National Rivers Authority
Anglian Region

SOUTH LINCOLNSHIRE LIMESTONE AQUIFER : SEALING OF WILD BOREHOLES

Final Report

April 1993

HALCROW

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NATIONAL RIVERS AUTHORITY ANGLIAN REGION

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FINAL REPORT

APRIL 1993

REPORT AUTHORISATION

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SOUTH LINCOLNSHIRE LIMESTONE AQUIFER:
SEALING OF WILD BOREHOLES

FINAL REPORT

Contents

SUMMARY

A project has recently been completed to seal and control 30 discharging artesian ("wild") boreholes in the Lincolnshire Limestone aquifer in the Fenland area to the east of Bourne, Lincolnshire. This project is the first major effort to control such discharges on a regional scale and has resulted in a considerable saving in water resources for the area, between 7.5 Ml/d and 18 Ml/d depending upon the extent of aquifer storage. In addition environmental conditions in the area were reviewed before, during and after the works to assess the ecological impacts resulting from the changes in groundwater discharge and distribution.

The objective of this report is to provide a record of the work done during this project and to act as a starting reference for any similar works that may be undertaken in the future.

1 INTRODUCTION

In June 1991 Sir William Halcrow and Partners Ltd were commissioned by the National Rivers Authority (NRA) to undertake the controlling of a number of "wild" boreholes in the Lincolnshire Limestone aquifer in the vicinity of Bourne in Lincolnshire. A wild borehole is defined as an artesian borehole that is no longer under control due to physical damage to its casing such that it is discharging continuously and uncontrollably.

Prior to carrying out this work initial assessments were made of the ecology and hydrology associated with each borehole. These studies complemented earlier ecological studies undertaken by Loughborough University and provided up to date flow information at each site for comparison with data collected by the Anglian Water Authority in the 1970's. The results of these assessments were reported in July 1991 (Halcrow, 1991).

The main objective of the project was to conserve water in an area severely depleted in groundwater resources following a four year drier than average period of rainfall. The loss of water resources in the area through the continual discharge of wild artesian boreholes was well documented during the 1970s, however remedial work had not been carried out since that time when a repair to a "wild" bore at Aslackby Fen proved extremely difficult. This project was the first major effort to control discharges on a regional scale. In addition to the practical problems of repairing the boreholes it was necessary to maintain supplies to existing surface water abstractions and to ecological environments that have resulted directly from the borehole discharges.

The objective of this report is to provide a record of the methods, techniques and materials used in order to seal or control these wild boreholes.

Between June 1991 and October 1992, 35 to 40 boreholes were assessed in an area extending from Helpringham in the North to the Deepings in the South (Figure 1.1). Thirty of the boreholes were repaired and this report details the work carried out on each and the initial effects seen as a result of the repairs.

The work had been planned to commence in June 1991 to take advantage of the low groundwater levels in the Lincolnshire Limestone at that time. It was considered, based on earlier experience, that the boreholes would be easier to repair under low flowing conditions. In fact, it was found that strong flows, whilst making working conditions difficult, were advantageous in cleaning out loose material from the borehole column, and a reasonable flow was necessary in order to locate old boreholes lost below ground level.

The low groundwater levels also meant that the immediate effects of repair might not be typical and that the full effects would only be seen after a prolonged period of recharge.

Because of constraints regarding existing use only 11 of the 30 boreholes could be sealed outright the remaining 19 had to be controlled, a more complicated process. The greatest problem encountered during the work was where previous repairs, sometimes more than once, had been attempted. These led to the longest times taken to control holes and in four cases resulted in only partial successes.

The contractual work was undertaken by Barradell Drilling Services under the supervision of a Resident Engineer and an Assistant Resident Engineer from Halcrow. Halcrow staff had received site Health and Safety training and ensured that good practice was carried out on site for the duration of the project. Additionally particular aspects of the repair works, for example shaft sinking, were subject to their own relevant British Standard Code of Practice.

At the end of the project the estimated saving achieved in water resources lies in the range 7.5 to 18 Ml/d depending on the level of aquifer recharge. The cost of the work, calculated in terms of the total Contract cost divided by the estimated water saving is between £60,000 and £110,000 per Ml/d of water.

At the end of the initial Contract period groundwater conditions were still favourable and progress was reasonably good. The NRA decided to extend the Contract and take in additional boreholes from their original list and also new boreholes identified during the project. Follow-up ecological and hydrological assessments were carried out to cover all the potential borehole sites. The results of these assessments were reported in March 1992 (Halcrow, 1992).

Further extensions to the Contract were subsequently approved by the NRA which allowed the number of boreholes to be repaired to reach thirty and to include all the known major uncontrolled artesian discharges in the area. One other wild borehole was repaired privately during the project under NRA approval.

2 HYDROGEOLOGY

2.1 Hydrogeological review

The Lincolnshire Limestone is an important aquifer in the region and is used extensively for public and private water supply.

In the study area, the Lincolnshire Limestone is some 25 to 30 metres thick. It is overlain by a sequence of interbedded clays and limestones followed by the Oxford Clay. All these strata are of Jurassic age. The Lincolnshire Limestone crops out to the west of Bourne in a broadly north- south direction and dips to the east at an angle of less than 1 degree. This means that the limestone is getting progressively deeper such that at Spalding the top of the limestone is about 80 metres below ground level. A simplified cross section is shown in Figure 2.1 and a typical borehole log in Figure 2.2.

Recharge to the aquifer occurs at outcrop by direct infiltration and is supplemented by infiltration of runoff from adjacent less permeable units such as Boulder Clay. The presence of swallow holes in the outcrop area results in two component recharge, with a rapid response to recharge being seen within a day or two of rainfall. This rapid response reflects the interconnection between the surface swallow holes and the extensive fissuring that occurs in the Lincolnshire Limestone. A much slower component of recharge takes place through intergranular permeability within the rock matrix of the Lincolnshire Limestone.

As the limestone dips eastward it becomes increasingly confined by the overlying clay strata, particularly the Oxford Clay, and the piezometric head of the aquifer is above ground level over an extensive area. The position at which it becomes artesian varies depending on the amount of recharge the aquifer is receiving. At the time of the present work the aquifer remained subartesian further eastwards than previously recorded reflecting the long period of no recharge.

Discharge from the aquifer occurs principally as:

- Baseflow to rivers
- Public water supply abstraction
- Overflow from wild boreholes in the Fenlands east of Bourne

It is the last of these discharges that this project is concerned with and as an introduction to the problem, the history of Fenland boreholes is discussed in the next section.

2.2 Fenland boreholes

The low lying area to the east of Bourne has been marshy and water logged throughout recent geological time. The Romans made the first attempt to control drainage in the area by constructing a catchwater drain, the Car Dyke, parts of which can still be seen today. However, it was not until the

Seventeenth Century, when people visited Holland and saw the drainage works carried out there that widespread drainage systems started to be installed in the Fenland region. By the mid Nineteenth Century the area was well drained and intensively farmed. However a safe and reliable water supply to the isolated fen farms was becoming an important issue; the first boreholes were drilled by hand and subsequently by steam engine. The work was carried out by family businesses with the majority of boreholes in the Bourne area being drilled by J E Noble of Thurlby.

Drilling of the boreholes was probably at 150 mm (6 inch) diameter through the surface deposits following which surface casing was installed. The drilling then continued at either 150 or 100 mm (6 or 4 inch) to the Lincolnshire Limestone. Once artesian water was struck in sufficient quantity, the permanent casing, 50 mm (2 inch), was inserted with either a lead swedge or a wooden plug at the end and driven into the top of the limestone to obtain a seal. The clays above the limestone were then presumed to swell or collapse around the casing to form a permanent seal. Figure 2.3(a).

Information obtained locally suggests that Noble had to carry out repairs to his boreholes after they were drilled. This was probably due to rapid corrosion of the iron casing that was installed. Noble also found that boreholes no longer required could be effectively sealed by plugging against the Lincolnshire Limestone or the Great Oolite Limestone higher in the sequence and backfilling with cement grout. Figure 2.3(b). He found by experience that trying to seal against the Cornbrash was unsuccessful as it tended to be a fractured hard band, and the confining layer above it tends to be thin. Boreholes were relined,in some cases with a phosphor bronze casing that was more expensive but much more durable. In one case this phosphor bronze casing extended for only one or two lengths down the borehole from the surface, the remainder of the casing being mild steel. This may reflect the fact observed during the course of the project that the severest casing corrosion tended to be in the top 6 metres of the borehole.

3 SITE SELECTION

3.1 Introduction

The uncontrolled discharge of artesian boreholes in the Bourne area had been known about and documented for many years. Studies were carried out by the then Anglian Water in the 1970's and routine flow measurements made to assess the significance of the discharges and identify the major contributors. In all a total of 66 boreholes were identified. A number of other discharges could not be confirmed as wild boreholes and were attributed to natural spring discharges.

3.2 Pre Project

In order to try and place a priority on the selection and sequence of the boreholes to be sealed or controlled the following factors were taken into account by the NRA at the planning stage:

- Magnitude of borehole discharge
- Effect on existing surface water abstraction licence
- Environmental impact

Secondary factors taken into account included site access and whether the borehole was still in everyday use. Applications encountered included domestic supply, filling of bowsers and sprayers, stock watering, amenity, garden watering, firefighting, wildlife etc.

A number of primary sites were identified and work was to commence at these locations. Once these boreholes had been successfully controlled a number of secondary sites were identified for work, subject to inspection.

A large number of individual landowners were involved, ranging from old age pensioners to the Crown Estates, but with assurances from the NRA regarding compensation for physical damage and preservation of established rights cooperation from landowners was most encouraging. In only one case was access refused. Certainly the drought, which drew attention to the loss of resources from wild boreholes, contributed to a general acceptance of the need for the work.

3.3 During Project

Once the project was underway additional wild borehole sites were identified through contact with local people, particularly farmers, and from householders approaching the NRA to have their own boreholes included in the programme. It became quite clear early in the project that the proposed sequence of operation would have to be flexible to accommodate owners who requested that work be carried out whilst they were on holiday or, in one case in hospital. Examples of where urgent work was required included a ground collapse in the driveway of a house and one particular borehole in Bourne which was rapidly becoming a feature in the lounge of a house under construction.

The sequence of borehole operations is presented in Table 3.1 which shows a steady progression of work from north to south.

4 METHODS OF REPAIR

4.1 Introduction

The general sequence of repair, as envisaged at the outset of the project, did not change significantly during the course of the works. It started with careful excavation of the headworks to locate and expose the top of the existing casing. Where practical, and access allowed, downhole logs using a cctv survey, natural gamma logs and calliper tools were run to help identify the problem and confirm the stratigraphic sequence. The TV survey in particular proved very useful although the equipment occasionally failed due to the difficult conditions in the boreholes. The risk of catching or trapping the camera within the old casing was always present. In spite of the potential problems, access to a TV system at all times is recommended for any future work. Geophysical logging was less useful, particularly because of the problem of getting equipment to site as soon as a problem was identified, and because of access into and size of borehole casings. If mobilisation of equipment took two days then an alternative solution to the problem was sought. It was felt that the cost of retaining rented logging equipment on site full time could not be justified. For future works it would probably be cost effective to purchase a limited range of geophysical equipment.

The repair programme was however continually adapted as circumstances demanded and it became apparent early on in the project that no two boreholes would be exactly the same. Contrary to our expectations before the work started a reasonably strong artesian flow was actually beneficial to borehole repairing as it very quickly cleared away any loose material that was accumulating in the borehole column.

Remedial work was carried out as detailed in the following sections and an assessment made of the type of casing materials to be used in the case of a controlled repair.

4.2 Problems Encountered

Problems encountered during the repairs to the boreholes could be subdivided into the following types starting with the simplest to overcome. The numbers refer to the borehole identification as detailed in Table 3.1.

- Broken headworks (L10, L4, W22, L14, L21, W54, W7, W13, W56, W57, W58)
- Damaged or corroded casing/ partially collapsed borehole (L6, L5, L12, W5, W27, W4, W59)
- Previous repair attempts (L1, L57, L13, L23, L35)
- Loss of casing below ground level (L9, L19, L59, L15, W14, L33, W18)

The last two, often in combination, caused the most problems and led to the longest completion times for individual boreholes.

4.2.1 Broken headworks

At these sites the headworks were damaged or missing as a result of physical damage, corrosion, frost action or a combination of these factors. Apart from the uncontrolled discharge at the surface the borehole casing was in good condition and repairs to these holes were generally effected in three to five days. In one case, L10, it was found that the near surface casing was merely unthreaded and tightening the casing was sufficient to effect a repair. A new headworks was then connected using a vitolic joint.

4.2.2 Damaged or corroded casing/partially collapsed borehole

Previous attempts at borehole relining often extended for only a few metres below ground level and the contact between the old and the newer lining could be badly damaged. Similar damage occurred where the casing had broken and partially collapsed a few metres below ground level. To try and reopen the casing to its original diameter a range of tapers, spikes and points was used, usually produced by the drilling crew or fabricated locally. In one case (L6) an oil industry milling bit was used to reopen buckled casing.

Weakness in the borehole lining due to corrosion resulted in some infilling of the borehole which required cleaning out before completion of the repair works. The method generally used was air flushing although care had to be taken not to cause further collapse of the weakened borehole walls. As an alternative water flush was used to remove debris from the hole. In cases of severe collapse it was necessary to shell out the collapse material and reline the borehole with temporary casing pending completion of the repair.

4.2.3 Previous repair attempts

The presence of previous repair attempts was generally an indication that the completion time for that borehole was going to be measured in weeks rather than in days. The reason for this was that with the exception of relining, the standard repair method had been to drive a larger diameter outer casing (200 to 760 mm (8 to 30 inch)) diameter (and 2 to 6 metres in length) over the position of the existing borehole, which was usually 50 mm (2 inch) diameter. Repairs of this kind dated from post war (1947) to the late 1970's. The original casing, if it had not completely corroded away in the top 6 metres, was removed to allow the repair to take place and the contractor then realised that he was unable to attach new 50 mm casing to the old casing. His new casing was placed alongside or just above the original and a hydraulic connection maintained by emplacing gravel. The annular space between the new 50mm and the outer casings was then filled with cement grout. These 'top-down' repairs generally resulted in leakage from the base of the outer sleeve as a result of corrosion of the replacement outer casing. At one site the farmer reported that the borehole had started to leak again before the contractors had even left the site. The causes of casing corrosion are discussed further in Appendix C.

At some of the present sites (Horbling Fen L1, Cobshorne L13) there was no alternative but to remove a previous repair intact complete with the 50 mm inner casing. This left the most difficult type of repair problem where the surface casing was then completely absent.

4.2.4 Loss of surface casing

Apart from where the casing had been physically removed from the ground the loss of surface casing was the result of total corrosion and loss of the original casing. It was found that where this had occurred it regularly happened to a depth of six metres. With the removal of the casing the borehole would stay open for some time since iron encrustation around the casing (a by-product of the corrosion processes) acted as a lining. Eventually the hole collapses and fine material within the surface deposits are washed away resulting in ground collapse in the area of the borehole. In the past these depressions were infilled with rubble (bricks and ironwork from demolished farm buildings) and rubbish. With time more fine material is washed out and the process would start again with the heavier material moving downwards. At one site fragments of a large kitchen sink were retrieved from six metres down.

In order to locate the top of the original casing and hence get back into the hole it was necessary to hand dig a 5 foot (1500mm) diameter shaft within a steel caisson tube until solid ground was encountered. This task proved time consuming and difficult with water being continuously removed from the shaft by suction pumps. In addition to normal site safety procedures all regulations stated in BS 5573 Safety Precautions in Borehole Construction needed to be followed.

4.3 Sealing

Boreholes no longer required for abstraction, surface water usage or ecological support were sealed permanently. The standard method was to insert an inflatable packer on the end of a PVC tube, obtain a control of the borehole flow and then pressure grout the hole below the packer until pressure limits ie. refusal of grout to inject were reached. A small amount of water was then injected to prevent the packer itself from being grouted in. Twenty four hours later the packer was deflated and removed and the remainder of the borehole column above the packer grouted up. In some cases it was found that the artesian flow in a borehole could be sealed without resorting to a packer but simply by using a heavy grout mix injected via a tremie pipe. The suitability of this technique together with a discussion on grouting methods is given in Appendix D.

4.4 Controlling

Where a borehole was still required by the owner as a direct supply, to supply a licensed surface water abstraction, or required to support an ecologically important ditch or pond, a controlled repair was effected. Apart from where new headworks were required, control involved the setting and sealing-in of a narrow diameter packer system wherever possible with a plastic rising main, to ensure the maximum operating life of the repair.

Whenever practical a packer was set either at the top of the Lincolnshire Limestone or against the Great Oolite Limestone higher in the geological sequence, and hence further up the borehole. Care had to be taken in setting the packer in the Lincolnshire Limestone as experience showed that at some locations a major flow zone occurred within 0.5 to 1.0 metres below the top of the limestone.

In some cases where the borehole had been discharging for a considerable number of years the diameter of the borehole at depth varied greatly due to the washing out of some formations and the heave of others. From experience gained during the course of the project, the solution which was found to work best in these cases was to obtain a packer seal wherever possible and to leave the packer inflated for a period of time, usually overnight, to check the integrity of the seal. As a further check, a valve on the packer rising main was closed and a pressure 'shut in ' test undertaken. This test was conducted by monitoring the borehole to check the integrity of the seal against the pressure from the artesian head in the Lincolnshire Limestone. The test was usually run overnight. In the morning if no water leakage was detected the packer was grouted in.

The main disadvantage of a packer system control is that the reduced diameter of the packer rising main above the packer restricts the available discharge at the surface which can cause problems when the water is being used either directly or via a surface water abstraction. There is no easy solution to this problem. It was found that owners could be persuaded to accept a reduction in discharge as part of the agreement for having the work completed at no charge to themselves. At one site the situation was overcome by constructing a small holding reservoir enabling the farmer to have sufficient volume to fill his crop spraying equipment.

4.5 Contract Supervision

The work involved with each wild borehole could not be specified or predicted in advance, varied from day to day and in some cases from hour to hour, and required a great deal of flexibility from both Contractor and Resident Engineer. A traditional Bill of Quantities contract was seen as inappropriate from the outset and a contract drawn up on a discounted dayworks rate basis was used throughout the project. The discounts offered on FCEC plant, labour and materials were the subject of competitive tendering. Six specialist drilling contractors were selected and invited to tender and the tenders were evaluated on the basis of postulated plant/labour/materials requirements. This type of Contract proved to be the only feasible way of progressing the works but required close and continuous site supervision by the RE's staff. However there were certain difficulties with large plant, such as JCB excavators, grouting equipment and large volume surface pumps which were only required for intermittent use. Downhole TV gear and geophysical logging equipment have been discussed elsewhere and were not provided by the contractor.

The main problem was the availability and short term hire terms of large plant. For example, the need for a JCB may only have become apparent late in the afternoon of a working day. Local demand for these items of plant was such that it might not be possible to obtain one until the day after the next day thereby causing a delay to work on that particular hole. When the machine arrived it might be required for only 1 hour and yet the minimum hire period could be 3 days. Similar problems arose with other items of equipment such as grouting equipment and high capacity surface pumps.

These items of plant were required on a fairly regular basis but, with the exception of the grouting equipment, could not be justified economically to be retained on long term hire. One solution would have been to purchase such equipment and then sell it at the end of the job to recoup some of the outlay. This was considered but rejected for the present job since the original project time scale was short and although the project was extended several times the duration of these extensions was only a few months each time and the costs involved could not be covered in the short time periods available. However it is considered that it could be cost effective for future projects to purchase certain items of large or specialist plant. An economic appraisal of the costings could be undertaken once the duration of a future project was known. Alternatively, future works could be tackled on a borehole by borehole basis.

5 RESULTS

5.1 Introduction

Thirty boreholes were repaired during the course of the project, which lasted from August 1991 to October 1992, of which eleven were sealed and nineteen were controlled. In addition it was necessary to drill four new holes at sites where control, although required, could not be achieved and the original hole was sealed. The sequence in which the boreholes were repaired was given in Table 3.1 .

5.2 Effects of Works

The Works have had two major impacts that can be seen in the area. The first was a decrease in water running to waste and hence an increase in available resource and the second a change to a greater or lesser extent in the environmental conditions around boreholes, depending on the borehole location and the repair undertaken.

5.2.1 Water Resources

A precise figure for the saving in water resources achieved during the project is difficult to present given the particularly low groundwater levels and hence artesian discharges at the time of the works. The average figure will lie somewhere between the low discharge flows measured by Halcrow in 1991 and the more normal flow figures measured by Anglian Water in the 1970's. A figure for water saving based on 1991 data would be c. 7.5 Ml/d. This is based on the analysis shown in Table 5.1. For normal flow conditions the saving may be as high as 18.0 Ml/d. Where a control has been achieved the amount required for compensation flow for ecological support has been deducted from the potential saving. Where the 1991 flow is greater than the previously recorded flow it is reasonable to assume that the borehole condition has deteriorated in the intervening period. No account has been taken of any abstractions by farmers as there is insufficient data to analyse.

In order to make an estimate of the amount of water required for controlled discharges it has been assumed that the flows during the summer of 1991 were sufficient to support the flora and fauna recorded in the associated ditches during this time. Whilst the local micro environments survived during that summer there is no evidence to confirm that they can survive longterm on those kinds of flows, although walkover assessments in 1992 suggested that little deterioration had taken place since the previous year. It must be pointed out that very little work has been done on minimum water flows for plants and that the figures used could in the future be shown to be incorrect. Suggestions for getting the best out of the area in terms of its flora and fauna are discussed in the next section.

Using the minimum flow discussed above it has been assumed that during every year there will be a period of up to 200 days when compensation flow to the ditches will be required, starting late Spring/early Summer and finishing in late Autumn/early Winter.

The additional water that, by the sealing and controlling of the boreholes, is now increasing the storage in the Lincolnshire Limestone aquifer will, if abstraction remains the same, eventually result in increased springflow, reissuing of previously dry springs and increased baseflow to streams. The sudden rejuvenation of the Bourne Eau in October 1992 may well have been an example of this increase already happening.

As a result of the work there could now be changes to the careful resource management of the aquifer in the Bourne area.It is possible that the NRA will receive an increase in groundwater abstraction licence applications based on the public knowledge that more water is being conserved. The response to such requests will have to reflect the new long term balance of demands on the resources of the aquifer as identified by the NRA.

5.2.2 Environmental

The regional importance of the wildbore fed Fen ditch system for flora and fauna was discussed in detail in the Ecological and Hydrological Assessments, Final Report(Halcrow, March 1992). That report proposed that ditches already showing good conservation value could be enhanced by sympathetic management to produce a network of ditches exhibiting original Fen habitat.

The first stage of this work, the maintenance of flow to the ditches, has been achieved during this project. The second stage, introduction of a management scheme, can only be implemented by the NRA in association with the Internal Drainage Board and local landowners.

The recommended minimum flows to ditches were based on the discharges supporting ecological communities during the dry summer of 1991. Whilst some research has been done to try and establish a relationship between water flow and number and variety of species that will survive at that flow, it is suggested that further studies are carried out next summer,and at regular intervals thereafter to assess any ecological changes that may have taken place.

5.3 Completion details

Details of the work undertaken at each borehole together with materials used are shown in Figures 5.1 to 5.31. A summary of the materials used is given in Table 5.2.

Careful consideration was given to the type of materials to be used for the completion of the boreholes. Wherever possible plastic casings, sockets and connectors were used to give a maximum life to the repair. If it was felt that a packer might not seal properly or that there was the potential for borehole collapse, the packer was connected to steel casing to improve the likelihood of retrieval of the complete packer installation.

Where boreholes were sealed, casing and grout were terminated approximately one metre below ground level to ensure that the tops were below the deep ploughing zone.

Controlled boreholes had a variety of completion designs depending on the expected end use. Most common was a 'T' piece pipe with one side going to an existing pond or ditch and the other half for farm supply. Each side of the 'T' piece was fitted with a valve and room was left in the manhole for the fitting of water metering equipment, if required. Headworks were placed inside a prefabricated concrete manhole, usually below ground unless requested otherwise by the owner, and all pipes were lagged for frost protection. Wherever practical a drain was installed in the manhole to run off any surface seepage or water from leaking pipework.

5.4 Leakage Problems

Of the 30 sites repaired, unsatisfactory seals or controls were obtained at 4 locations, Quadring Fen, Walkers Barn, Helpringham Fen and Sycamore Farm. The reason for leakage at these sites was the same in each case. The original borehole was not positively located at depth during the works and the subsequent repair, which was neither in the original casing nor at Lincolnshire Limestone/Gt Oolite Limestone horizons, was only partially effective as a result.

The inability to get into the original casing and/or reach either the Gt Oolite of Lincolnshire Limestones was a result of a combination of drilling problems including previous repair attempts, damaged original casing, lack of original casing and washing out of the original borehole walls.

Given the above drilling problems, each of the four repairs reached the stage where it was considered no longer economic to continue and a decision had to be made to stop the work and effect the best possible repair that could be made at that stage. In each case it was initially felt that there was a good chance of a successful repair. However, the lack of success with these holes emphasises that to stop the repair work, for whatever reason, and effect a partial repair will not be successful and that once work on a hole has been started it should be completed and completed within the original bore if at all possible.

6 CONCLUSIONS

6.1 General

The project has shown that appreciable savings in water resources can be achieved at a relatively low capital cost by the sealing and controlling of wild artesian boreholes. The unit cost of reducing water wastage achieved by this project has been estimated at between £60,000 and £110,000 per Ml/d, depending on the level of storage in the aquifer.

This work has been well received by the public who have been pleased to see the NRA take the initiative over such an obvious loss of water resources, especially at a time of drought.

The benefits of the works may already have been seen with the reappearance of flow at St Peters Pool spring and the Bourne Eau flowing through Bourne again for the first time in several years. It may take longer to separate the full effects from other influences such as the above average wet autumn of 1992.

There are likely to be positive and permanent environmental benefits resulting from the works but may take several years of careful monitoring to fully evaluate any impacts and to separate them from external influences acting upon the area.

