of the land and its freshwaters is rising sharply as the power of man to change his environment is growing, and with it the scale of his impact. Comprehensive research facilities (laboratories, field studies, computer modelling, instrumentation, remote sensing) are needed to provide solutions to the challenging problems of the modern world in its concern for appropriate and sympathetic management of the fragile systems of the land's surface.

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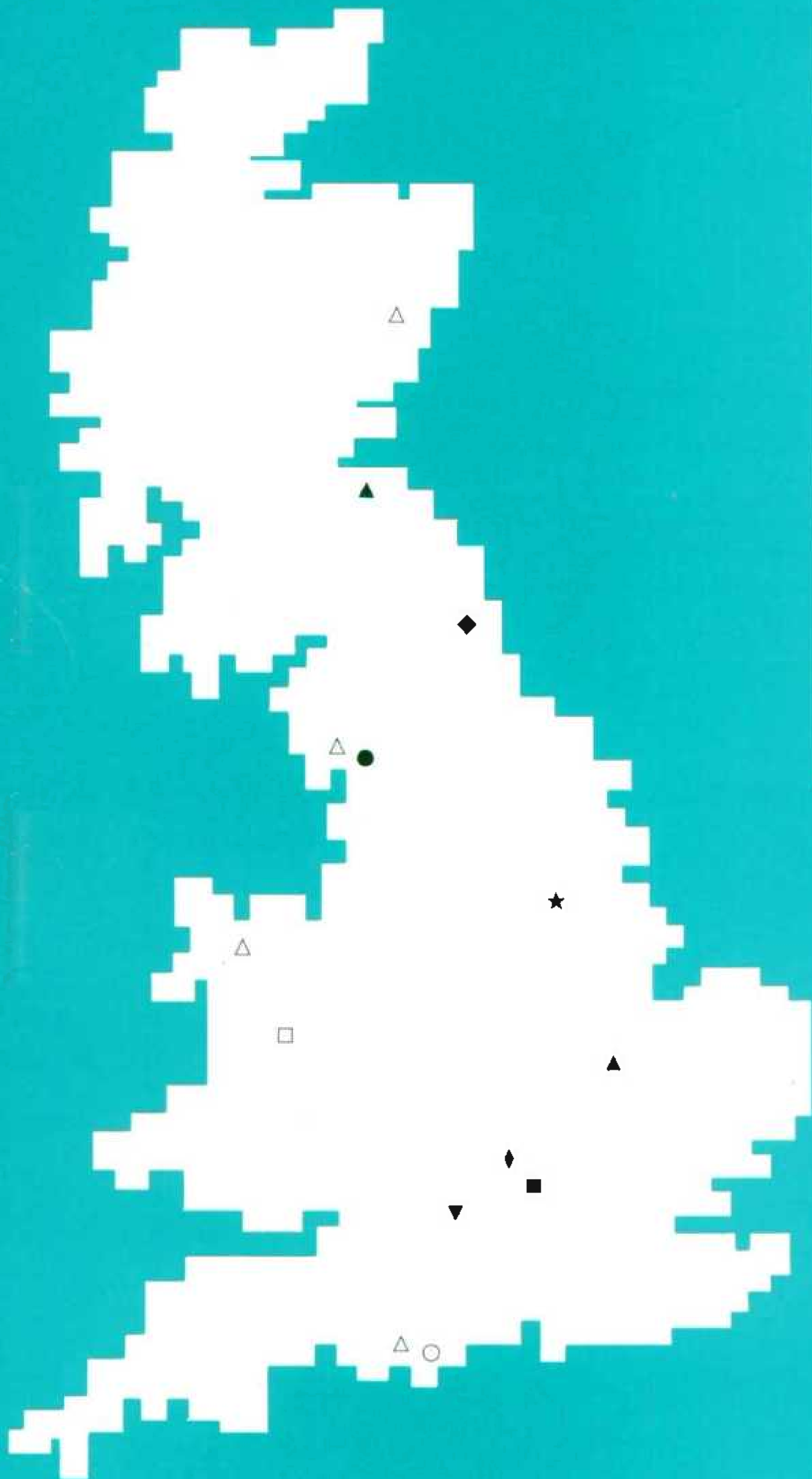

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