6.2 Technical

Experience during the project has shown that no two repairs followed exactly the same sequence. Furthermore, the assumption that apparently similar boreholes would require similar repairs work was generally unfounded. As a general rule boreholes that had previously undergone repair attemps provide the most challenging demands for correct repair using present day technicques.

To be sure of a successful control or seal the original casing must be found and entered so that control at depth can be assured. This may require large diameter drilling or shaft sinking in which case the work becomes more difficult, and more specialised, and can take a lot of time.

In the first instance, existing headworks should be removed carefully and preferably by hand so that any existing ceurities beneath the headworks can be identified. If the headworks has a large concrete base, ties bolted to the concrete and to the surface secured can aid retrieval should the base collapse.

Ground stabilisatiion measures should be undertaken where necessary, the setting up of heavy plant around the borehole under repair. Special consideration should be given to boreholes adjacent to existing buildings and structures.

Repair work on boreholes next to inhabited dwellings must take into conciderațion the impact of noise an d vibration and if it is felt appropriate surveys of the structural condition of the property should be undertaken prior to the commencement of work. The scheduling of the work to coincide with th eabsence of the occupier (holidays, etc) is to be encouraged, whenever possible.

Whenever possible careful evaluation of a previous repair attempet should be made prior to work commencing, to establish whether or not that repair was positioned centrally over the original borehole or off-centred as can be the case.

Geophysical logging was of limited value due to a restricted borehole access, small diameter and broken/damaged casing, however, downhole tv camera inspections were extremely useful. Camera sizes allowed access down the 50mm borehole casings giving invaluable information on the condition of the borehole at depth as well as enabling the progress of the work to be monitored.

The use of air flush as a method of cleaning out the hole worked well but required careful supervision, particularly if the hole was prone to collapse. Water flush is an alternative worth considering

A reduced artesian discharge will result from the control of a borehole using a packer system. In some cases this lead to objections from the user of the borehole and it was necessary to emphasise the benefits of controlling the hole whilst, still allowing a regulated supply of water.

6.3 Contractural

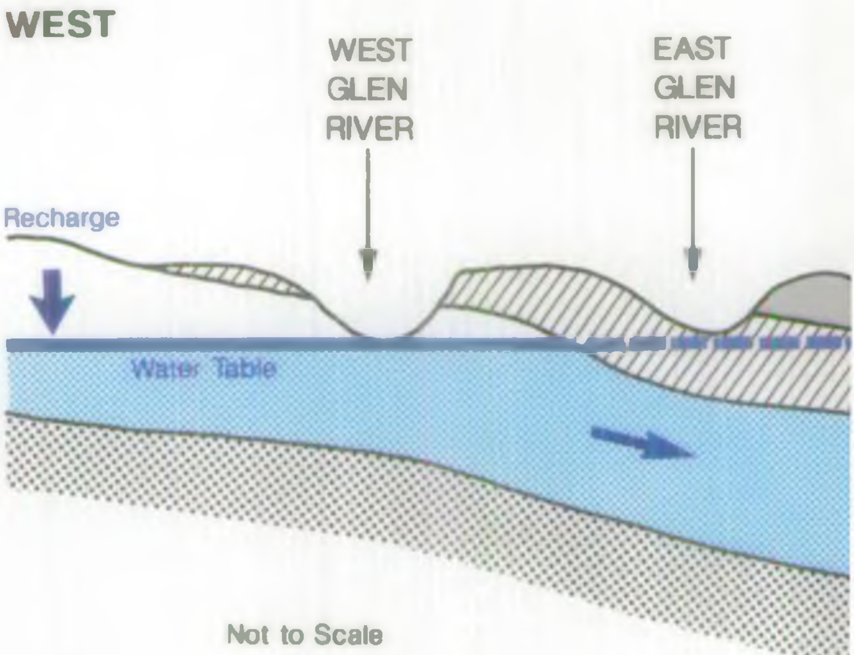
A contract based on discounted dayworks rate proved to be an effective and efficient method of running the site works, however it requires close supervision. Detailed consideration should be given to the method of provision of large items of plant such as JCB, grouting equipment and surface pumps.

7 RECOMMENDATIONS

Further work has been identified and is detailed in Appendix F. These items could be tackled individually, in groups of two or three, or as a single contract covering them all.

Equipment identified during this project as difficult to obtain at short notice and usually only required for short periods of time should be detailed in a future contract document and retained on site for the duration of the works. Such items should include downhole TV equipment, grouting equipment, a JCB and large capacity surface pumps. Consideration should be given to the most cost effective method of achieving this: purchase, FCEC dayworks schedules or lump sum hire charge appropriate to the size and duration of the contract.

Further studies should be carried out to assess whether any ecological changes have occurred as a result of the controlled borehole flows that have been maintained since the completion of the project.



CONCEPTUAL HYDROGEOLOGICAL
CROSS SECTION

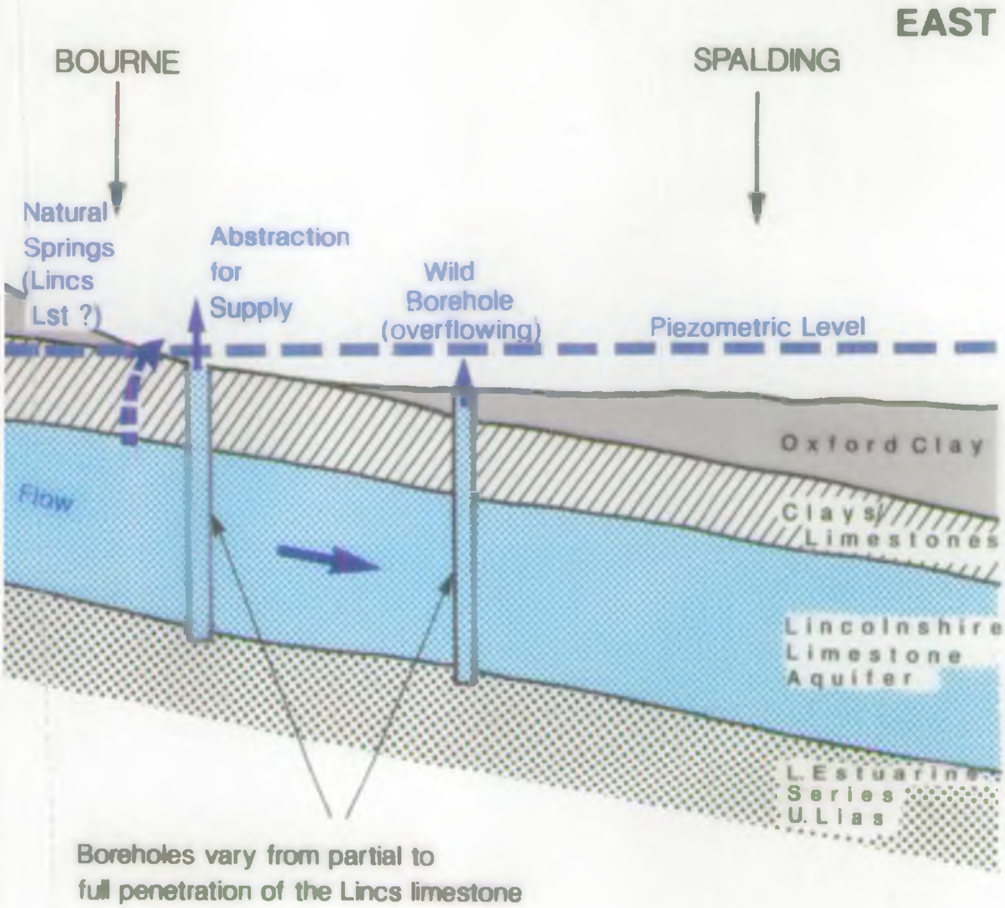

EAST
BOURNE
SPALDING
Natural Springs (Lincs Lst ?)
Abstraction for Supply
Wild Borehole (overflowing)
Piezometric Level
Oxford Clay
Clays/ Limestones
Flow
Lincolnshire Limestone Aquifer
L. Estuarine Series
U. Lias
Boreholes vary from partial to full penetration of the Lincs limestone

Figure 2.1

Figure 2.2

SOUTH LINCOLNSHIRE LIMESTONE AQUIFER

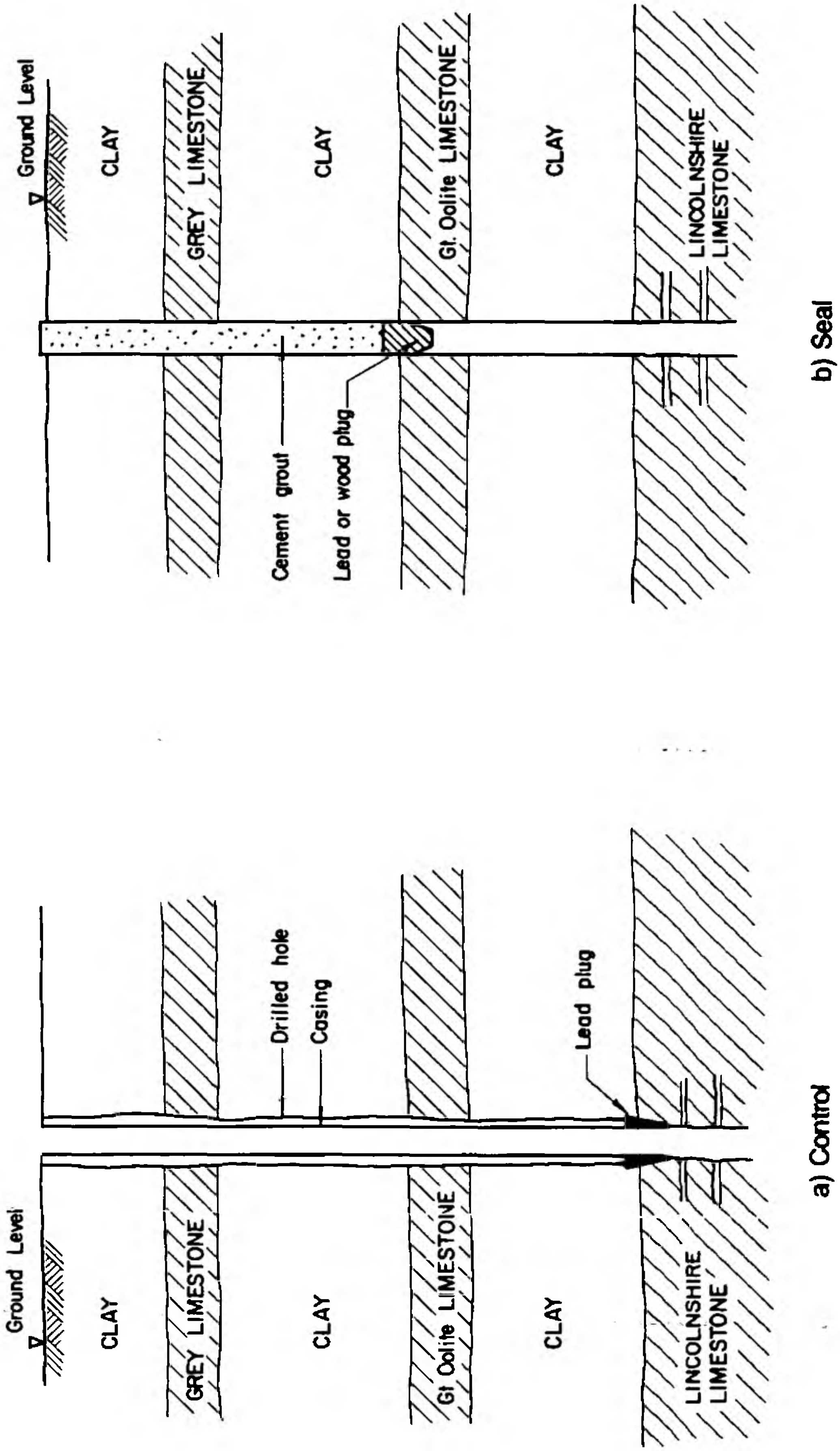
Sealing of Wild Boreholes

Geological Sequence:

	Thickness metres
Alluvial deposits	varies
Oxford clay	0 - 20
Kellaways sand and clay	3 - 6
Cornbrash	2 - 3
Blisworth clay	c.8
Great Oolite Limestone	c.3
Up Estuarine Series	8.5
Lincolnshire Limestone	20 - 30

TYPICAL BOREHOLE LOG

Figure 2.3



EARLY CONTROLLING AND SEALING METHODS (AFTER J.E. NOBLE)

BOREHOLE (ID)	N.G.R. TF	DATE STARTED	DATE FINISHED	CHANGES IN ARTESIAN DISCHARGES		COMMENTS
				FLOW START ML/d	FLOW FINISH ML/d	
SEMPRINGHAM FEN (L9)	136 330	1/8/91	15/8/91	0.22	NIL	SEAL
BOTTOM FEN FARM (L10)	163 331	5/8/91	27/8/91	0.17	CONTROL	SUPPLY FOR FARMER
FEN FARM B'BORO (L6)	154 339	6/8/91	22.10.91	0.12	CONTROL	SUPPLY FOR FARMER (NEW BORE DRILLED)
B'BORO BREWERY (L4)	118 340	13/8/91	17/8/91	0.09	NIL	SEAL
B'BORO FEN POND (L5)	137 343	27/8/91	1/11/91	0.26	CONTROL	COMPENSATION FLOW
THE SLIPE, BOURNE (W22)	107 198	27/8/91	11/9/91	0.24	NIL	SEAL
GLEBE FARM HORBLING (L1)	141 354	28/8/91	18/10/91	0.43	CONTROL	SUPPLY FOR FARMER/POND (NEW BOREHOLE DRILLED)
WALKERS BARN (L57)	166 354	12/9/91	18/5/92	0.06	CONTROL	COMPENSATION FLOW (NEW BOREHOLE DRILLED)
COBSHORNE (L13)	126 309	20/9/91	2/12/91	0.80	CONTROL	SUPPLY FOR FARMER PLUS COMPENSATION FLOW
CONNANTS (L19)	151 303	4/11/91	13/2/92	1.50	CONTROL 0.9	SUPPLY FOR FARMER PLUS COMPENSATION FLOW
DECOY FARM (L14)	137 311	22/11/91	26/11/91	0.14	CONTROL	COMPENSATION FLOW
BARNES FARM (L59)	155 389	6/12/91	8/5/92	0.05	CONTROL 0.001	COMPENSATION FLOW NEW BOREHOLE DRILLED
QUADRING FEN (L12)	202 329	4/2/92	11/3/92	0.27	CONTROL 0.13	SUPPLY FOR FARMER PLUS COMPENSATION FLOW
CHURCH FARM (L15)	148 315	18/3/92	17/6/92	0.35	CONTROL	SUPPLY FOR OWNER COMPENSATION FLOW
DUNSBY FEN (L23)	163 274	24/3/92	4/6/92	0.09	CONTROL	COMPENSATION FLOW

TABLE 3.1 SEQUENCE OF BOREHOLE OPERATIONS AND ASSOCIATED CHANGES IN WATER DISCHARGES

BOREHOLE (ID)	N.G.R. TF	DATE STARTED	DATE FINISHED	CHANGES IN ARTESIAN DISCHARGES		COMMENTS
				FLOW START ML/d	FLOW FINISH ML/d	
DUNSBY FEN (L25)	162 273	14/5/92	18/6/92	-	-	INVESTIGATION ONLY
CAMP FARM (L21)	131 282	21/5/92	1/6/92	0.04	CONTROL	SUPPLY FOR FARMER
SYCAMORE FARM (L35)	148 211	24/6/92	4/9/92	0.43	CONTROL 0.22	COMPENSATION FLOW
TUNNEL BANK FARM (W54)	108 191	24/6/92	25/6/92	0.10	CONTROL	SUPPLY FOR FARMER
ALBRIGHT & WILSON (W7)	106 196	29/6/92	2/7/92	0.10	NIL	SEAL
CHIMNEY FARM (W13)	174 176	2/7/92	6/7/92	0.02	CONTROL	COMPENSATION FLOW
SCHOOL FARM (W14)	167 191	2/7/92	15/9/92	0.16	NIL	SEAL
BARNES DROVE (L33)	125 217	7/7/92	23/7/92	0.14	NIL	SEAL
BUILDING SITE (w57)	104 199	22/7/92	23/7/92	0.03	NIL	SEAL
SOUTH FEN ROAD (W18)	108 195	24/7/92	6/8/92	0.90	CONTROL	STANDPIPE SUPPLY TO HOUSEHOLDERS
BLACK HOUSE FARM (W56)	133 190	24/7/92	29/7/92	0.16	CONTROL	SUPPLY FOR FARM HOUSES
HEREWARD CRESS BEDS (W5)	103 188	4/8/92	12/8/92	0.22	NIL	SEAL
CAR DYKE THURLBY (W27)	104 170	14/8/92	25/8/92	0.09	NIL	SEAL
MAXEY HOUSE (W4)	141 095	26/8/92	24/9/92	0.12	NIL	SEAL
THURLBY FEN BARN (W58)	124 173	29/9/92	14/10/92	0.86	CONTROL	SUPPLY FOR FARMER
THURLBY FEN FIELD (W59)	123 169	1/10/92	20/10/92	0.43	NIL	SEAL

TABLE 3.1 SEQUENCE OF BOREHOLE OPERATIONS AND ASSOCIATED CHANGES IN WATER DISCHARGES

BOREHOLE (ID)	N.G.R. TF	PREVIOUS MEASURED FLOW ML/D	FLOW AT REPAIR TIME	RECOR-DED MIN FLOW	POTENTIAL RESOURCE LOSS	POTENTIAL SAVINGS	
						MAX	MIN
SEMPRINGHAM FEN (L9)	136 330	0.30	0.22	-		0.30	0.22
BOTTOM FEN FARM (L10)	163 331		0.17	-		0.17	0.17
FEN FARM B'BORO (L6)	154 339	0.30	0.12	-		0.30	0.12
B'BORO BREWERY (L4)	118 340	1.00	0.09	-		1.00	0.09
B'BORO FEN POND (L5)	137 343	0.70	0.26	0.12	0.07	0.63	0.19
THE SLIPE, BOURNE (W22)	107 198	0.29	0.24			0.29	0.24
GLEDE FARM HORBLING (L1)	141 354	0.34	0.43			0.34	0.43
WALKERS BARN (L57)	166 354	-	0.06	0.03	0.02	0.04	0.04
COBSHORNE (L13)	126 309	1.50	0.80	0.40	0.22	1.18	0.58
CONNANTS (L19)	151 303	3.50	1.50	0.90	0.49	3.01	1.01
DECOY FARM (L14)	137 311	0.50	0.14	0.06	0.03	0.47	0.11
BARNES FARM (L59)	155 389	-	0.05	0.01	0.01	0.04	0.04
QUADRING FEN (L12)	202 329	0.70	0.27	0.13	0.07	0.63	0.20
CHURCH FARM (L15)	148 315	0.30	0.35	0.11	0.06	0.29	0.29
DUNSBY FEN (L23)	163 274	0.70 (+L24)	0.09	0.09	0.05	0.65	0.04
CAMP FARM (L21)	131 282	0.20	0.04			0.20	0.04
SYCAMORE FARM (L35)	148 211	-	0.43	0.22	0.12	0.31	0.31
TUNNEL BANK FARM (W54)	108 191	-	0.10			0.10	0.10
ALBRIGHT & WILSON (W7)	106 196	0.79	0.10			0.79	0.10
CHIMNEY FARM (W13)	174 176	-	0.02	0.02	0.01	0.01	0.01
SCHOOL FARM (W14)	167 191	0.35	0.16			0.35	0.16
BARNES DROVE (L33)	125 217	0.30	0.14			0.30	0.14
BUILDING SITE (W57)	104 199	-	0.03			0.03	0.03
SOUTH FEN ROAD (W18)	108 195	3.40	0.90			3.40	0.90
BLACK HOUSE FARM (W56)	133 190	-	0.16			0.16	0.16
HEREWARD CRESS BEDS (W5)	103 188	0.32	0.22			0.32	0.22
CAR DYKE THURLBY (W27)	104 170	0.31	0.09			0.31	0.09
MAXEY HOUSE (W4)	141 095	1.00	0.12			1.00	0.12
THURLBY FEN BARN (W58)	124 173	-	0.86			0.86	0.86
THURLBY FEN FIELD (W59)	123 169	-	0.43			0.43	0.43
						18.10	7.44

TABLE 5.1 BREAKDOWN OF POTENTIAL WATER SAVINGS

BOREHOLE (ID)	N.G.R. TF	DATE STARTED	DATE FINISHED	MAIN MATERIALS USED
SEMPRINGHAM FEN (L9)	136 330	1/8/91	15/8/91	8" x 10.5M CASING + SHOE, 4" PACKER
BOTTOM FEN FARM (L10)	163 331	5/8/91	27/8/91	NIL
FEN FARM B'BORO (L6)	154 339	6/8/91	22.10.91	NEW BORE, 3" PACKER 2" PLASTIC CASING TO 40M
B'BORO BREWERY (L4)	118 340	13/8/91	17/8/91	NIL
B'BORO FEN POND (L5)	137 343	27/8/91	1/11/91	4" PACKER, 30M X 2" PLASTIC CASING
THE SLIPE, BOURNE (W22)	107 198	27/8/91	11/9/91	NIL
GLEBE FARM HORBLING (L1)	141 354	28/8/91	18/10/91	NEW BORE 4" PACKER, 39M X 2" PLASTIC CASING
WALKERS BARN (L57)	166 354	12/9/91	18/5/92	8m 36" TUBE. NEW BORE 4" PACKER 45.5m 4" PVC CASING
COBSHORNE (L13)	126 309	20/9/91	2/12/91	1M x 3M LONG STEEL TUBE, 4" PACKER
CONNANTS (L19)	151 303	4/11/91	13/2/92	4" PACKER, 16M X 2" CASING
DECOY FARM (L14)	137 311	22/11/91	26/11/91	3" PACKER 36M X 2" PLASTIC CASING
BARNES FARM (L59)	155 389	6/12/91	8/5/92	NEW BORE42M x 2" PVC CASING, 42M x 4" PVC CASING
QUADRING FEN (L12)	202 329	4/2/92	11/3/92	14M OF 4" CASING
CHURCH FARM (L15)	148 315	18/3/92	17/6/92	8" X 4.5M CASING
DUNSBY FEN (L23)	163 274	24/3/92	4/6/92	9M X 6" CASING, 4" PACKER
DUNSBY FEN (L25)	162 273	14/5/92	18/6/92	NIL
CAMP FARM (L21)	131 282	21/5/92	1/6/92	21 MTRS 2" PLASTIC CASING, 9 MTRS 4" PVC CASING
SYCAMORE FARM (L35)	148 211	24/6/92	4/9/92	4" x 25M, 20" x 27 MTRS STEEL CASING
TUNNEL BANK FARM (W54)	108 191	24/6/92	25/6/92	2" PACKER, 15M X 2" PLASTIC CASING
ALBRIGHT & WILSON (W7)	106 196	29/6/92	2/7/92	NIL
CHIMNEY FARM (W13)	174 176	2/7/92	6/7/92	2" PACKER, 56 MTRS OF 1" PVC PIPE
SCHOOL FARM (W14)	167 191	2/7/92	15/9/92	20" x 12M CASING + SHOE, 16 MTRS 2" PLASTIC CASING
BARNES DROVE (L33)	125 217	7/7/92	23/7/92	8" x 9M CASING
BUILDING SITE (W57)	104 199	22/7/92	23/7/92	NIL
SOUTH FEN ROAD (W18)	108 195	24/7/92	6/8/92	2" PACKER, 17M X 2" PLASTIC CASING
BLACK HOUSE FARM (W56)	133 190	24/7/92	29/7/92	2" PACKER, 21M X 2" PLASTIC CASING
HEREWARD CRESS BEDS (W5)	103 188	4/8/92	12/8/92	15 MTRS 2" PLASTIC CASING, 4" PVC CASING TO 12 MTRS
CAR DYKE THURLBY (W27)	104 170	14/8/92	25/8/92	NIL
MAXEY HOUSE (W4)	141 095	26/8/92	24/9/92	4" x 10.5M CASING + SHOE
THURLBY FEN BARN (W58)	124 173	29/9/92	14/10/92	4" PACKER, 15 MTRS 2" PLASTIC CASING
THURLBY FEN FIELD (W59)	123 169	1/10/92	20/10/92	6" x 10.5M CASING + SHOE

TABLE 5.2 MAIN MATERIALS USED DURING REPAIR WORK

REFERENCES

Halcrow 1991 SOUTH LINCOLNSHIRE LIMESTONE AQUIFER: SEALING OF WILD BOREHOLES
Preliminary Ecological and Hydrological Assessment July 1991

Halcrow 1992 SOUTH LINCOLNSHIRE LIMESTONE AQUIFER: SEALING OF WILD BOREHOLES

Ecological and Hydrological Assessment. Final Report. March 1992.

Appendix A

TERMS OF REFERENCE

HALCROW

NATIONAL RIVERS AUTHORITY - ANGLIAN REGION

SOUTH LINCOLNSHIRE LIMESTONE AQUIFER
SEALING OF WILD BOREHOLES

CONSULTANTS' TERMS OF REFERENCE

The South Lincolnshire limestone aquifer becomes artesian where it dips below the overlying clay strata east of a line from Sleaford to Market Deeping. This line also coincides with the western edge of the South Forty Foot and Deeping fens.

Within these fens numerous small boreholes have been sunk through the clay to reach the limestone for agricultural and domestic purposes over the past hundred or more years. With the changing pattern of rural settlement many of these boreholes have become disused and many have also, through damage or decay, become "wild" - discharging uncontrollably to surface watercourses in the fen under varying artesian pressure. Over one hundred such boreholes are known to exist, though a large majority of these, especially those in the Deeping fens, involve insignificant leakage.

These "wild" boreholes, both individually and collectively, represent a significant loss to the water resources of this aquifer. It is therefore the intention of the National Rivers Authority (NRA) to take the excellent oportunity presented by the current drought and its associated low groundwater level/ artesian pressure conditions to seal as many of these wild bores as practicaly and legally possible within the next six to eight months.

It is intended to appoint Consultants to plan a programme of work to be carried out within this timescale; to seek, receive and evaluate tenders from appropriately qualified contractors; to liaise as required with landowners and occupiers, and to supervise the work of the duly appointed contractor and bring the work to a successful conclusion. It is envisaged that between 6 and 12 of the major wild bores will be sealed during the course of the project.

Particular consideration should be given to the following:

A) Preliminary Investigations. (To expedite the project these items should be carried out concurrently with those in (B) below, i.e. contract work on some boreholes should be in progress whilst preliminary investigations are still taking place on others.)

1) Primary efforts should be directed at those wild boreholes identified by Dr G.Petts of Loughborough University in 1990 - see attached schedule. Work on other wild bores should not proceed until sufficient experience has been gained on the six "primary sites" boreholes listed in the schedule.
2) Locate and study any available historical records relating to each wild bore to identify factors relevant to a suitable engineering solution.
3) Identify any licensed surface water abstraction or other protected rights downstream of each wild bore which would be derogated if the borehole were sealed.

7/1.4.S

4) Identify land ownership and access rights for each borehole to be sealed, including any adjoining land which may be affected by work carried out on that borehole.
5) Select, instruct and supervise an appropriate specialist contractor to carry out (only as and where necessary) borehole logging and CCTV survey of wild boreholes.

All necessary legal processes and negotiations with landowners, occupiers, public bodies and other affected parties will be carried out by NRA staff but technical back-up by Consultants' staff may be necessary in certain instances in preparing plans, attending meetings, making routine visits etc.

B) Operations to Seal Wild Boreholes.

1) Prepare a select list of suitably qualified and experienced contractors to undertake the work.
2) Prepare a Schedule of Work and contract documents. Consideration should be given to a "negotiated cost plus" form of contract or the use of a schedule of rates for labour and plant for predetermined activities, because of the uncertainty surrounding the nature of the work needed at each site to achieve effective sealing of the wild bore until work has comenced.
3) Recommend, for each wild bore, an optimal approach for the sealing or reinstatement (see 4 below) of that borehole and to instruct the contractor accordingly.
4) Provide all necessary site supervision and contract administration services. A significantly higher level of site supervision will be essential where "cost plus" or "schedule of rates" forms of contracts are used.
5) In those cases where a compensation flow downstream of the original wild bore is deemed necessary, to reinstate (where possible) the sealed bore to permit a controlled and metered compensation flow to be released to an adjacent watercourse.
6) Where a controlled compensation flow is deemed necessary, but where reinstatement of the wild bore to achieve this is not possible, evaluate the cost of providing a new borehole for controlled compensation flow purposes against the costs of leaving the wild bore unsealed or partially sealed, and discuss the options with the NRA before proceeding.
7) Prepare and submit (on at least a monthly basis) as work progresses, a summary or estimate of the cost of sealing each wild bore in order that the NRA may budget accordingly for the remainder of the project.

C) Assesment and Report.

1) On completion of the project (which will to a considerable extent be determined by financial and hydrogeological factors) review the work carried out, assess the relative success and costs of the various methods used to seal the wild bores and report accordingly. Six copies of this report should be submitted to the NRA within four months of completion of work on site.

NFO/BB 30/4/91

NRA

National Rivers Authority
Anglian Region

7th May 1991

Sir William Halcrow & Partners
Consulting Engineers
Burderop Park
Swindon
Wiltshire SN4 0QD

Our Ref: BB/GT/655/09/00

Dear Sirs

South Lincolnshire Limestone Aquifer - Sealing of Wild Boreholes

Since I wrote to you on 30th April 1991 we have received the second draft of the Loughborough University Report on their ecological assessment of the wild bores in the South Forty Foot Fens.

This draft places a substantially greater emphasis on the ecological significance of the discharge from many of the principal wild bores and this is reflected in their latest recommendations that, where bores are sealed, provision should be made for a controlled discharge facility. My schedule of Wild Bores to be Sealed has consequently been reviesed to account for this shift of emphasis and I enclose the latest edition of this schedule.

Yours faithfully

B Barton
Project Engineer (Water Resources)

Enclosure

WP-1/GT7MAY7

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7/13

Appendix B

ASSESSMENT OF SPRING FLOWS

HALCROW

APPENDIX B ASSESSMENT OF SPRING FLOWS

1 INTRODUCTION

A number of groundwater discharges exist between Horbling and Bourne which are generally considered to be natural springs. They fall in a North - South line approximately along grid line TF 11 (Figure B1). This brief review assesses the available information as to their origin and their significance to the water resources of the South Forty Foot Drain.

2 PREVIOUSLY IDENTIFIED SPRINGS

Twelve spring fed streams were recorded by the Water Resources Board in 1972 as contributing flows to the South Forty Foot Drain, at some time during the year. Of these four are north of our present study area. The remainder are summarised in Table B1 (at end of note). This list was not comprehensive and with the exception of Horbling well excluded the springs now under review.

The springs show a strong response to heavy rainfall events in the period January to April. Of the eight springs Sempringham, Pointon and Old Beck may have some contribution from deeper, possibly Lincolnshire Limestone water as indicated by their perennial flow during the year.

3 PRESENT SITUATION

The discharges under review were visited by Halcrow in late December 1991 and their details are shown in Table B2. The St Peter Pool discharge in Bourne is added for completeness.

TABLE B2

DISCHARGE	N G R	OD M's	CONDITION DURING 1991
1 Horbling Well	TF 118 353	6.9	Dry (late August)
2 Horbling Spring	TF 114 353	c.9	Dry (late August)
3 Billingborough	TF 117 342	9	Dry (late August)
4 Browell Head	TF 115 285	10	Dry (late August)
5 Dunsby Fen Pond	TF 125 263	3	Flowing
6 Eau Well, Dyke	TF 108 221	4	Dry (mid Oct)
7 St Peters Pool, Bourne	TF 094 198	c.13	Dry (early August, possibly mid July)

It is apparent from Table B2 that, regardless of the source of the water, discharge is controlled by the elevation of the location.

The case for St Peters Pool is complicated by abstraction from the nearby public water supply boreholes in Bourne which reduces the piezometric head in addition to the recession of natural groundwater levels.

With the exception of the two Horbling sites the actual locations of the discharges have been modified by the development of artificial ponds although Browell Head source is believed to rise in a copse beyond the pond, (Figure B2).

4 ORIGIN OF DISCHARGES

A review of information has shown that little evidence is available to clearly define the origin of these sources. The case for a natural (spring) source is presented together with supporting data and this is followed by the case for an artificial wild (borehole) source.

4.1 Spring Source

The origin of these discharges most frequently quoted in reports on the Lincolnshire Limestone is that of natural or spring sources.

There is some geological evidence to support this view but the evidence is inconclusive for two interrelated reasons:

- the Fenland area has not been accurately mapped due to lack of rock outcrop and limited borehole information.
- geological structures are therefore, by necessity, interpolated from adjacent sheets ie. B G S sheet 143, Bourne.

A further problem has been the inability of investigators to agree on the geological strata from which the waters originate.

In one of the first detailed reviews of the area eight springs were recorded as issuing from Upper Jurassic strata. Table B3 (W R B 1969). The springs included in this review are identified by the numbers used in Table B2. The north-south alignment was noted and reported as corresponding to the boundary between the superficial deposits of the Fenland and either the Great Oolite Series of the Upper Jurassic strata. The groundwater was not considered to be from the Lincolnshire Limestone but variously from the Cornbrash, Kellaways Sands and Great Oolite Limestone.

In a 1972 progress report (W R B 1972) it was reported that in order to identify the origin of the spring sources tritium analyses had been taken for the eight springs plus two samples from Lincolnshire Limestone borehole sources. It was believed that a low tritium count would reflect an older water and a high count a more recently recharging water.

TABLE B3 ORIGINS OF SPRINGS FLOWS - WRB TESTING

SITE	TYPE	N G R	OD M's	TRITIUM UNITS	SOURCE OF WATER
S. of Aslackby	Spring	087 296	40	124.8	Cornbrash
1 Horbling Well	Spring	118 353	6.9	71.9	Gt Oolite/ Cornbrash ?
Folkingham	Spring	072 333	40	132.8	Gt Oolite
3 Billingborough	Spring	118 342	9	82.0	Gt Oolite/ Cornbrash?
6 Eau Well, Dyke	Spring	108 221	4	50.9	?
2 Horbling Spring	Spring	114 353	c.9	147.9	Cornbrash
4 E of Rippingale	Spring	115 285	10	63.3	Gt Oolite/ Cornbrash?
Dowsby Hall	Borehole	110 291	16	62.8	Gt Oolite/ Lincs Lst
5 Dunsby	Spring	125 263	3	41.1	Gt Oolite/ Cornbrash?
White House, Dunsby	Borehole	109 267	10	44.4	Lincs Limestone

As it can be seen from Table B3 the results were not conclusive. This may be partly expalined by what we now understand to be a rapid recharge component of recharge to the Lincolnshire Limestone.

On the basis of tritium count the two Horbling sources are unlikely to contain water from the Lincolnshire Limestone whilst the results for the other sources are capable of being interpreted in several ways. Indeed, the Dowsby Hall borehole, initially considered to be solely Lincolnshire Limestone water, was reinterpreted due to its relatively high tritium count as having some leakage from the Great Oolite.

A number of investigators have concluded that whilst the origin of the water might well be from minor Middle and Upper Jurassic aquifers, its surface issuing is fault controlled. This is certainly true for Billingborough spring pond where a fault is recorded on the geological sheet 143, Bourne area. In other cases it is possible to infer that faults may continue beneath the Fenland superficial deposits, however this cannot be confirmed due to generally inadequate borehole records which in turn give a lack of understanding of the rock structures.

An Anglian Water report (Smith 1979) noted that leakage of groundwater from the Lincolnshire Limestone into overlying permeable strata (Cornbrash, Gt Oolite limestone, Kellaways Sandstone) can occur in the vicinity of geological faults. Smith recorded the St Peters Pool, Bourne as a Lincolnshire Limestone source determined through comparative chemistry and piezometric head measurements.

4.2 Borehole Sources

If the discharges are not considered as natural sources then they must be the result of early borehole constructions for which no information has been recorded.

As mentioned earlier many of the sites have been so modified that the original location of the source has been lost. However, if they were originally drilled as boreholes to supply water to farms and stock then the buildings associated with the farms should have been recorded on earlier editions of the Ordnance Survey Maps for the area.

With the help of the Lincoln Library examination of the available OS maps, at a scale of 6" to 1 mile, from the 1906 survey and the 1950 survey have shown no buildings in the vicinity of any of the discharges.

5 CONCLUSIONS

From the available information the most likely origin of the discharges are natural springs which in all cases are to some extent fault controlled. It is believed that a proportion of the discharge is Lincolnshire Limestone water although confirmation of this through comparative chemistry would be time consuming. The contribution of Lincolnshire Limestone water is corroborated by the field observation of degassing at several of the spring sites. It is worth noting that the ponds supplied by these springs are unable to sustain fish life; a situation repeated in ponds supplied via boreholes from the Lincolnshire Limestone.

The identification of the discharges as spring sources considerably reduces the opportunity to control the flows in a manner similar to the work being presently undertaken, even if it were considered desirable to do so.

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Water Resources Board, 1972 — Groundwater Resources of the Lincolnshire Limestone. Progress Report 1972.

TABLE B1 **WRB DATA (1972)**

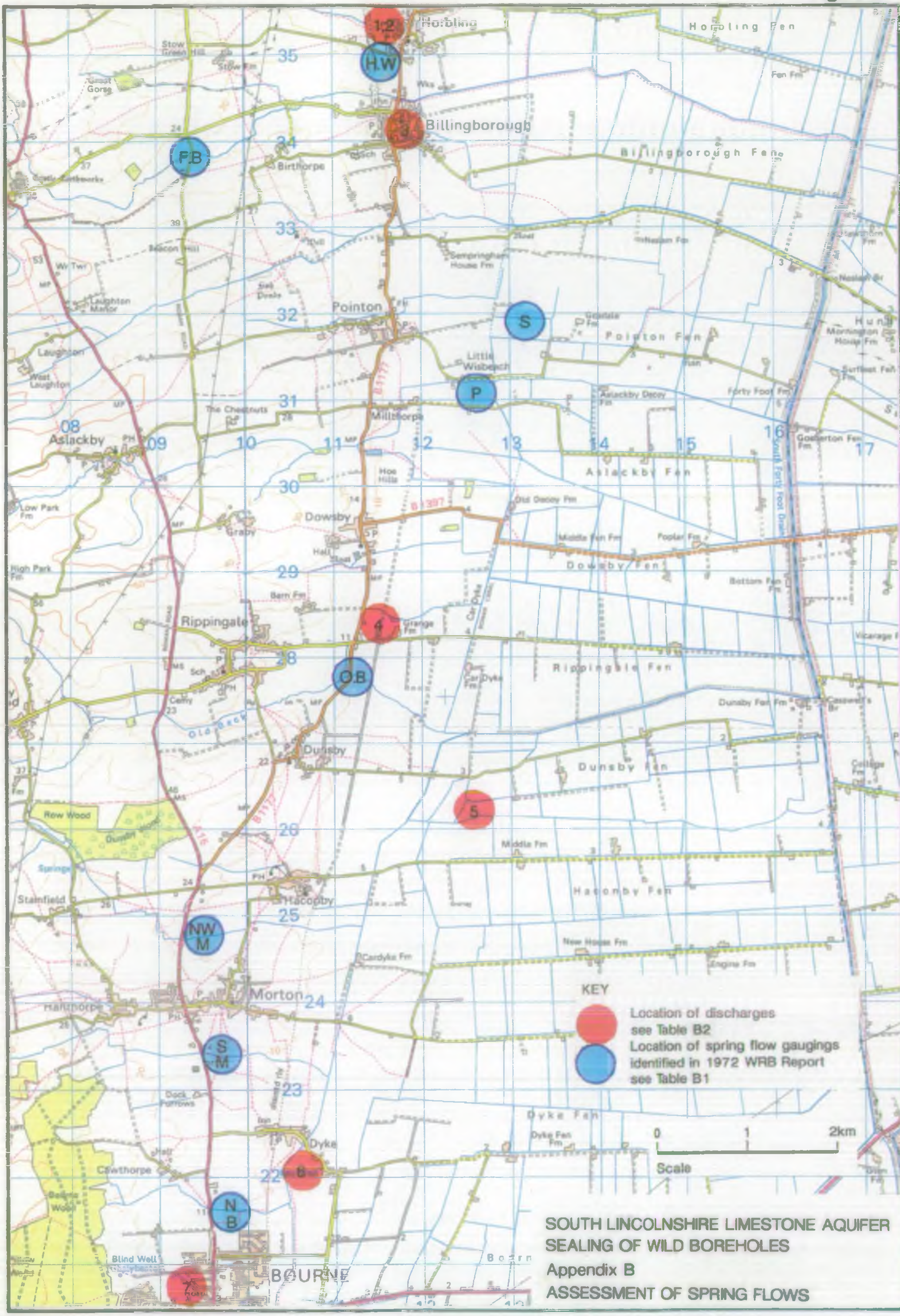
AVERAGE FLOW (l/s)

SPRING	N G R T F	OD M's	JAN 7	FEB 4	MAR 3	APR 7	MAY 5	JUN 2	JUL 7	AUG 4	SEP 1	OCT 6	NOV 3	DEC 1
Folkingham Beck	094 339	19	72	NM	87	115	26	11	IF	NF	NF	NF	NF	NF
Sempringham	131 320	.45	18	200	NM	NM	NM	25	14	13	3	5	IF	3
Pointon Lode	125 312	5	27	235	NM	NM	36	IF	10	7	IF	1	3	7
Old Beck, Dunsby	112 278	10.5	40	119	65	84	24	26	6	3	IF	IF	6	3
NW. of Morton	093 248	19	31	130	24	25	5	IF	IF	IF	NF	NF	NF	NF
S. of Morton	095 234	14	29	85	10	15	4	IF	NF	NF	NF	NF	NF	NF
N. of Bourne	096 217	3	11	100	10	10	2	IF	IF	IF	IF	IF	IF	IF
Horbling Well	118 353	6.9	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF	IF

Key

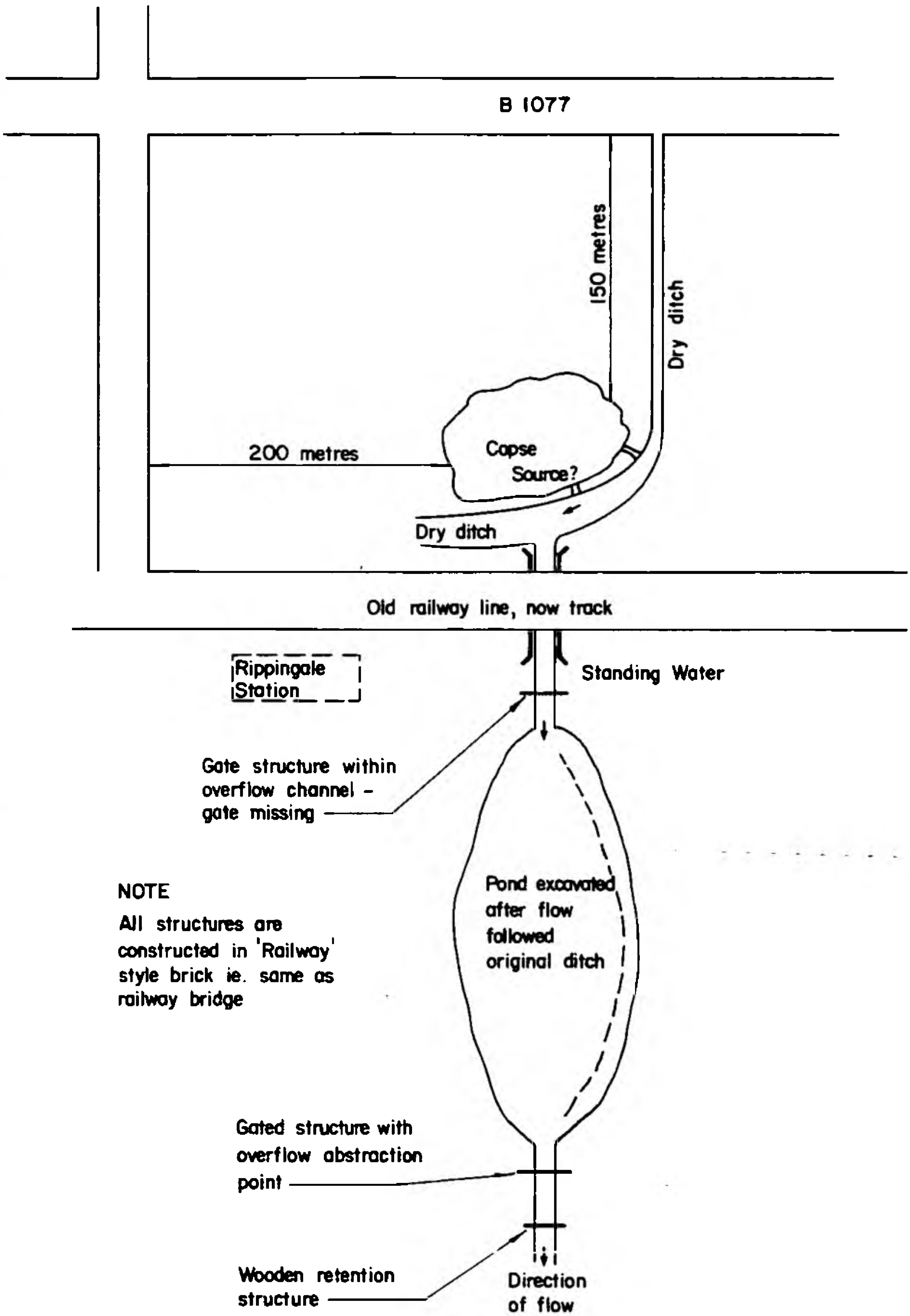
NM : No Measurement
IF : Insignificant Flow
NF : No Flow

Figure B1



SOUTH LINCOLNSHIRE LIMESTONE AQUIFER
SEALING OF WILD BOREHOLES
Appendix B
ASSESSMENT OF SPRING FLOWS

Figure B2



SOUTH LINCOLNSHIRE LIMESTONE AQUIFER
SEALING OF WILD BOREHOLES
GROUNDWATER DISCHARGES REPORT

LOCATION OF BROWELL HEAD DISCHARGE AND CONDITION
December 1991

Appendix C

CASING CORROSION

APPENDIX C CASING CORROSION

The Fenland area around Bourne has a considerable number of wild boreholes. It is evident from examination of old borehole casings that there is a serious casing corrosion problem. Repairing boreholes that have gone wild becomes more and more difficult the longer the hole is allowed to remain wild. If it is repaired fairly soon after the leakage is first noticed then the work involved is not too difficult as the old casing still has sufficient integral strength to allow it to be pulled and replaced. Alternatively the inside of the casing is still smooth enough to allow the borehole to be relined using a slightly smaller lining. However as time progresses the work involved becomes more onerous. Several of the sites involved in this project were first reported as wild bores in 1947.

Corrosion is the result of chemical reactions between groundwater from the Lincolnshire Limestone, which may itself undergo changes in chemical equilibrium upon release from depth, and the borehole casing material which is usually mild steel. Sections of borehole casing removed from holes as part of the repair operations exhibit the classic lacework patterns of attack by carbon dioxide, in this case in the form of carbonic acid. In addition this is generally accompanied by the encrustation on the outside of the casing indicating the deposition of iron and manganese carbonates. See Plate 1.

The corrosion process does not necessarily require a long time to take effect. Previous repairs at Horbling Fen undertaken in the late 1970's show advanced corrosion features. However steel debris(crowbars and box sections) lost or thrown down the hole at the time of the repair have remained in pristine condition, only rusting on exposure to air at the surface. This apparent contradictory chemical behaviour is the result of complex chemical processes occurring in and around the borehole. The advanced corrosion of part of the 12 mm thick 0.914m diameter metal tube inserted into the ground around the original hole was accelerated by the high groundwater velocity (leakage) around the edge of the tube. Driscoll (1986) reporting on tests carried out on the effects of entrance velocities upon well screen slot size concluded that upto a limiting velocity, corrosion processes increase directly in relation to the velocity. Slight leakage under artesian pressure at one location of the steel tube perimeter would produce similar conditions of high velocities and would account for the rapid corrosion effects.

The inside of the steel tube showed the typical blistering texture resulting from sulphate reduction by bacteria in an anoxic environment. This anoxic environment would tend to support the view that the pristine condition of steel debris found during the excavation resulted from the production of mild sulphuric acid, hydrogen sulphide, H_2S, being present in small amounts in the groundwater.

Corrosion of steel in groundwater results from the establishment of anodic and cathodic areas on the metal surface (Clarke, 1980). These areas known as corrosion cells exist on both a micro and macro scale, and anode and cathode within a cell may be close to each other or far removed. The cell is completed by current lines ie an electric current flowing through the earth from the anodic to the cathodic area and returning along the well casing.

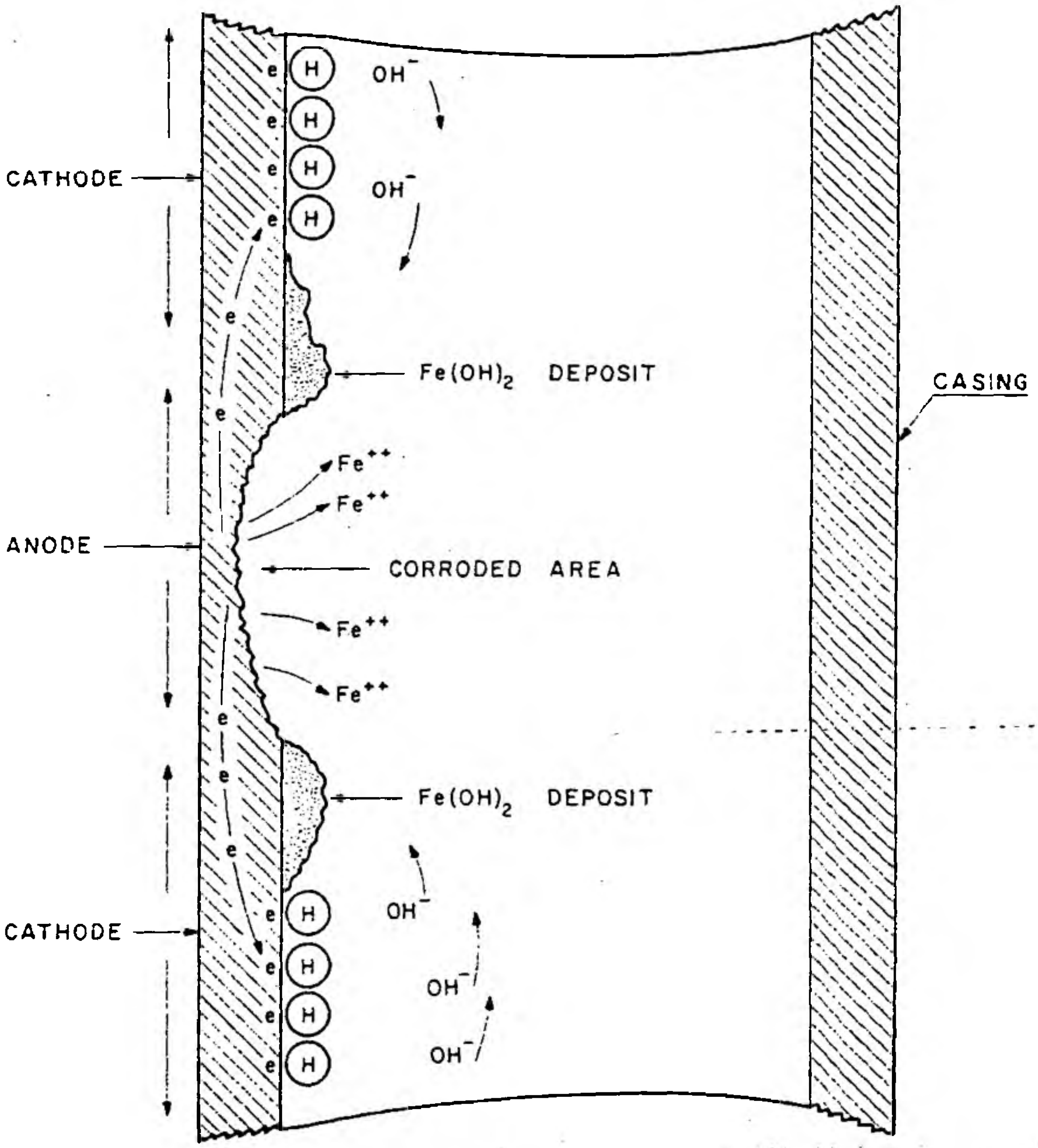
Regardless of the source and size of the corrosion cell the basic corrosion process is the same, commencing with metal dissolution at the anode to form ions and release electrons which pass through the metal to the cathode and react with hydrogen ions in the water to form atomic hydrogen. This deposits on the cathode and tends to protect it. The deposition of atomic hydrogen on the cathodic area leaves an excess of hydroxyl ions in surrounding water. These react with iron ions to form ferrous hydroxide, a relatively insoluble product which deposits in the cathodic area. This is shown diagrammatically in Figure C1. These processes result in the lacework casing phenomenon already described. In extreme cases such as seen at Connants (L19) the original casing is totally removed, apart from the thicker casing collars, and the borehole is well supported by the iron and manganese encrustations that built up around the original casing.

REFERENCE:

CLARKE. F,E,. 1980 Corrosion and Encrustation in water wells. A field guide for assessment, prediction and control.

FAO Irrigation and Drainage Paper No 34.

DRISCOLL. F,G,. 1986 Groundwater and Wells. 2nd Edition. 1089pp. Johnson Division



Electrolytic Corrosion Process

2" casing reduced to typical Lacework structure by acid attack.
Note : thicker casing collar (at bottom of casing) resists attack.

Failure of previous repair.
Corrosion gash (bottom left) an effect of acid attack. Pitted inner surface as a result of anaerobic corrosion. Pre-cast concrete plug in top 1 metre of 3 metre long pipe prior to repair.

Appendix D

GROUTING METHODS

HALCROW

APPENDIX D GROUTING METHODS

For the duration of the project the same method of grouting boreholes was used. The basic mix consisted of cement and water in the ratio of 3 bags (50 kgs)of cement to 80 litres of water, a water cement ratio, by weight of 0.53. Bentonite was added to the mix In small proportions to improve the initial injection and later the setting of the mix. The mix was injected into the borehole via a tremie pipe under a range of pressures from nominal to 400 psi. A calculation of the expected annular space was made before each grouting operation to give an indication of the amount of materials required. The use of more than the predicted amount of grout was not considered to be a problem as it was usually reflecting the amount of washing out that had occurred over the years since the bore went wild. However if less than the expected amount of grout was used it could indicate bridging in the annulus and hence an incomplete seal.

To ensure that the grout mixed by the contractor was up to standard, field samples were taken and assessed throughout the project. To quantify the strength of the grout, cube samples were taken and sent to a recognised concrete testing laboratory for analysis. The results from the laboratory indicate a seven day strength in the order of 27.9 to 52.5 N/mm^2 rising to 49.6 to 56.7 N/mm^2 after twenty eight days. Table D.1. There was no problem in the strength of the grout mix, since a recognised target uniaxial compressive strength, typically for grout in structured ground anchors works, is 28 N/mm^2 (Littlejohn 1982). In addition to its strength the density of the grout must also be examined.

The density was of significance since a number of boreholes were successfully sealed by the injection of a heavy mix of grout. This heavy mix was achieved by increasing the amount of cement to 4 bags for the same amount of water. This resulted in a change in the solid density of the grout from 1840 kg/m3 to 1960 kg/m3, as reported by the testing lab. The slurry density can be estimated (Driscoll 1986) and gives a difference for the normal to heavy mix of 1790 kg/m3 to 1930 kg/m3.

The permeability of a cement grout is related to its original water/cement ratio. In this case a final permeability of 10^9 m/sec is expected.

It was found that whilst some boreholes could be sealed by a heavy mix injected under gravity (Maxey House, water discharge velocity at surface 0.55 m/s) this was not always the case, grout in some holes was washed straight out after such an injection (Thurlby Fen Dutch Barn, water discharge velocity at surface 0.38 m/s). This inverse relationship between discharge flow and sucessful grouting was not expected. Efforts to relate the uphole velocity of the water to the success of grouting proved unsuccessful since the discharge at the surface cannot be used as indicative of the uphole velocities throughout the borehole column. There are clearly changes in the velocity of the water due to the irregular diameter of the borehole column. It is assumed that the critical factor is the uphole velocity at the point of grout injection ie. the bottom of the tremie pipe. If the borehole is to gauge, drilled diameter, at this position then if the uphole velocity is sufficient it will start to fluidise the mix and disperse the grout.The fact that the borehole may open out in diameter further up, and hence reduce the uphole velocity, is not important, the damage in terms of the grouting has already been done.

SAMPLE	DATE CAST	AGE AT TEST (Days)	MASS (kg)	DENSITY (Kg/m^3)	FAILING LOAD (KN)
1	13.10.92	13 28	1.865 1.836	1960 1970	315 496
2	19.10.92	7 28	1.980 1.955	1980 1960	525 567
3	19.10.92	7 28	1.781 1.949	1930* 1950	279 561

Table D1 Laboratory results of Grout Compression Testing

Note:

Samples 2 and 3 were from a Heavy Mix Grout

*Cube had a damaged base, approximate density

References:

Driscoll, 1986. Groundwater and Wells 1089 pp. Johnson Division

Littlejohn, 1982. In Grouting in Geotechnical Engineering ASCE Conference, 1982.

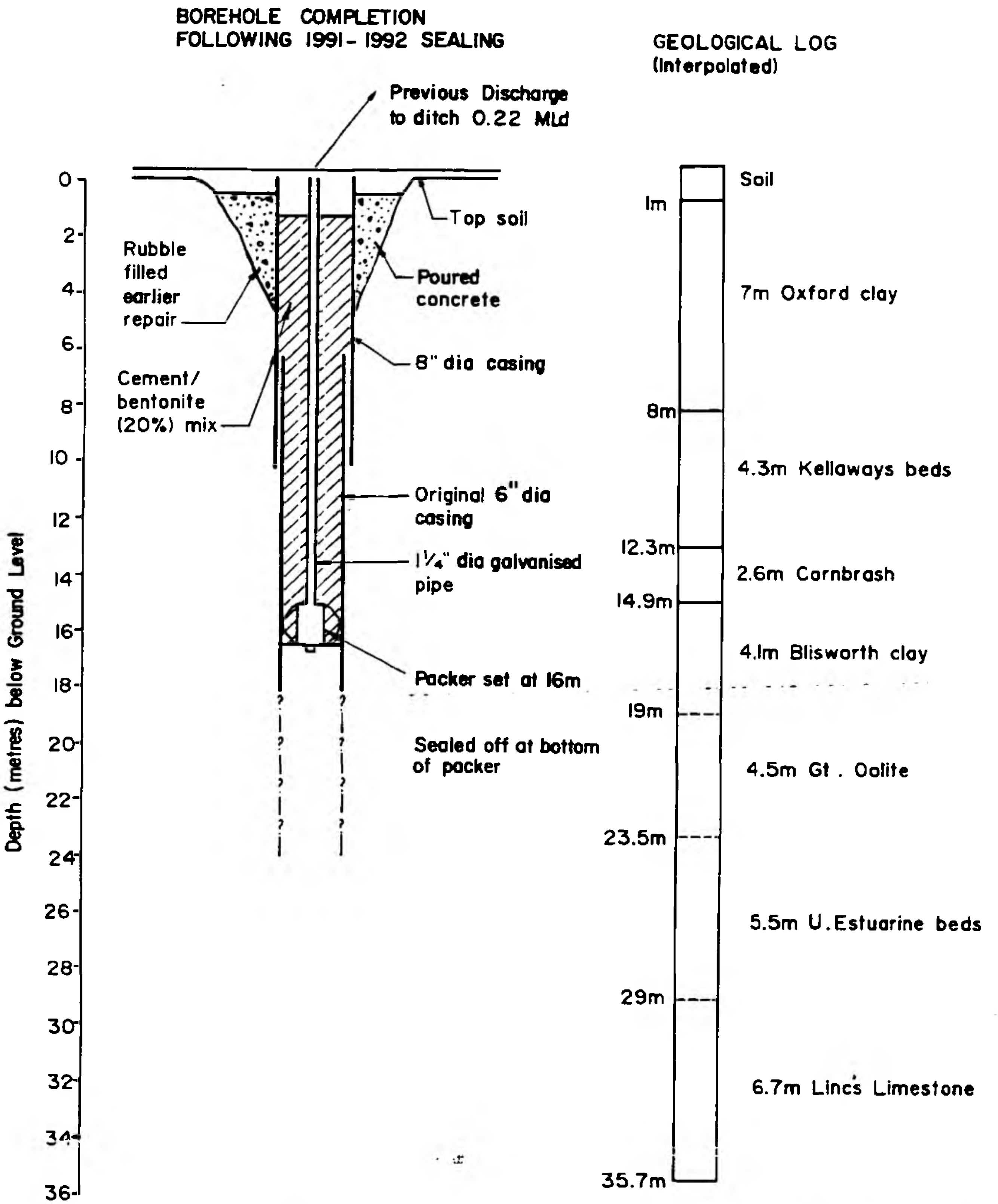
Appendix E

BOREHOLE COMPLETIONS

APPENDIX E - BOREHOLE COMPLETIONS

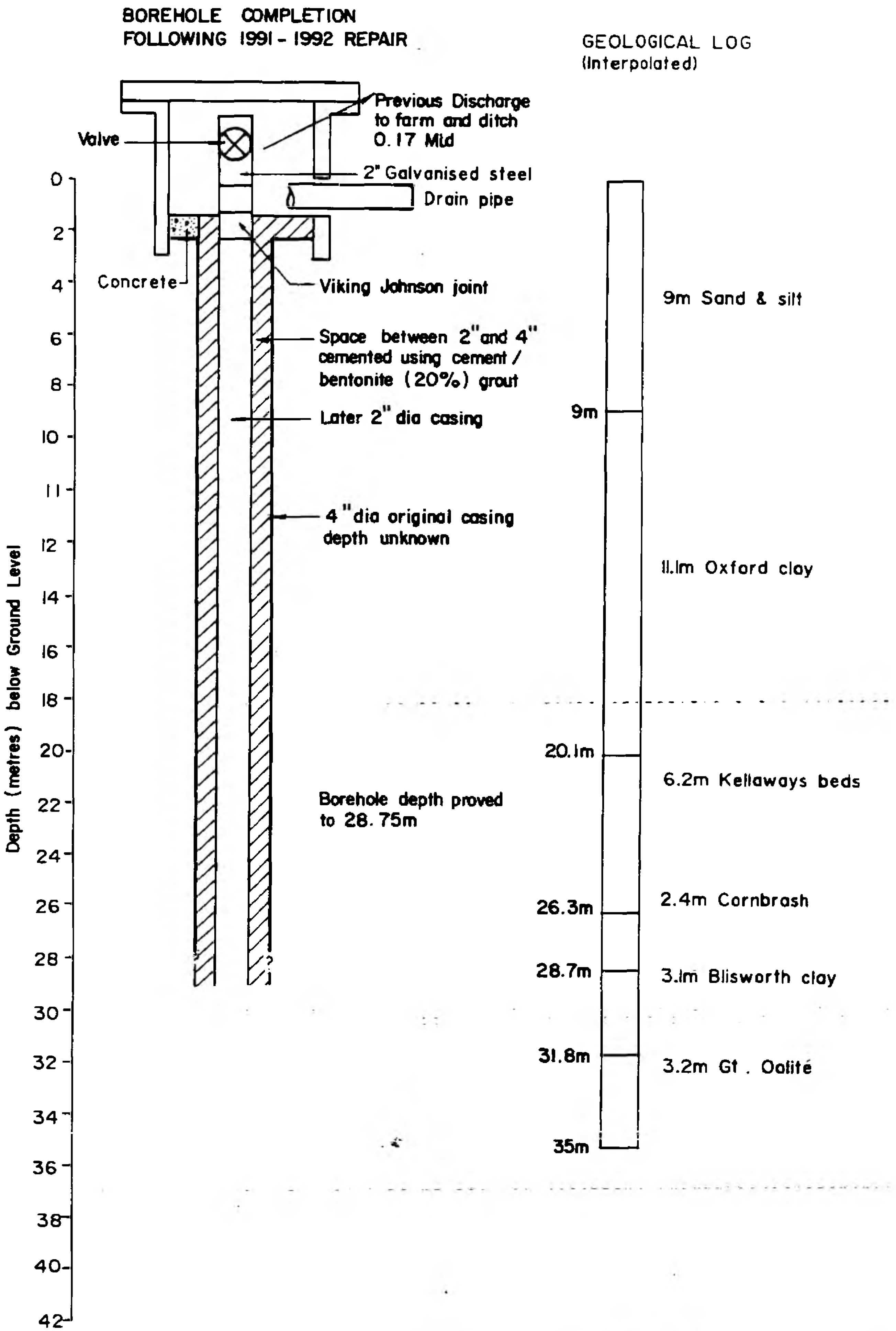
The borehole completion figures are presented in the sequence that the work was undertaken. The figures present the condition of the borehole after sealing or controlling together with details of previous casings and repair attempts. The stratigraphy (geological sequence) at the site, either known or interpolated, is presented alongside the borehole outlay diagram.

Figure E1



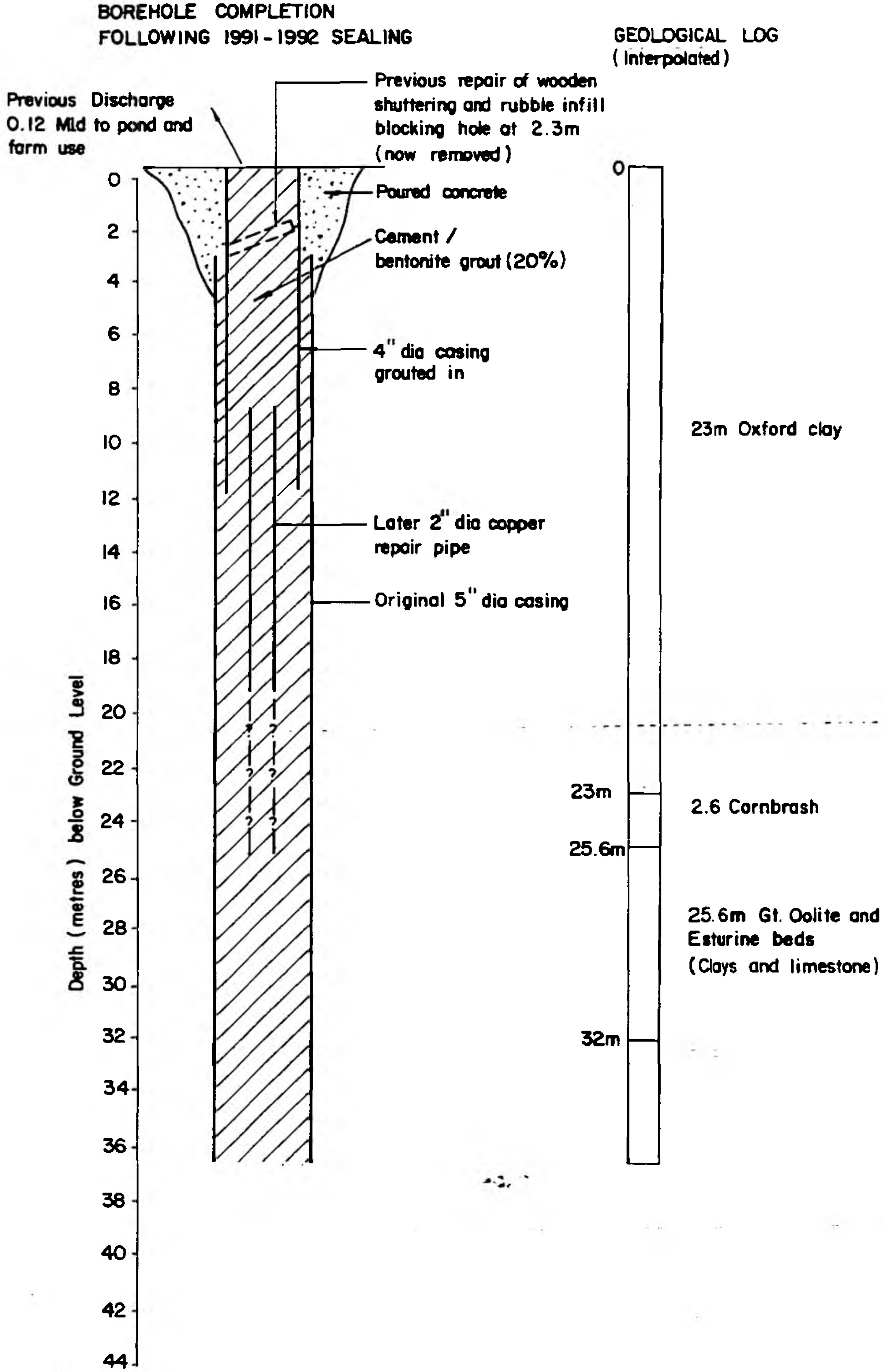
BORE HOLE SEMPRINGHAM FEN (L9)
N.G.R. TF 137 331

Figure E2



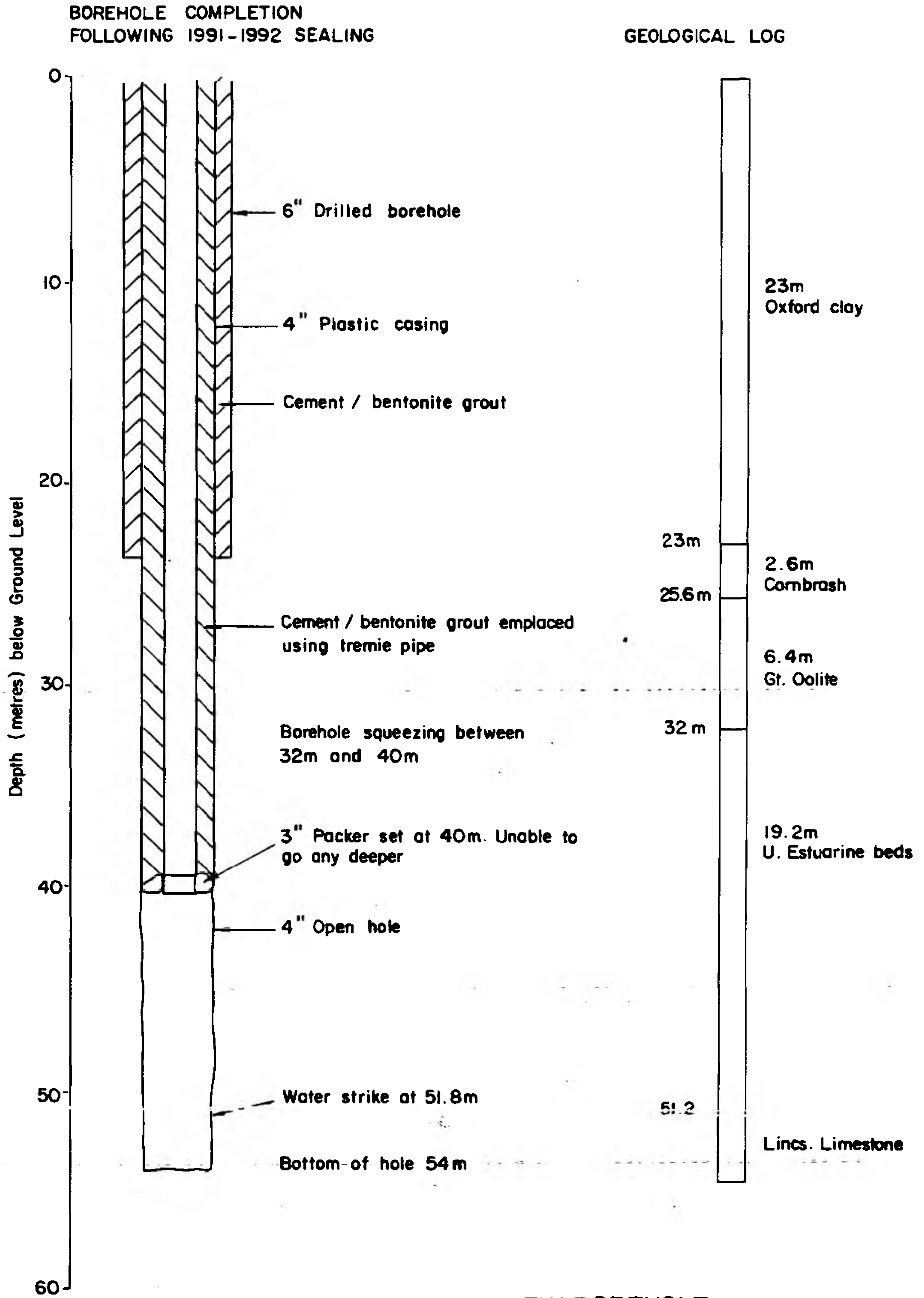
BOREHOLE BOTTOM FEN FARM (L10)
N.G.R. 163 331

Figure E3



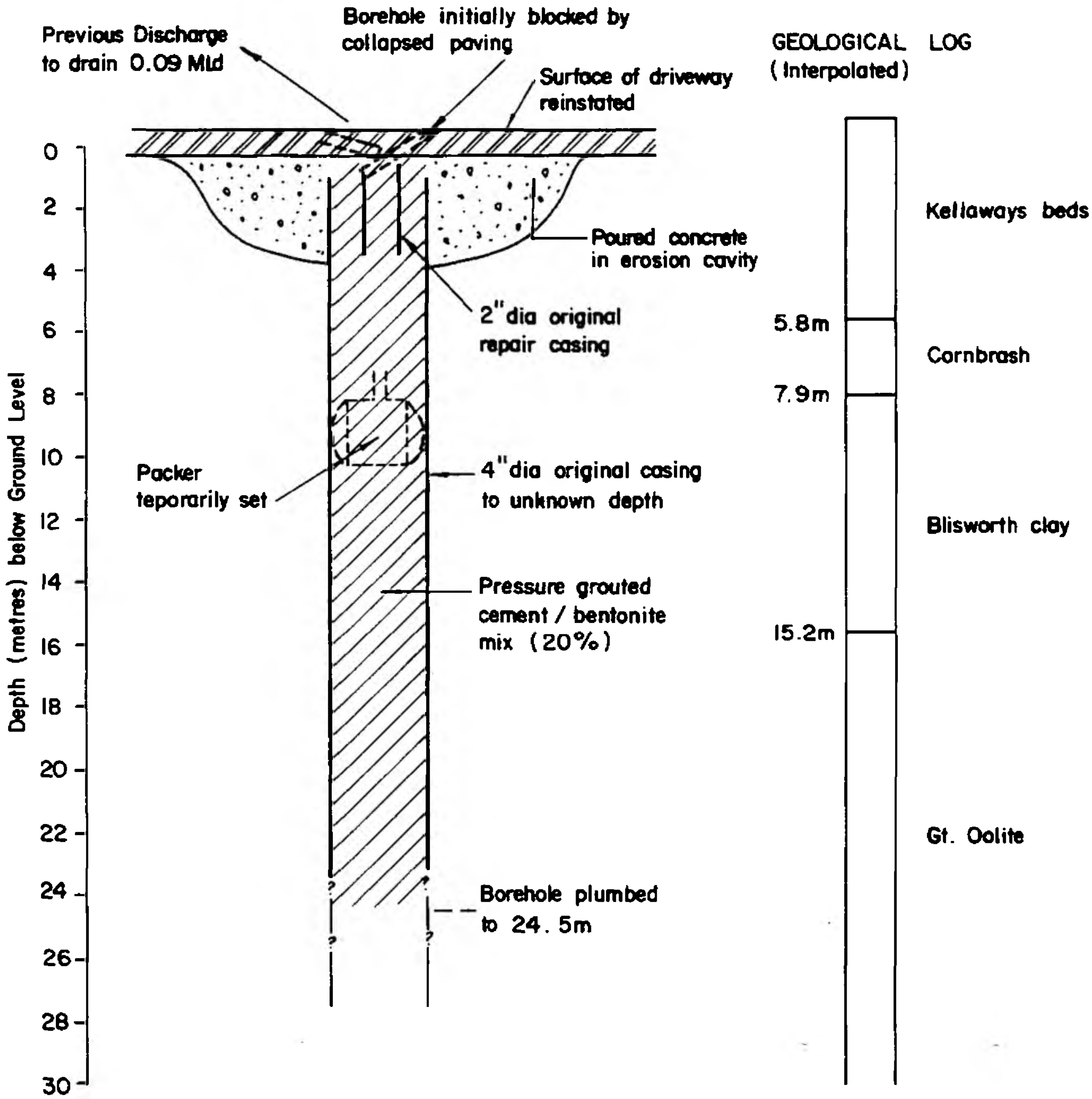
BOREHOLE FEN FARM BILLINGBOROUGH (L6)
N.G.R. TF 154 339

Figure E3a



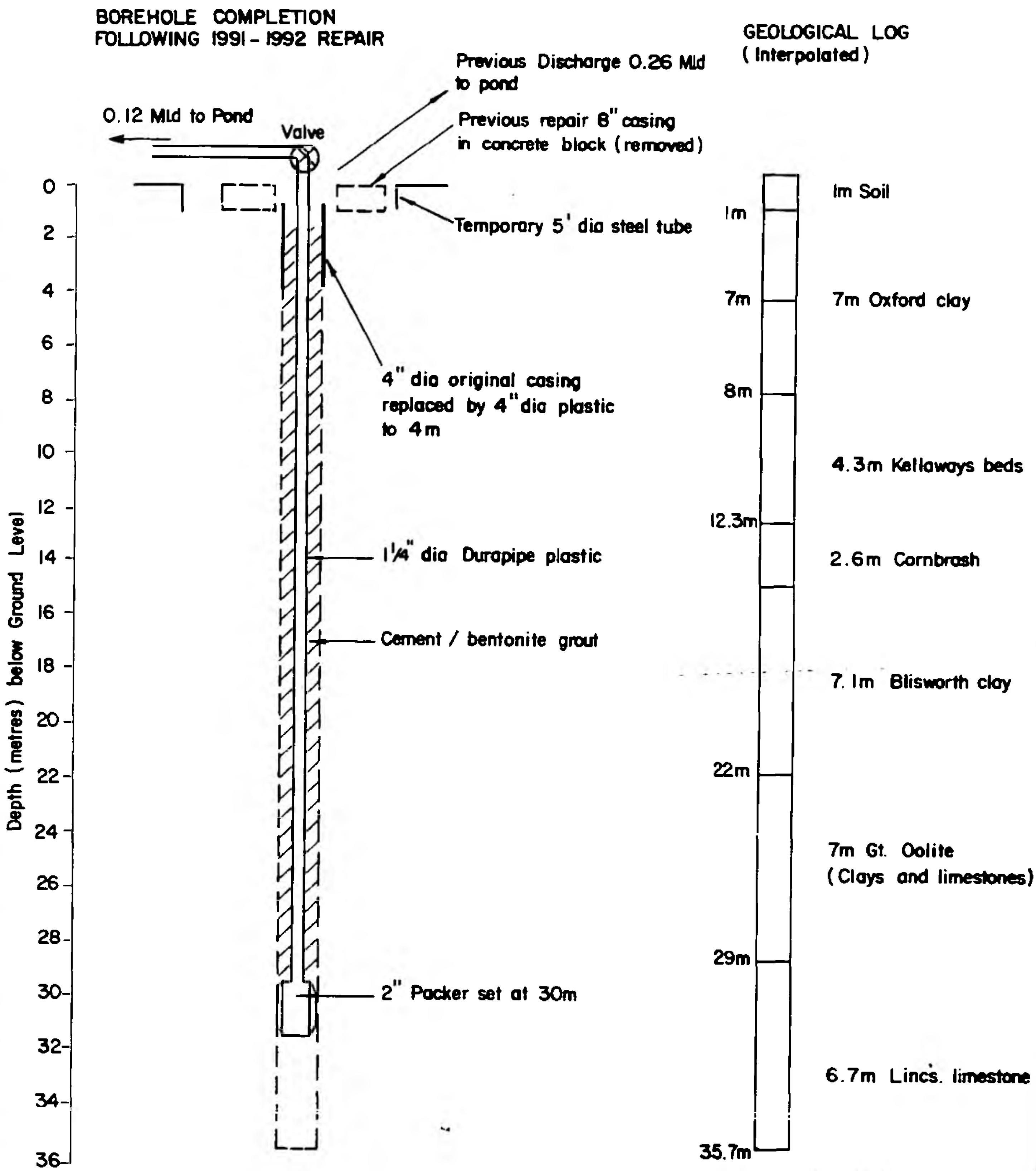
NEW BOREHOLE
FEN FARM BILLINGBOROUGH (L6)
NGR TF 154 339

BOREHOLE COMPLETION
FOLLOWING 1991 - 1992 SEALING

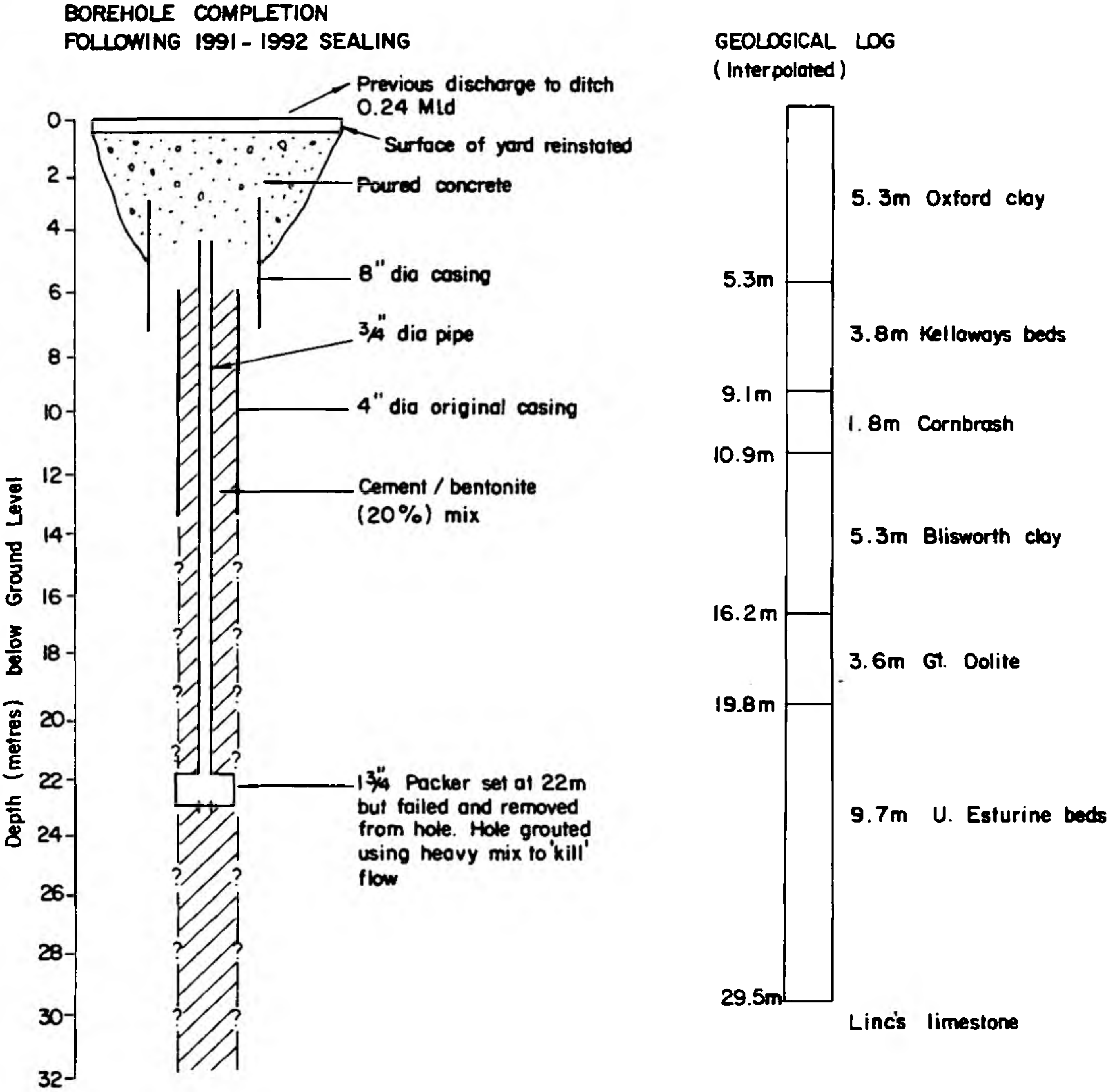


BOREHOLE BILLINGBOROUGH BREWERY (L4)
N.G.R. TF 118 340

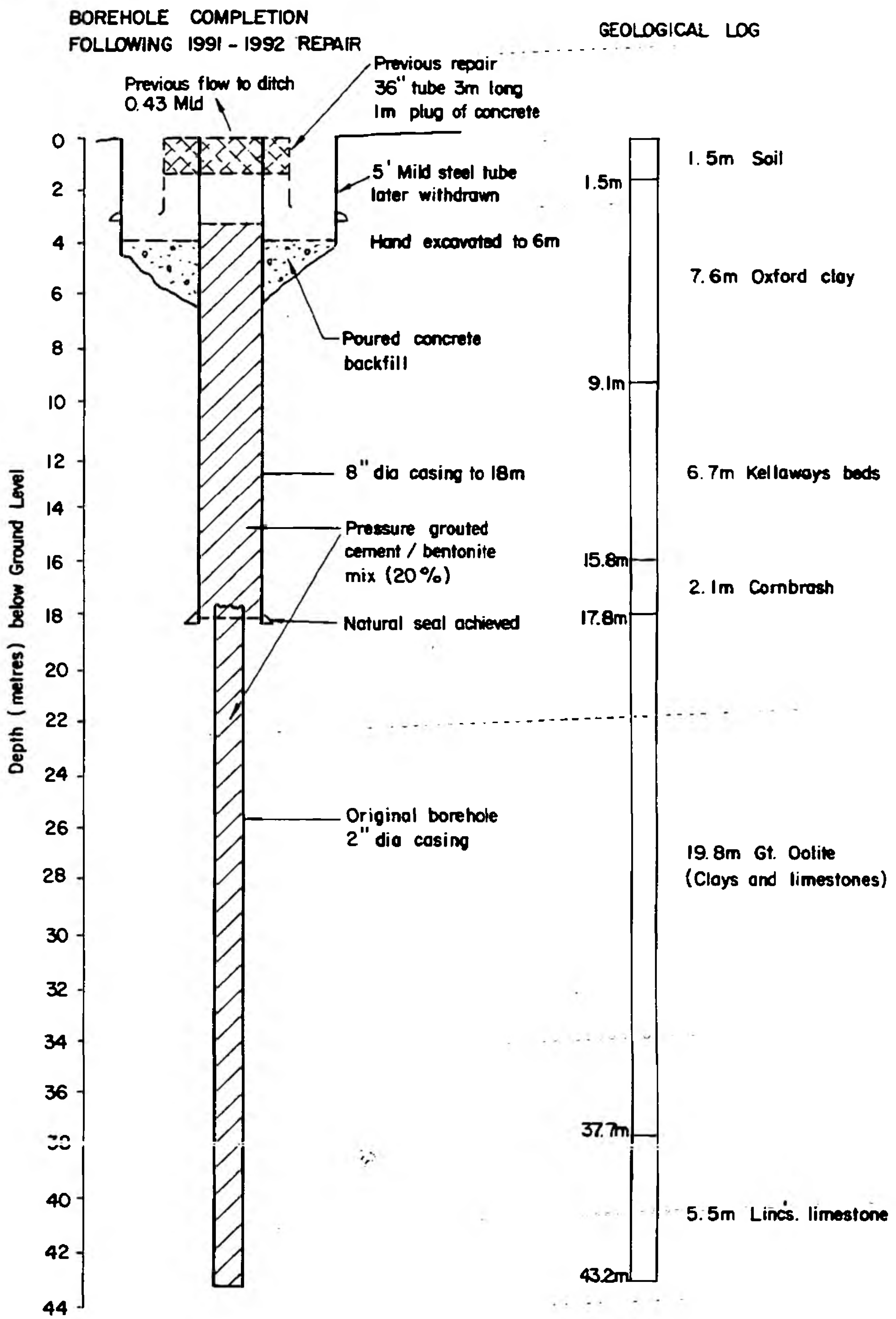
Figure E5



BOREHOLE BILLINGBOROUGH FEN (L5)
N.G.R. 137 341



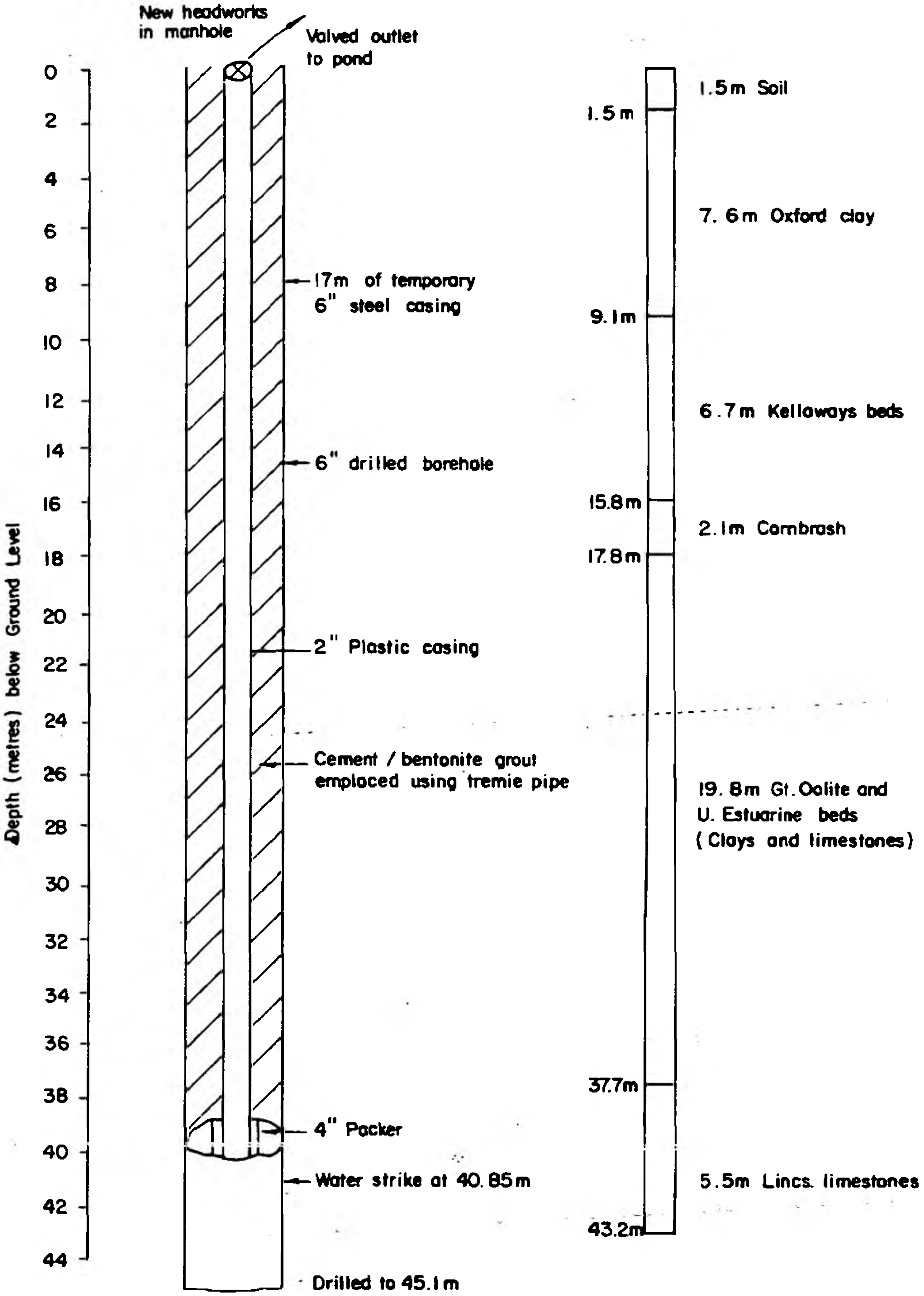
BOREHOLE THE SLIPE (W22)
N.G.R. 107 198



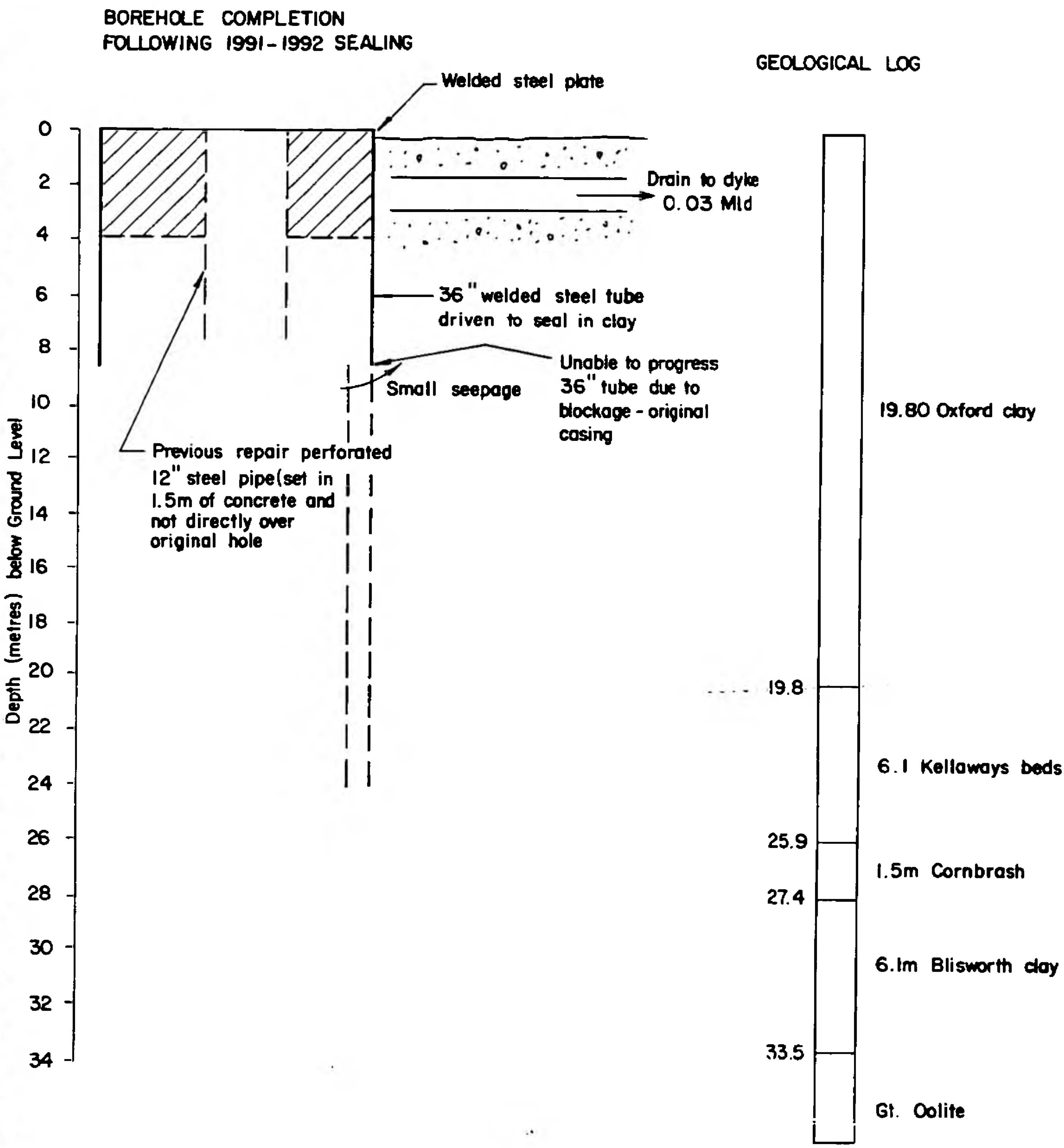
BOREHOLE HORBLING FEN (L1)
N.G.R. TF 141 354

BOREHOLE COMPLETION
FOLLOWING 1991 - 1992 SEALING

Figure E7a



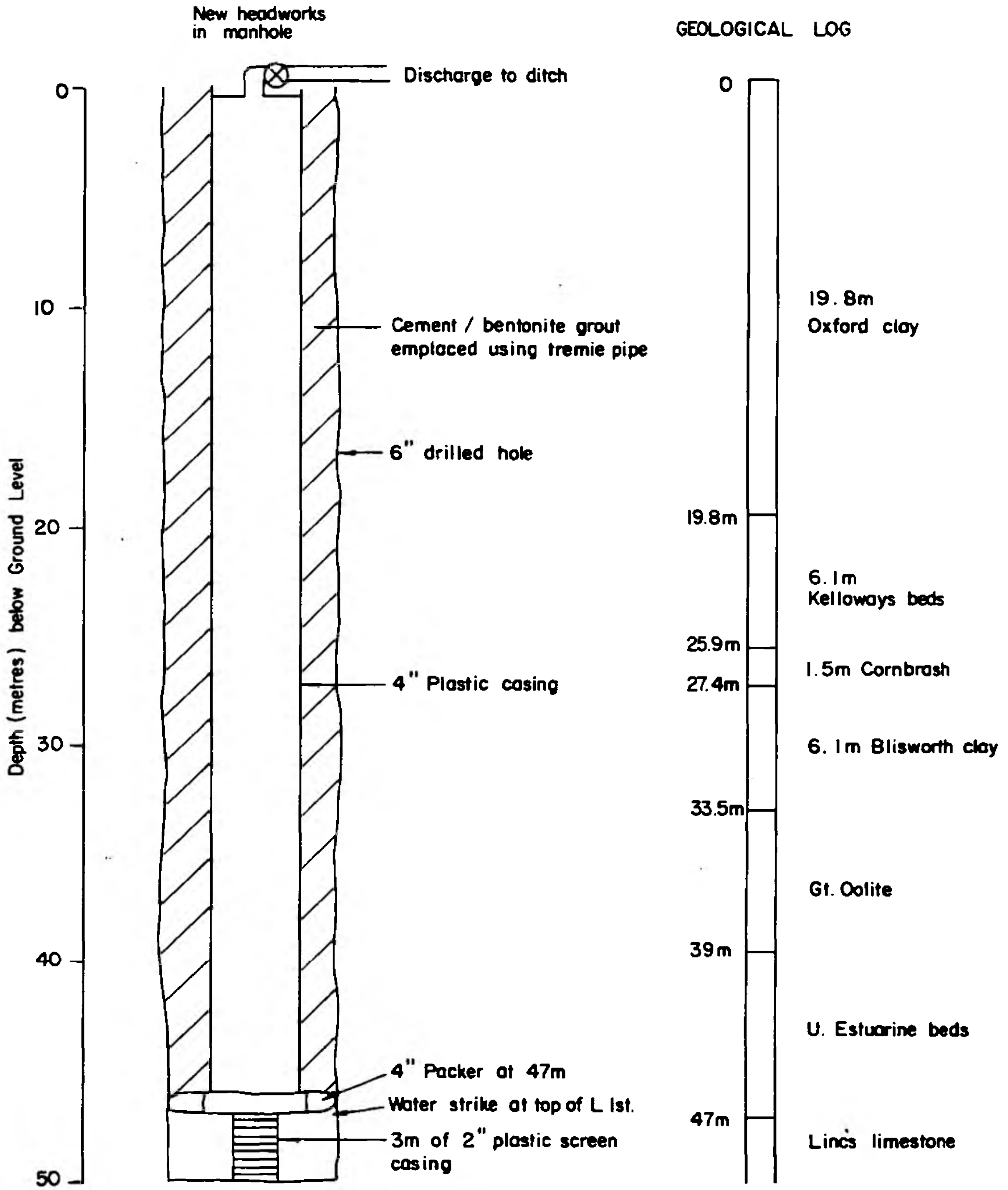
NEW BOREHOLE HORBLING FEN
NGR TF 141 354



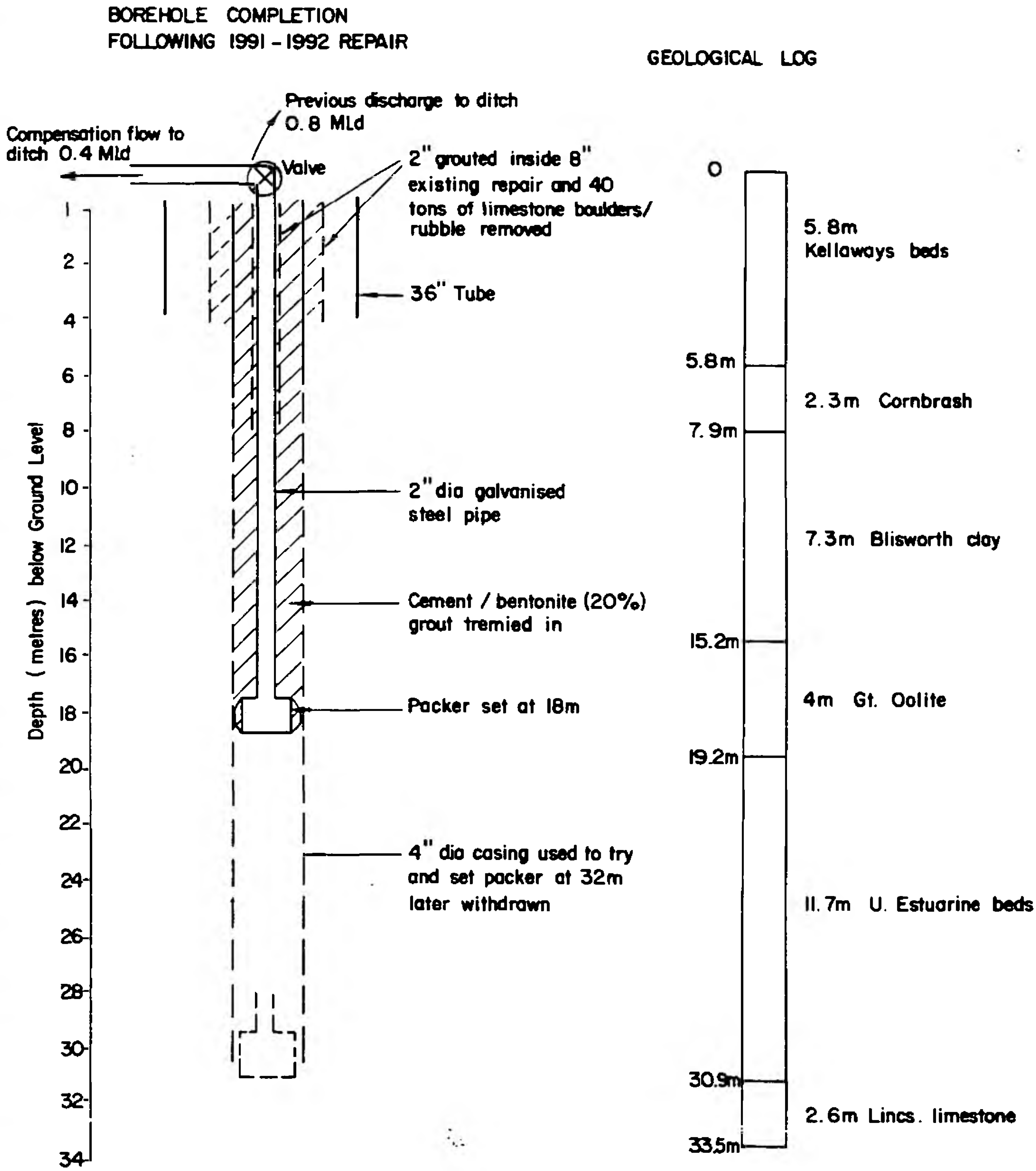
BOREHOLE WALKERS BARN (L57)
N.G.R. 166 354

BOREHOLE COMPLETION
FOLLOWING 1991 - 1992 SEALING

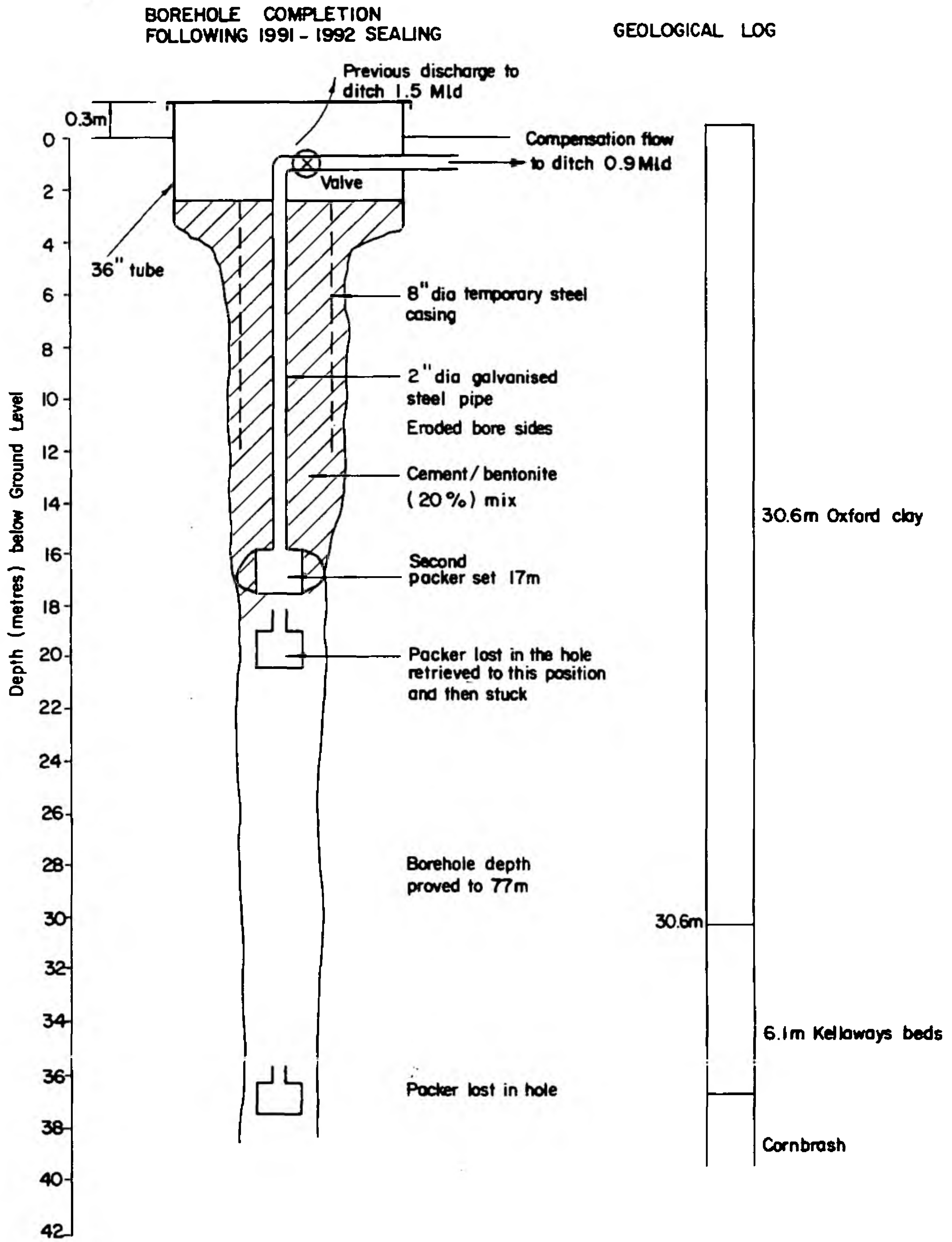
Figure E8a



NEW BOREHOLE WALKERS BARN
NGR 166 354

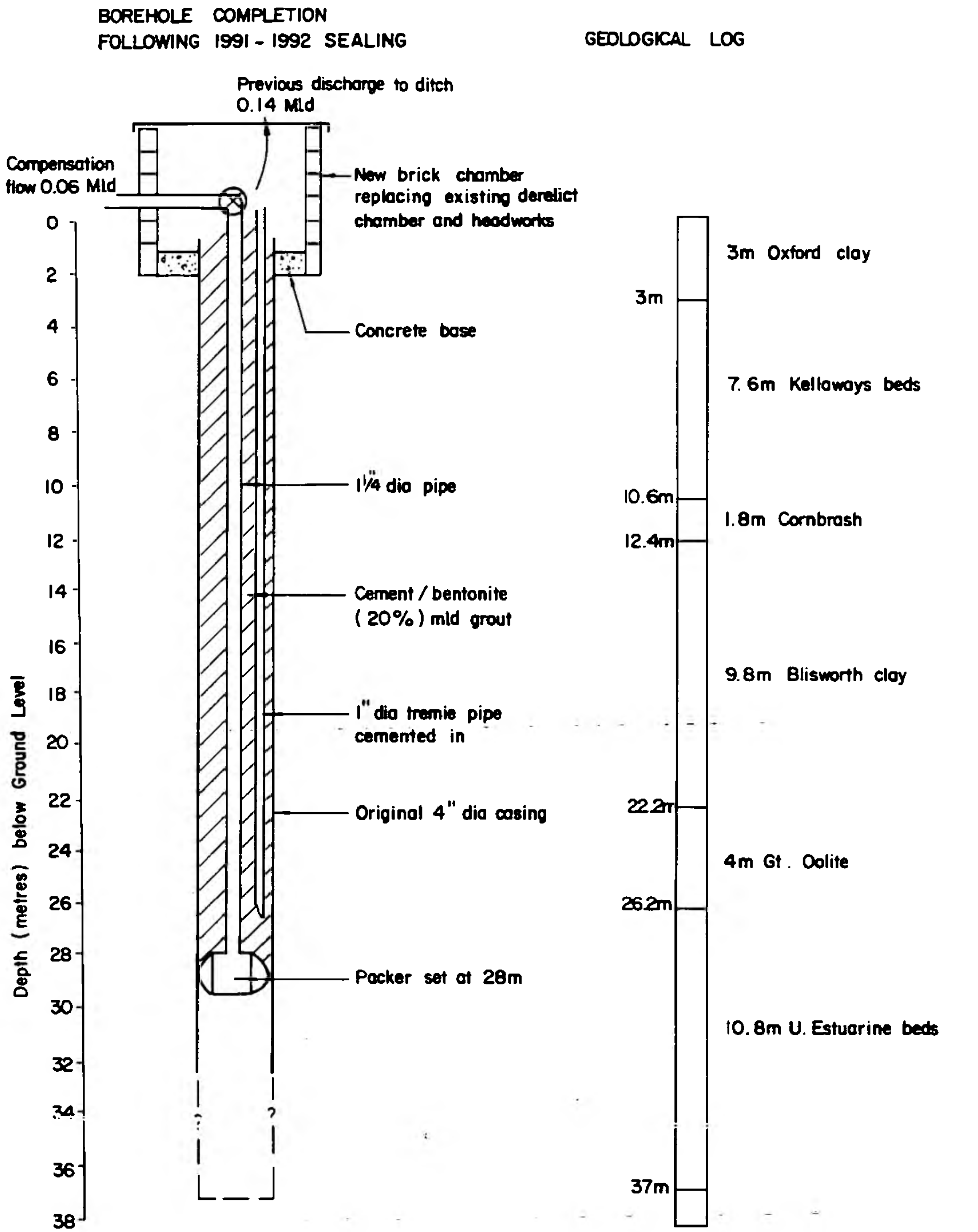


BOREHOLE COBSHORNE FARM (L 13)
N.G.R. TF 126 309

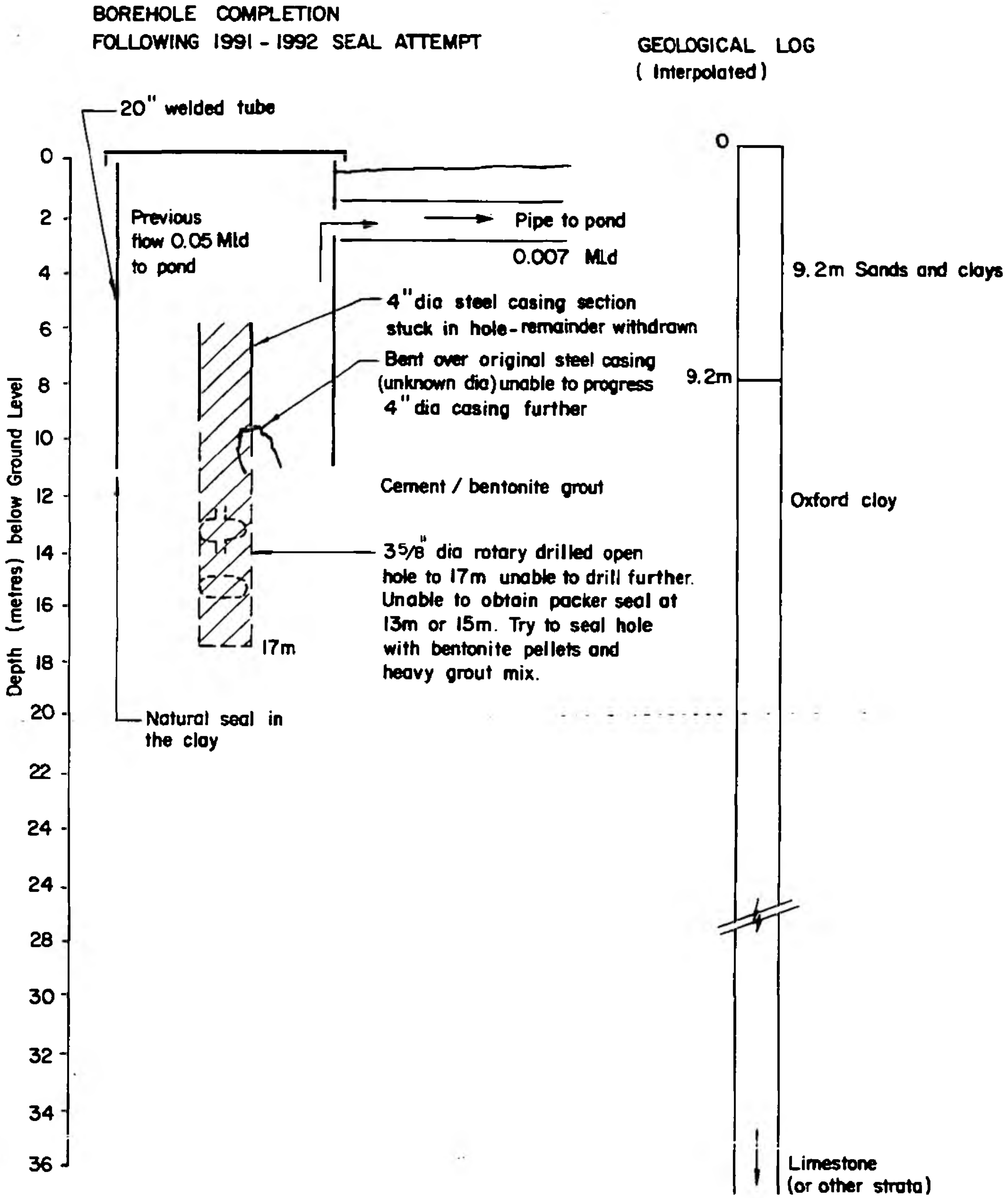


BOREHOLE CONNANTS FARM (L19)
N.G.R. 151 303

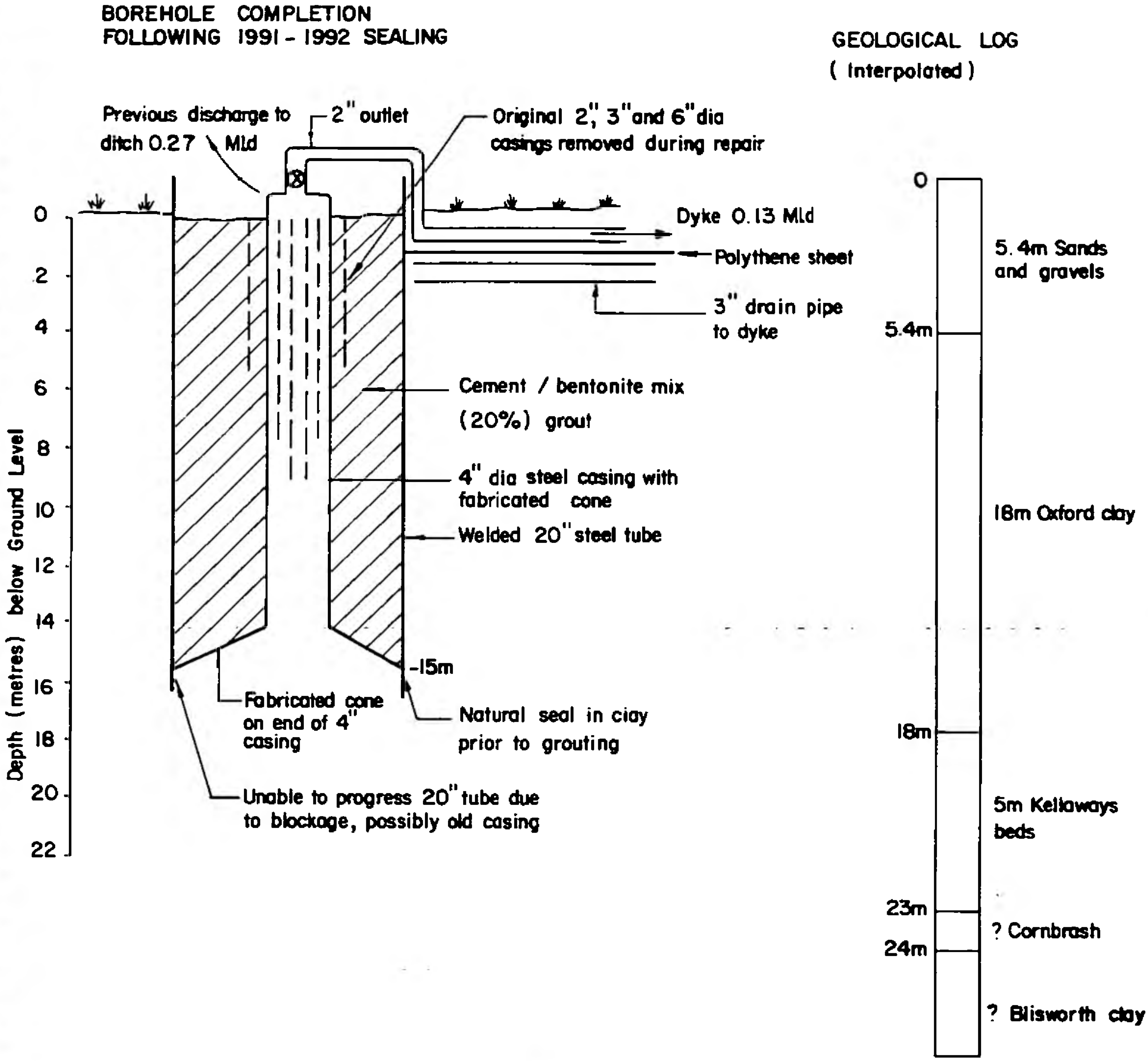
Figure E11



BOREHOLE DECOY FARM (L14)
N.G.R. TF 137 310

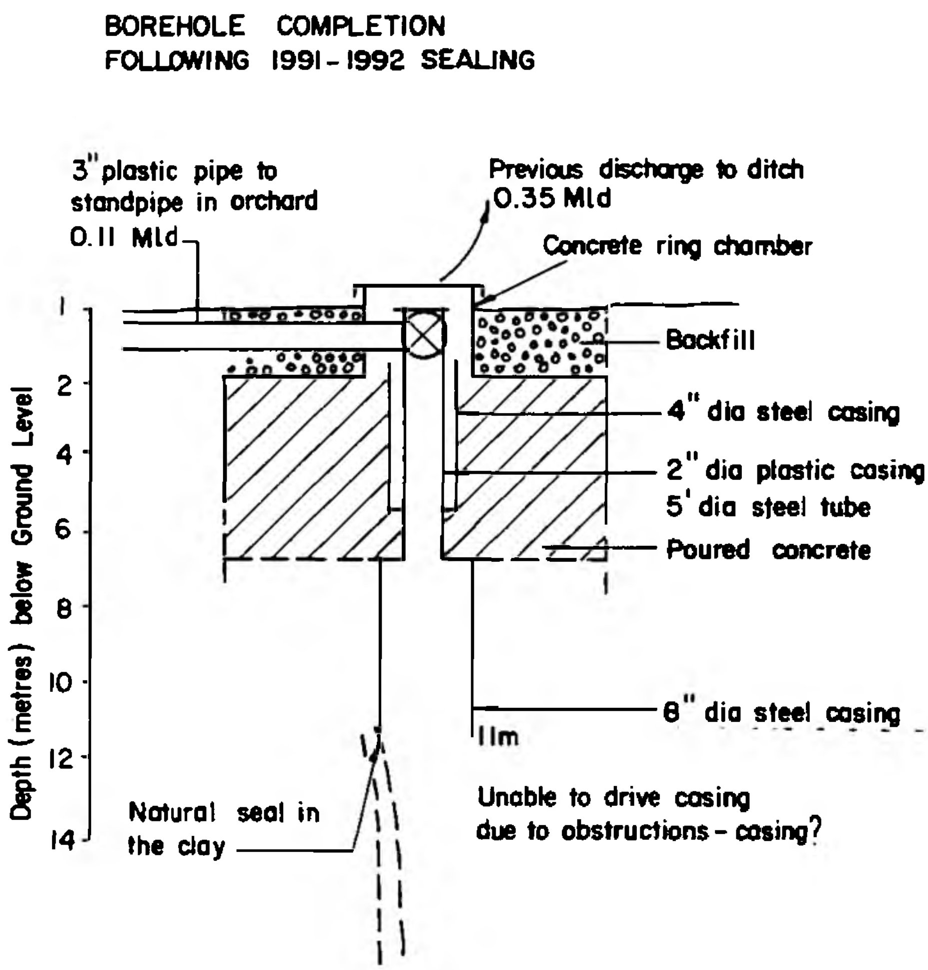


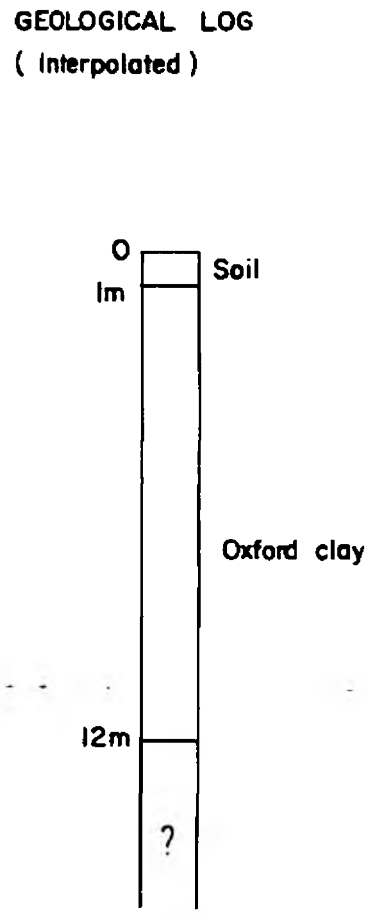
BOREHOLE BARNES FARM (L59)
N.G.R. 155 389



BOREHOLE QUADRING FEN FARM (L12)
N.G.R. TF 202 329

Figure E14

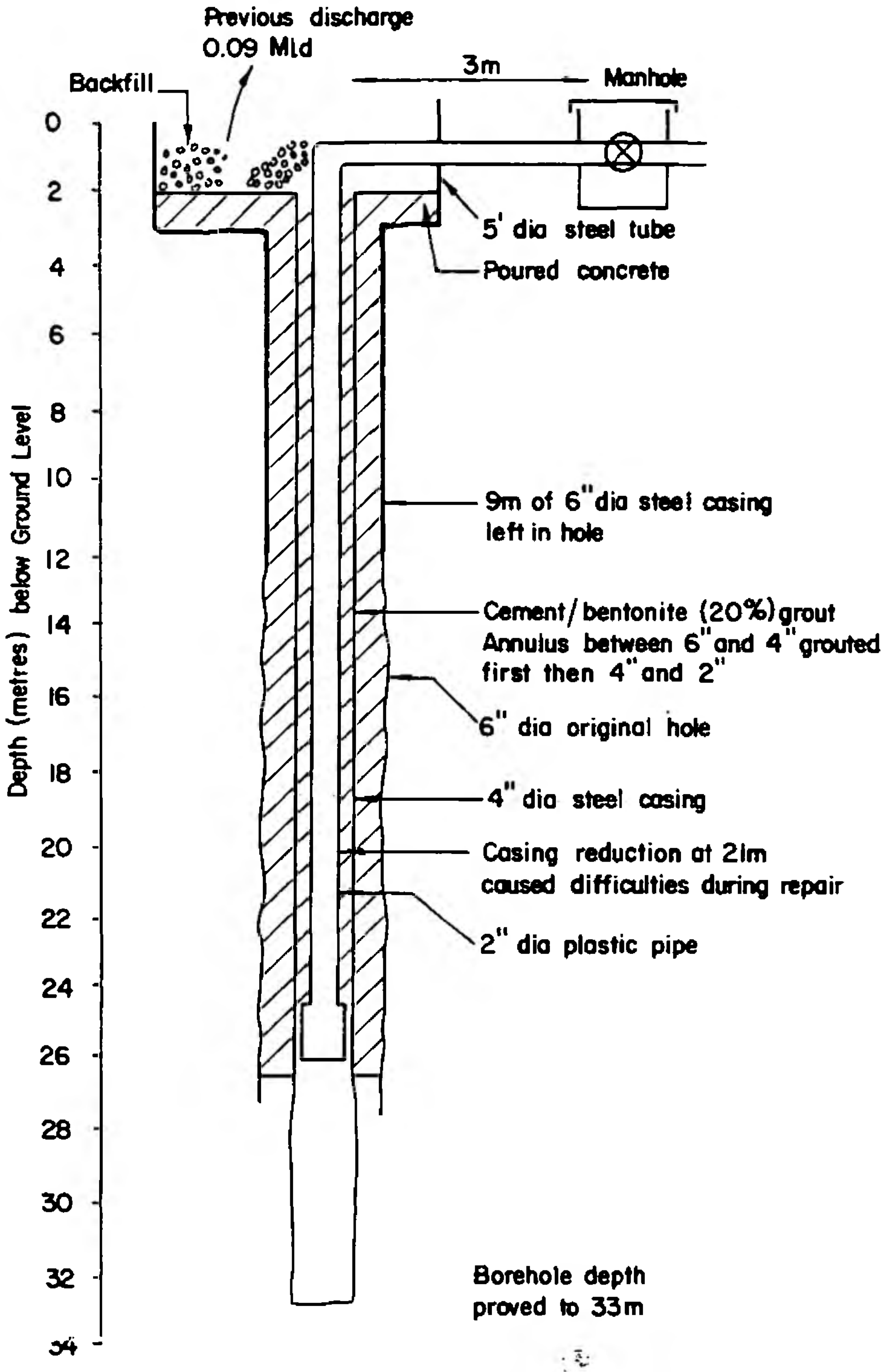




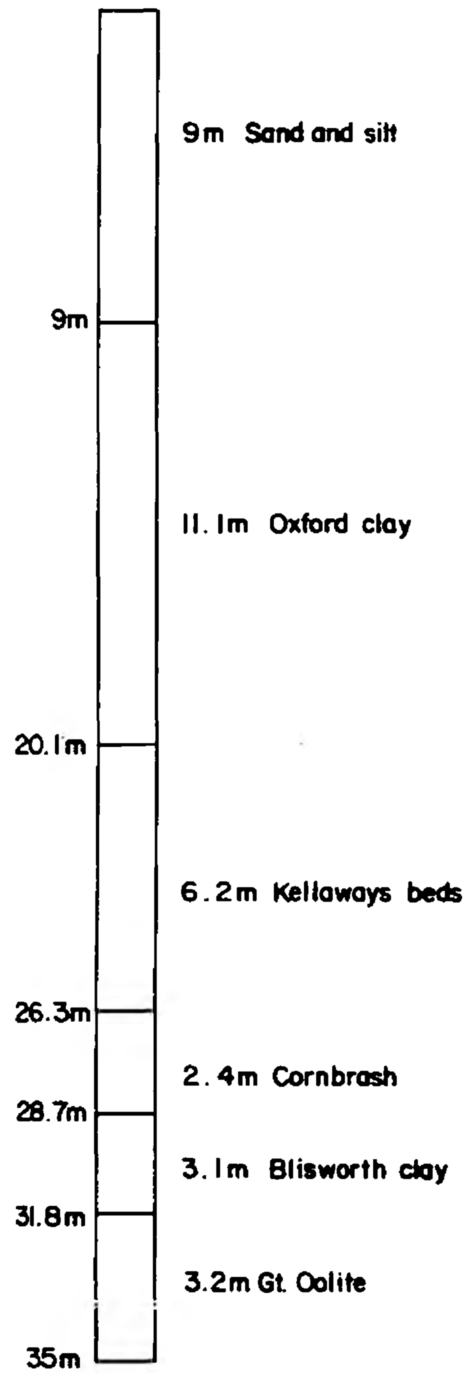
BOREHOLE CHURCH FARM (L15)
N.G.R. 148 315

Figure E15

BOREHOLE COMPLETION
FOLLOWING 1991 - 1992 SEALING

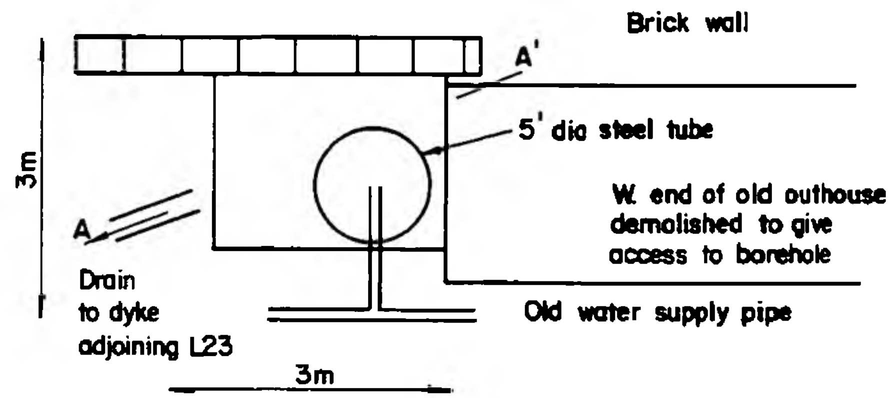


GEOLOGICAL LOG

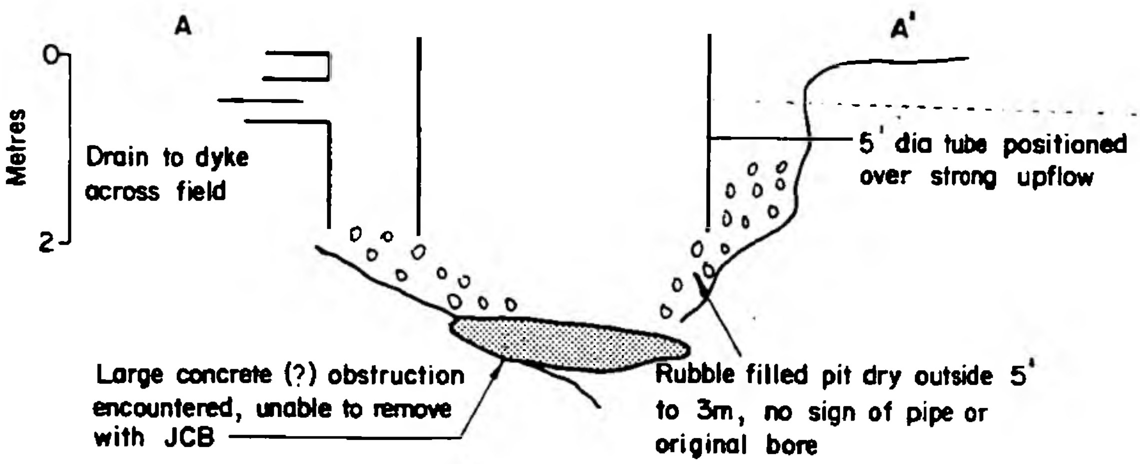


BOREHOLE DUNSBY FEN I (L23)
N.G.R. 163 274

BOREHOLE WORK COMMENCED
BUT ABANDONED



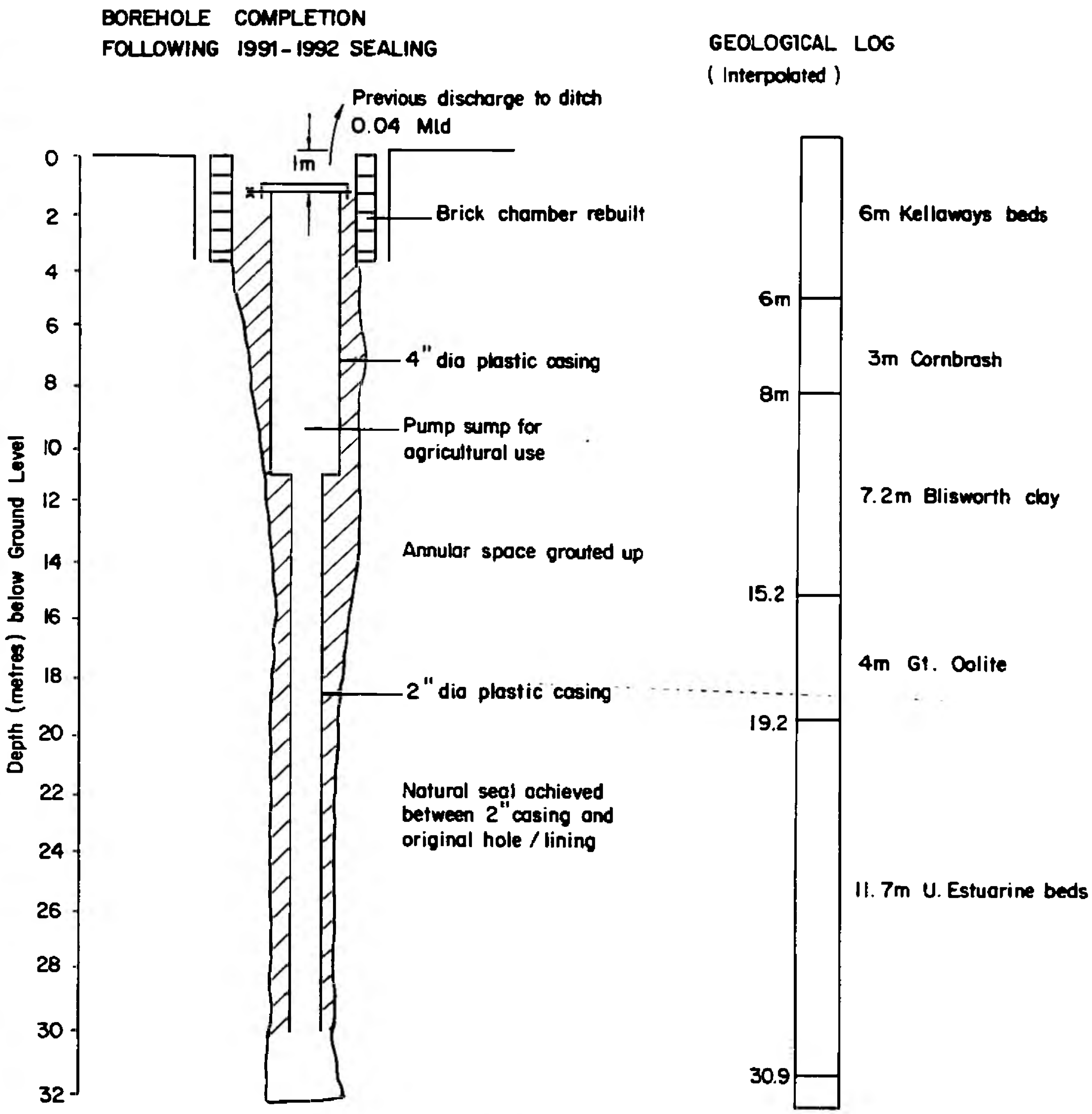
PLAN



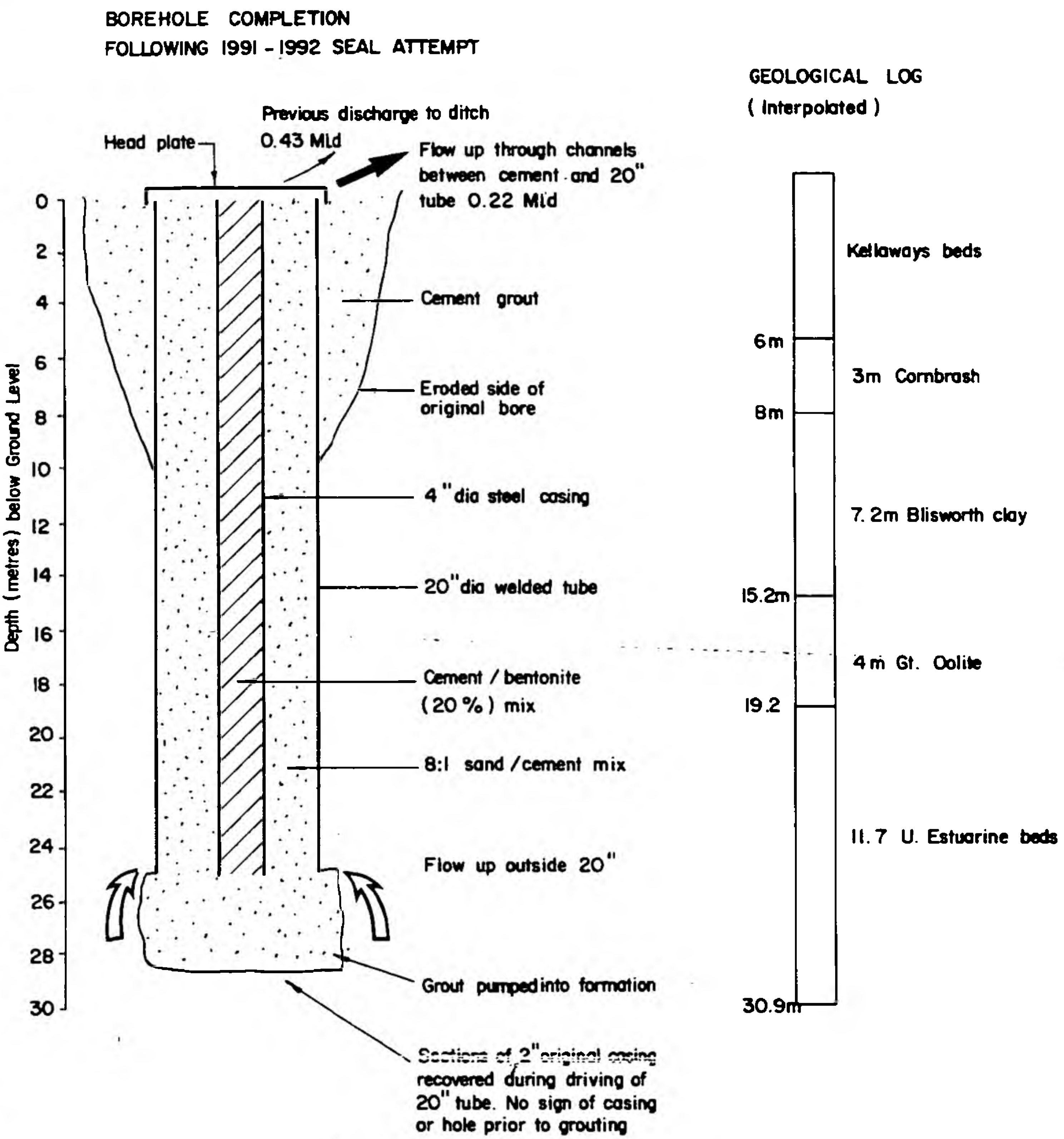
SECTION

BOREHOLE DUNSBY FEN II (L25)
N.G.R. 162 273

Figure E17

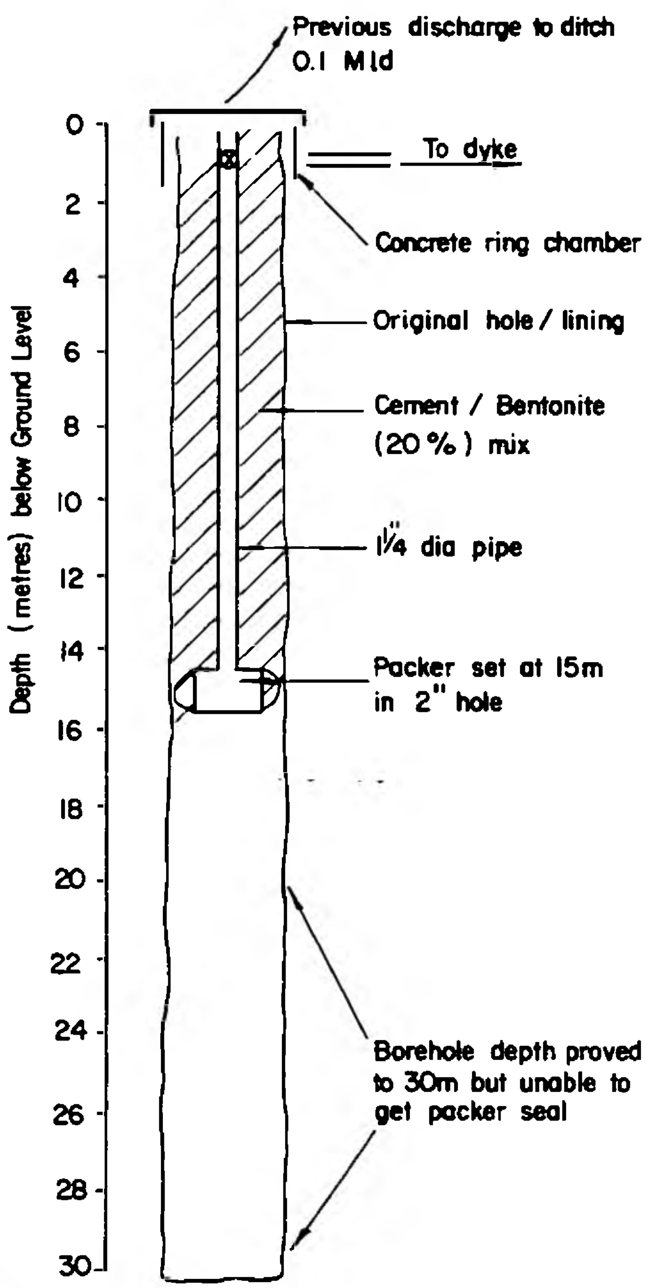


BOREHOLE CAMP FARM (L21)
N.G.R. 131 282

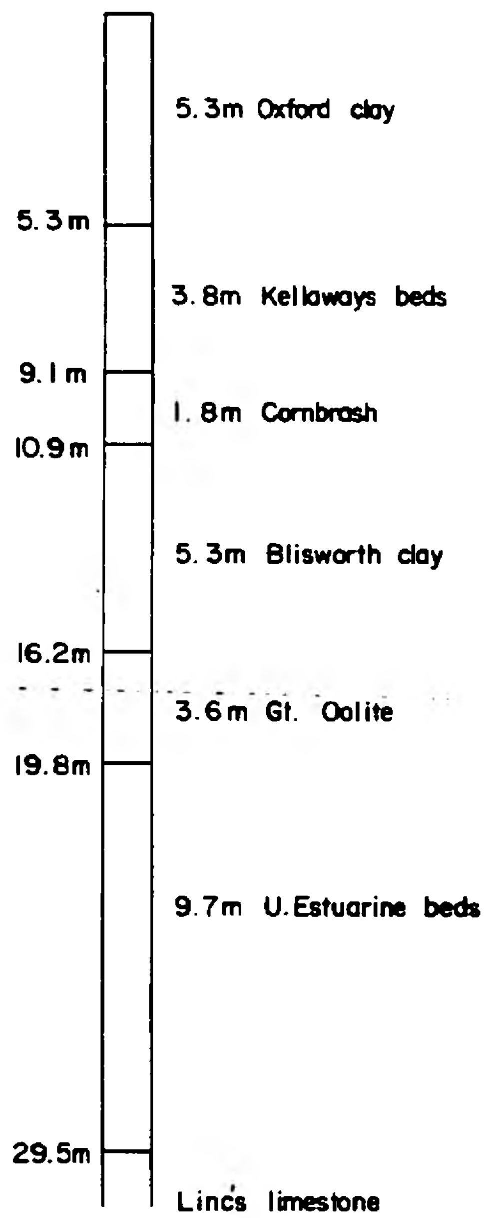


BOREHOLE SYCAMORE FARM (L35)
N.G.R. 148 211

BOREHOLE COMPLETION
FOLLOWING 1991 - 1992 SEALING

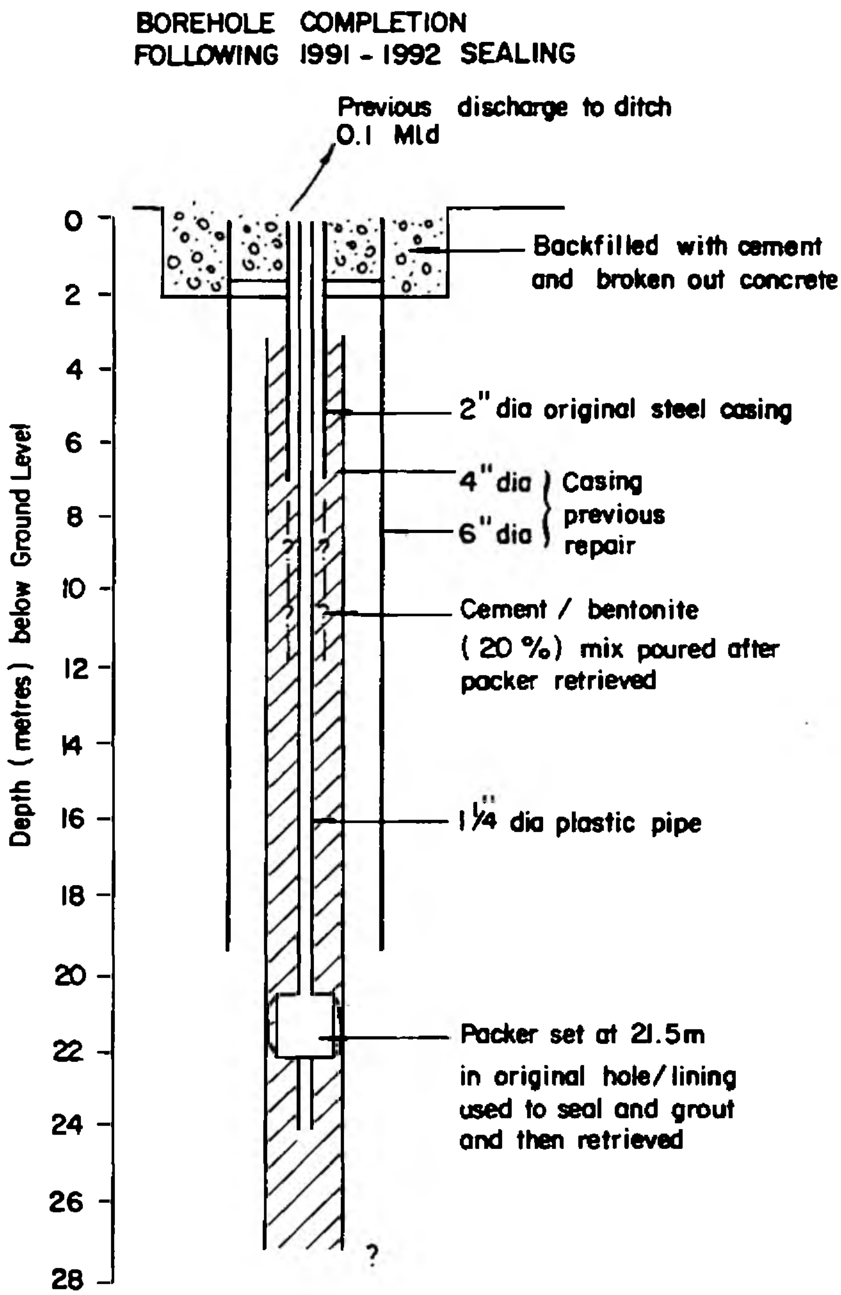


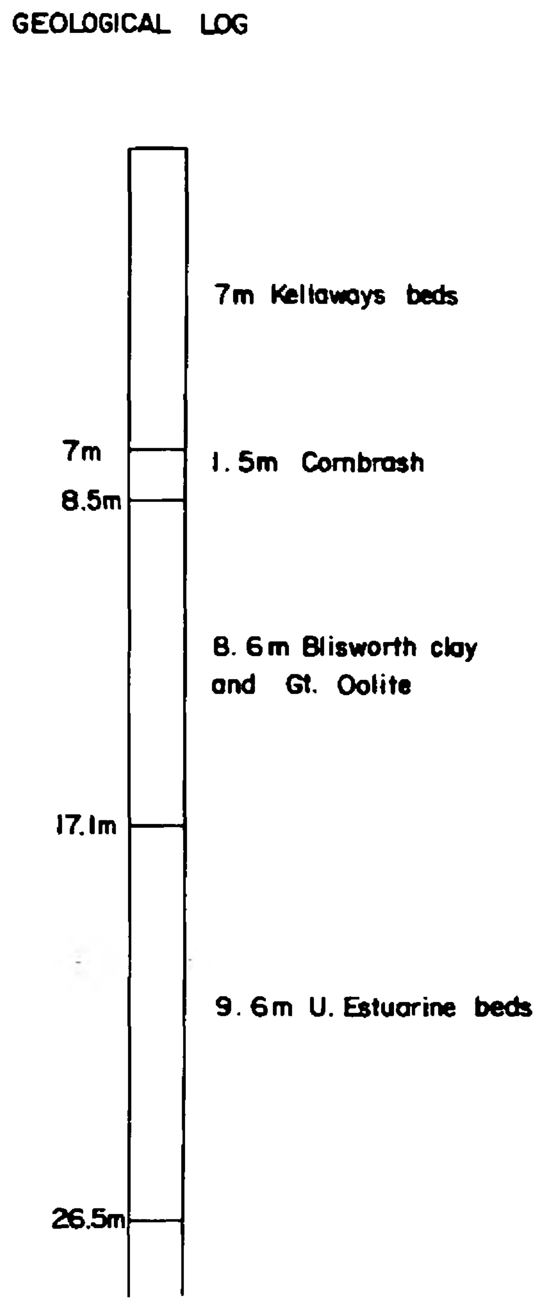
GEOLOGICAL LOG



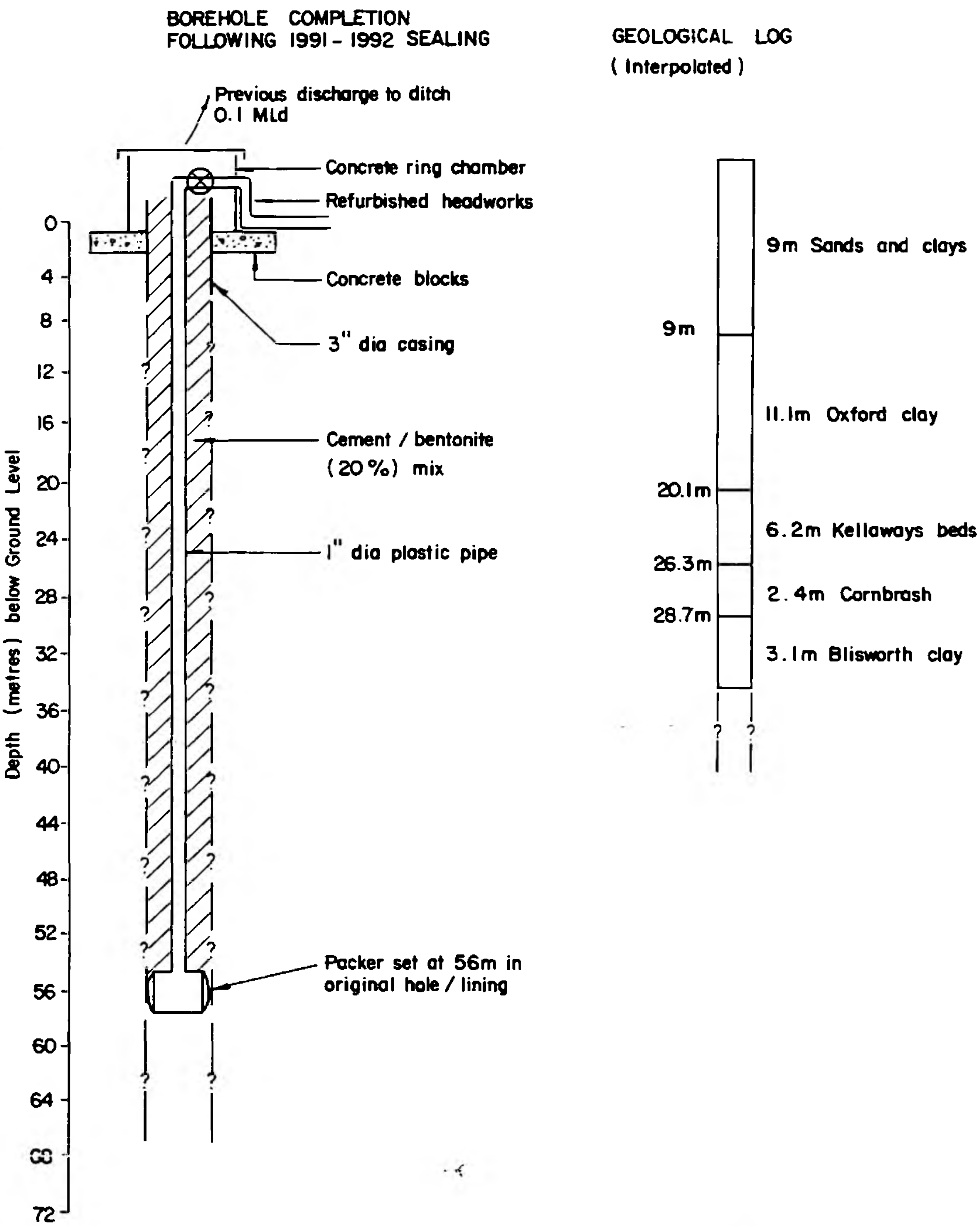
BOREHOLE TUNNEL BANK FARM (W54)
N.G.R. 108 191

Figure E20



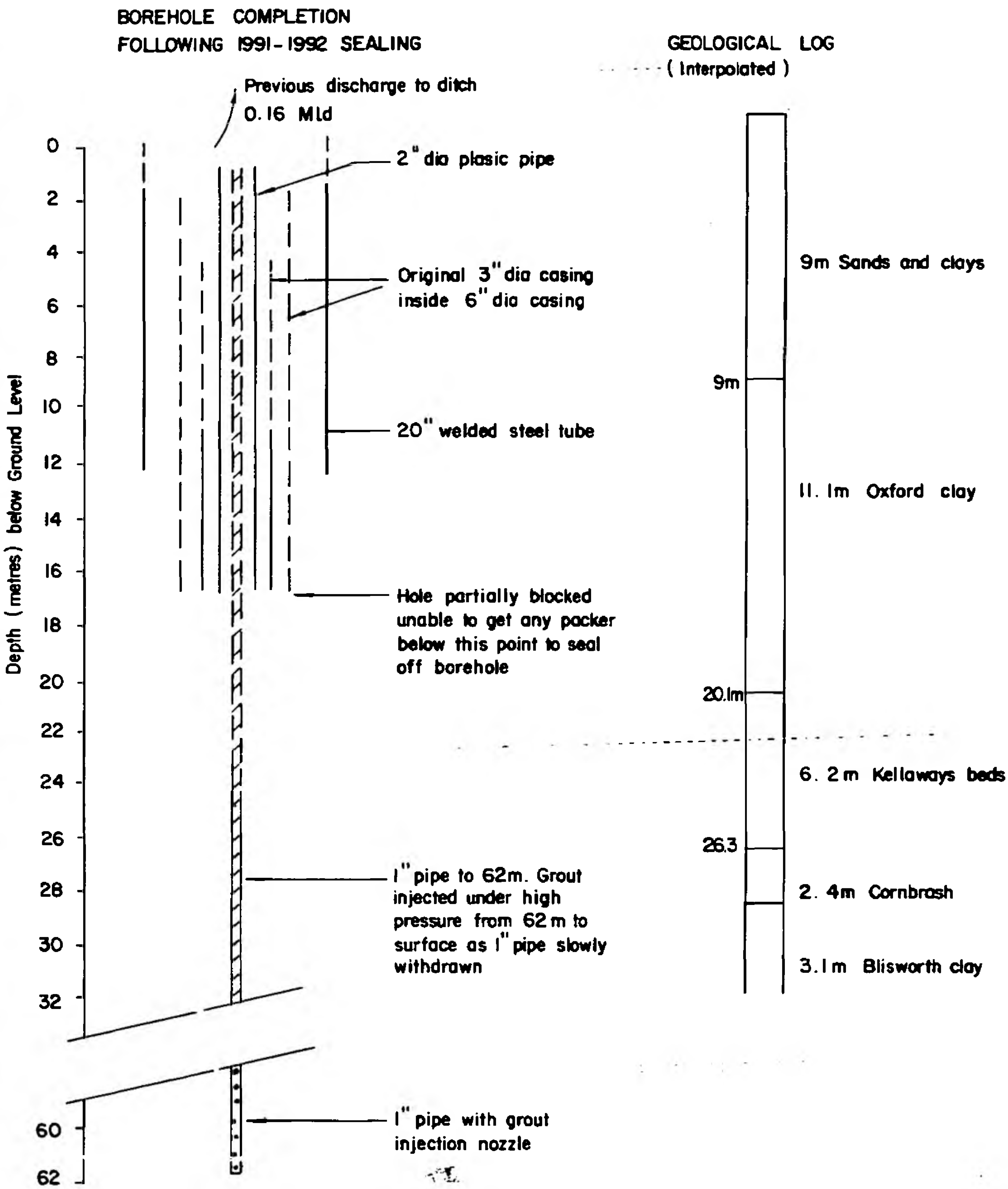


BOREHOLE ALBRIGHT & WILSON (W7)
N.G.R.106 196



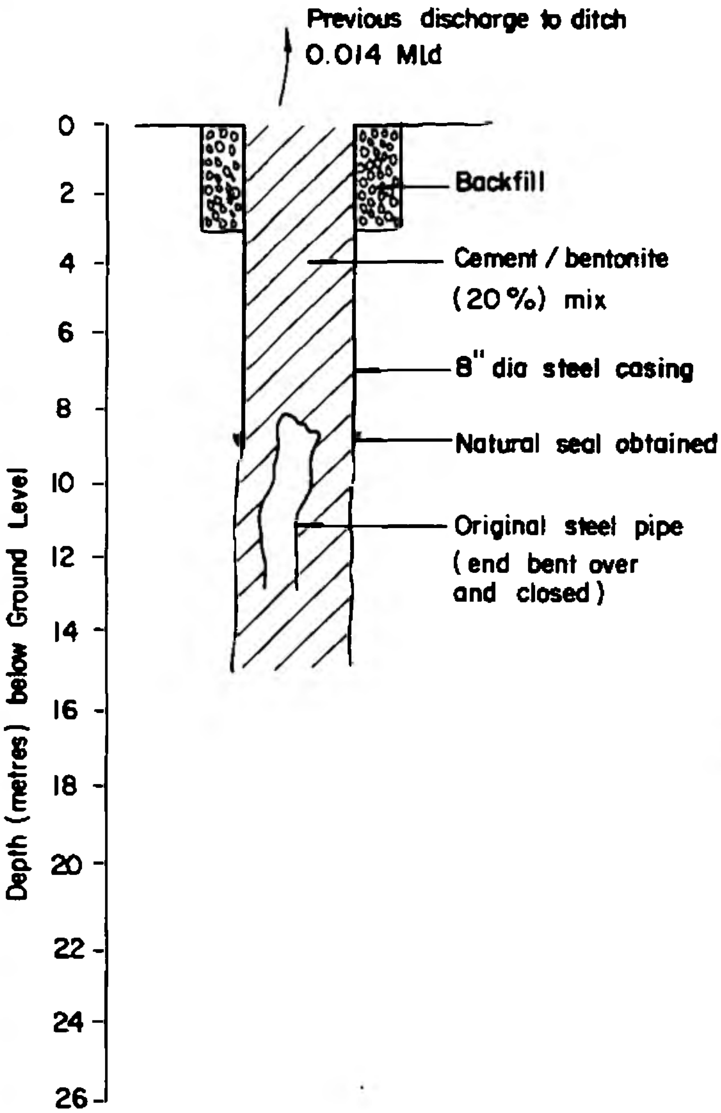
BOREHOLE CHIMNEY FARM (W13)
N.G.R. 174 176

Figure E22

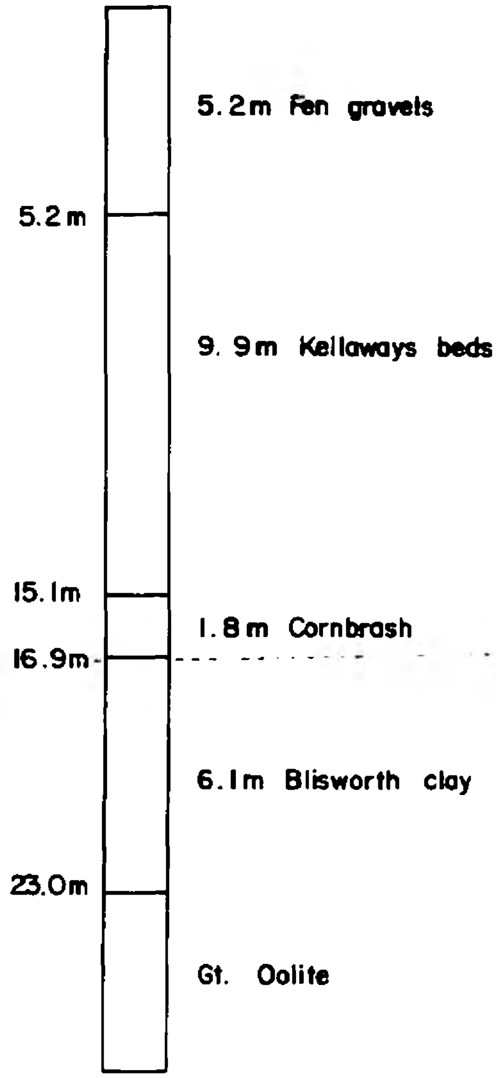


BOREHOLE SCHOOL FARM, TONGUE END (W14)
N.G.R. 167 191

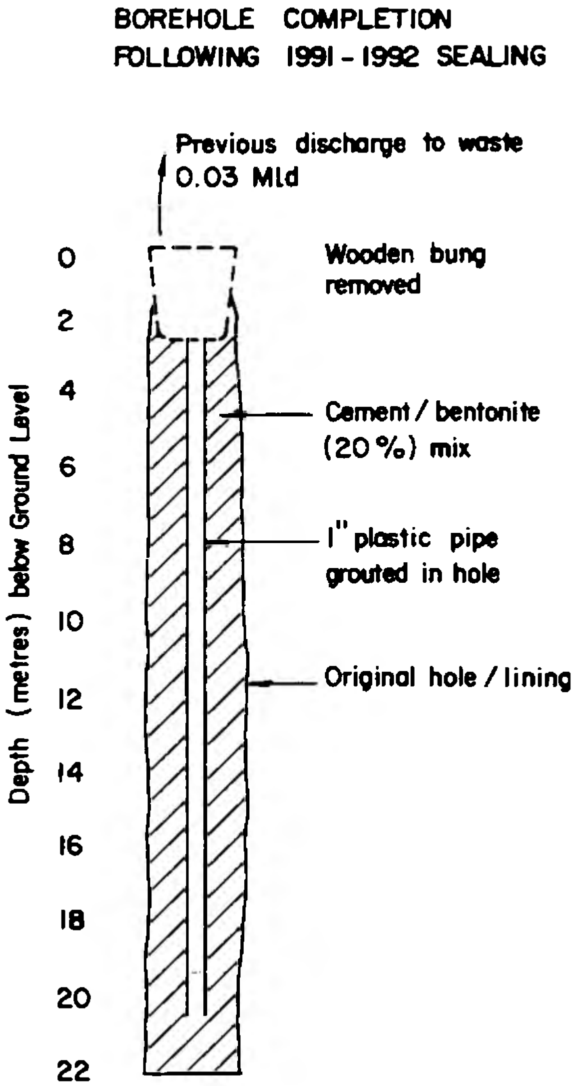
BOREHOLE COMPLETION
FOLLOWING 1991 - 1992 SEALING

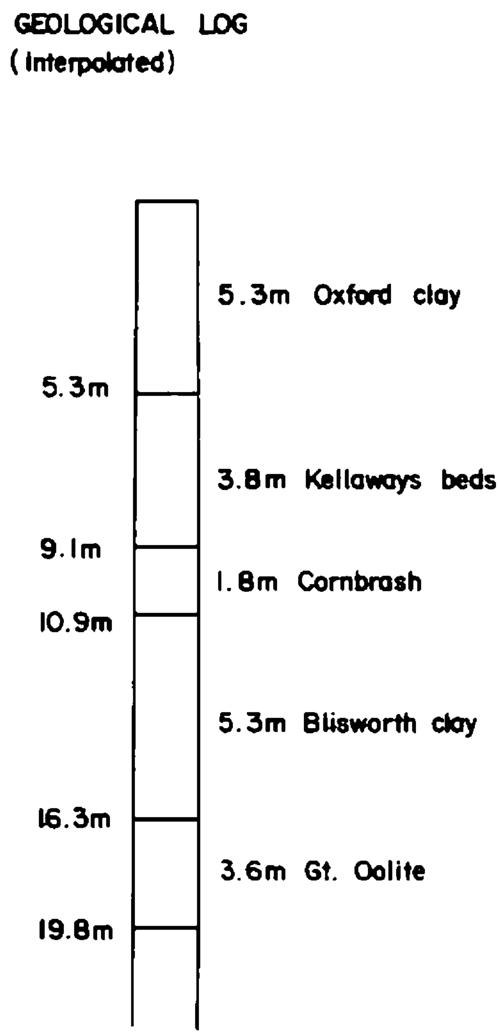


GEOLOGICAL LOG



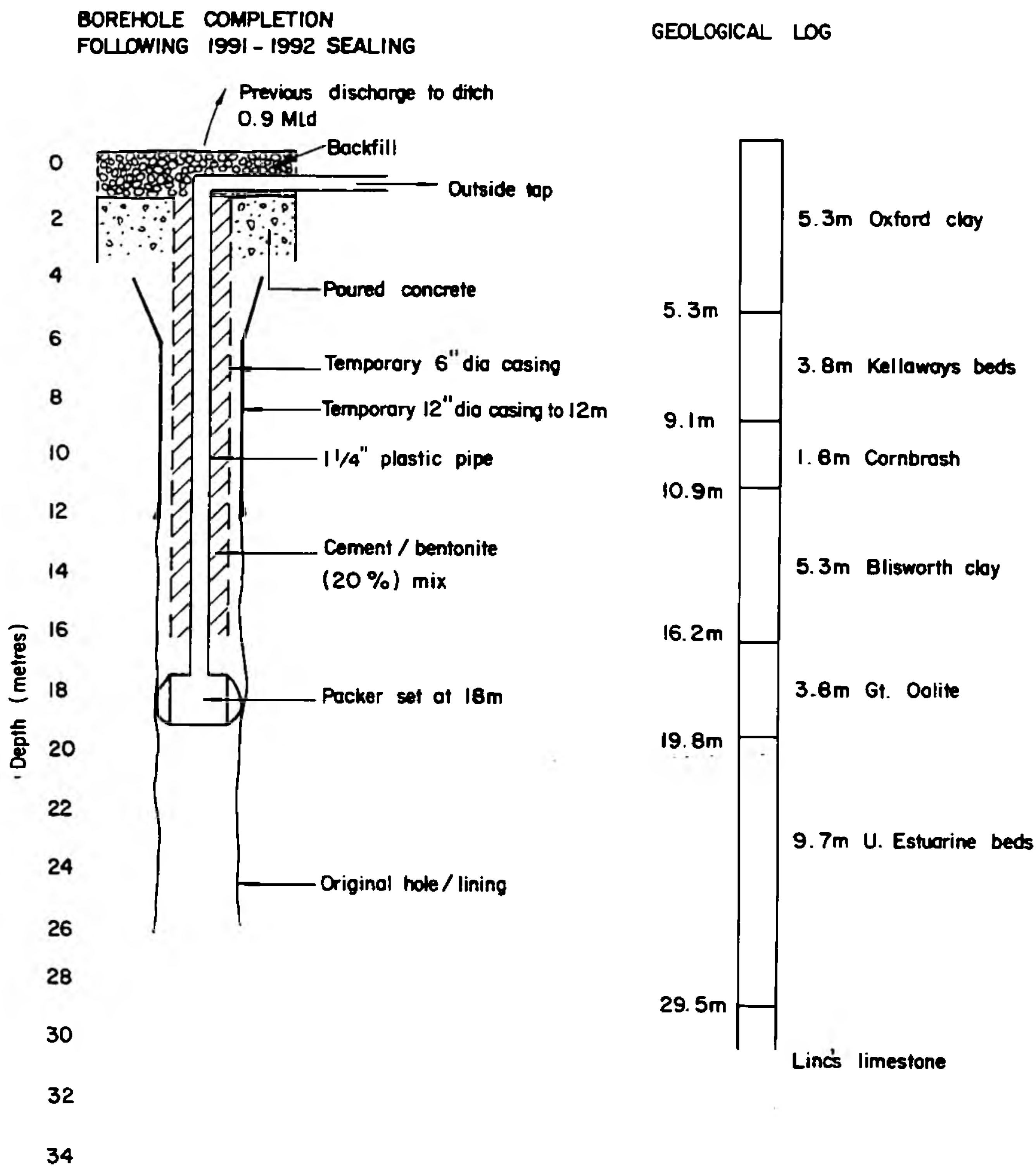
BOREHOLE BARNES DROVE (L33)
N.G.R. 125 217



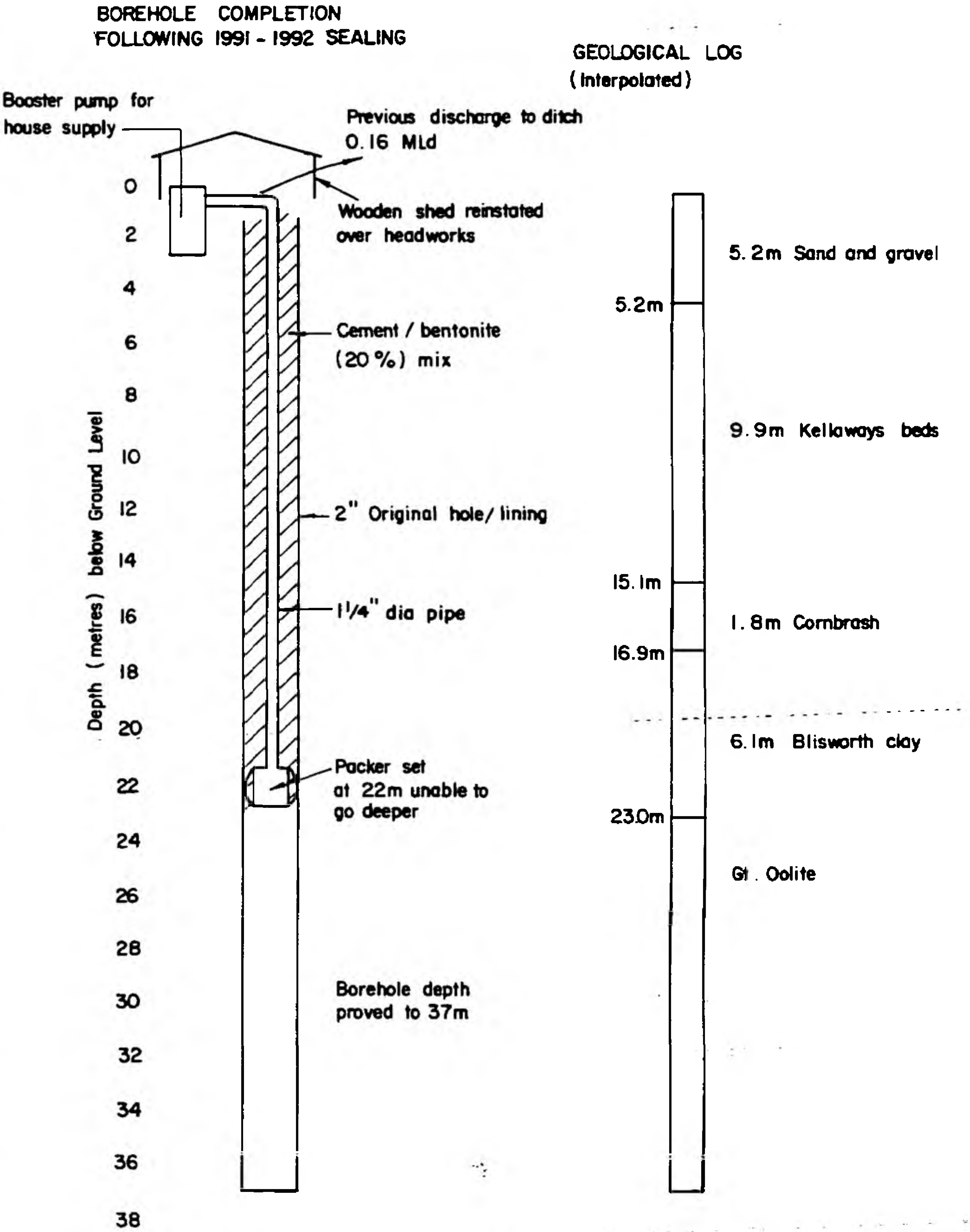


BOREHOLE EASTGATE DEVELOPEMENT (W57)
N.G.R.104 199

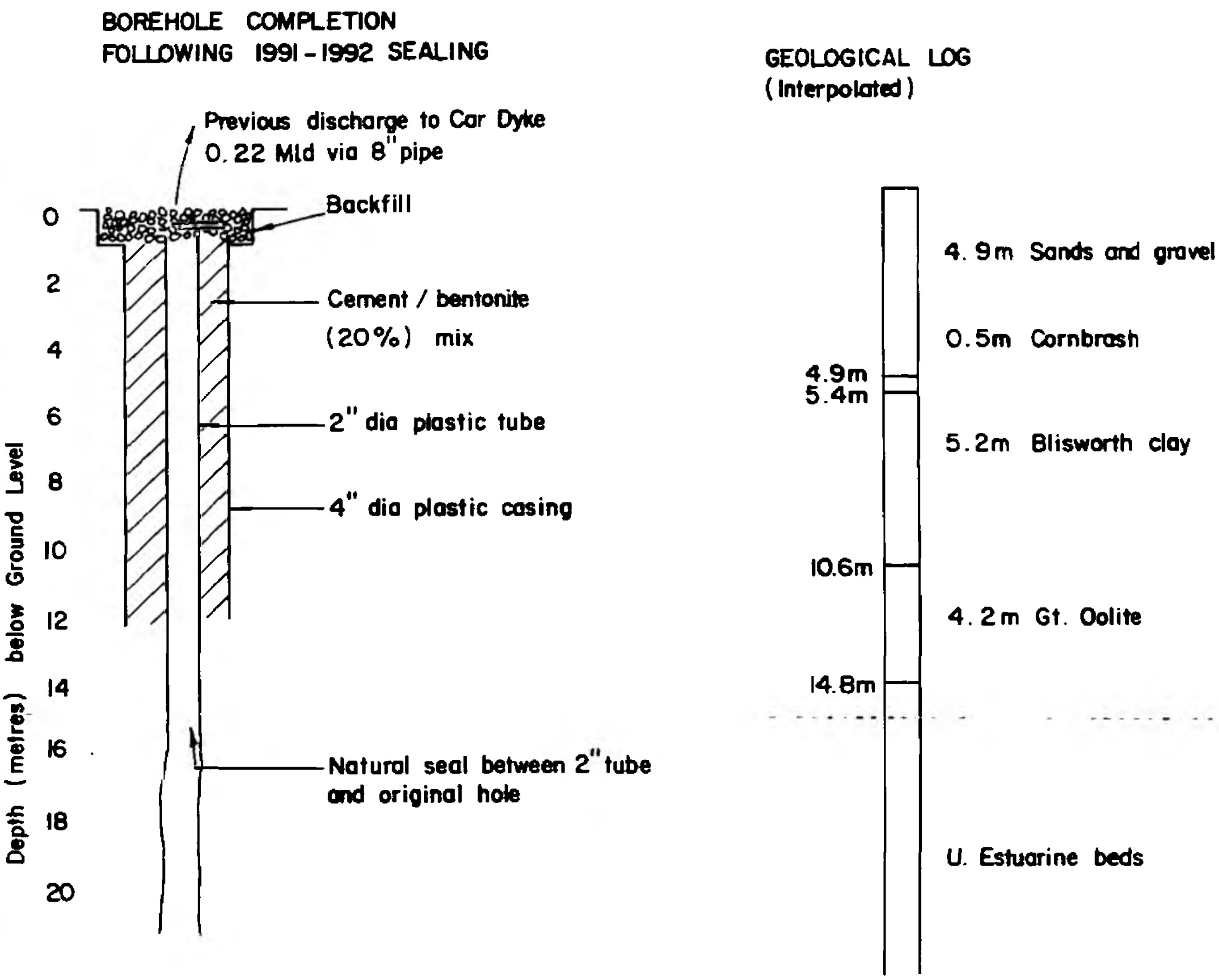
Figure E25



BOREHOLE SOUTH FEN ROAD (W18)
N.G.R. 108 195

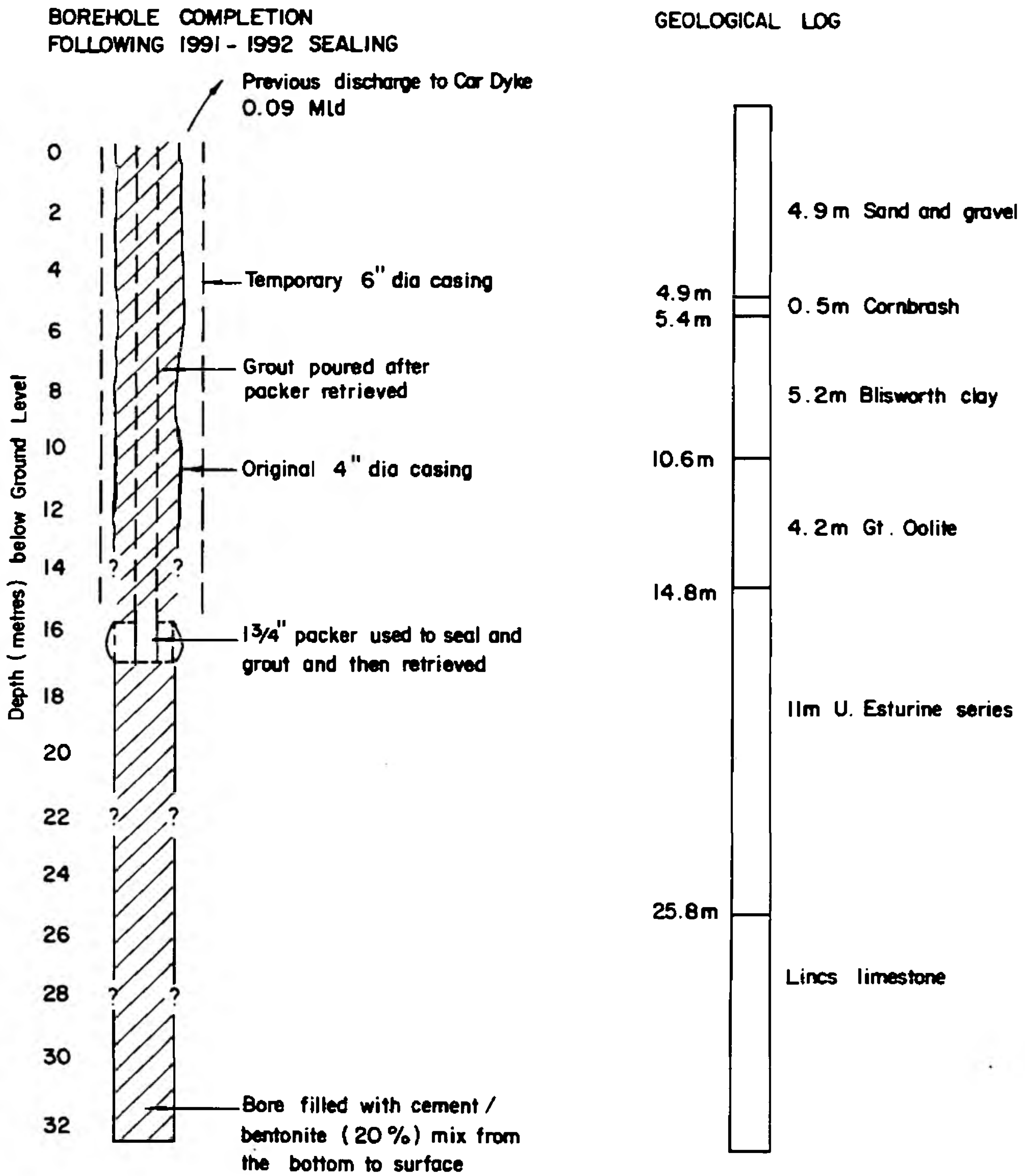


BOREHOLE BLACK HOUSE FARM (W56)
N.G.R. 133 190

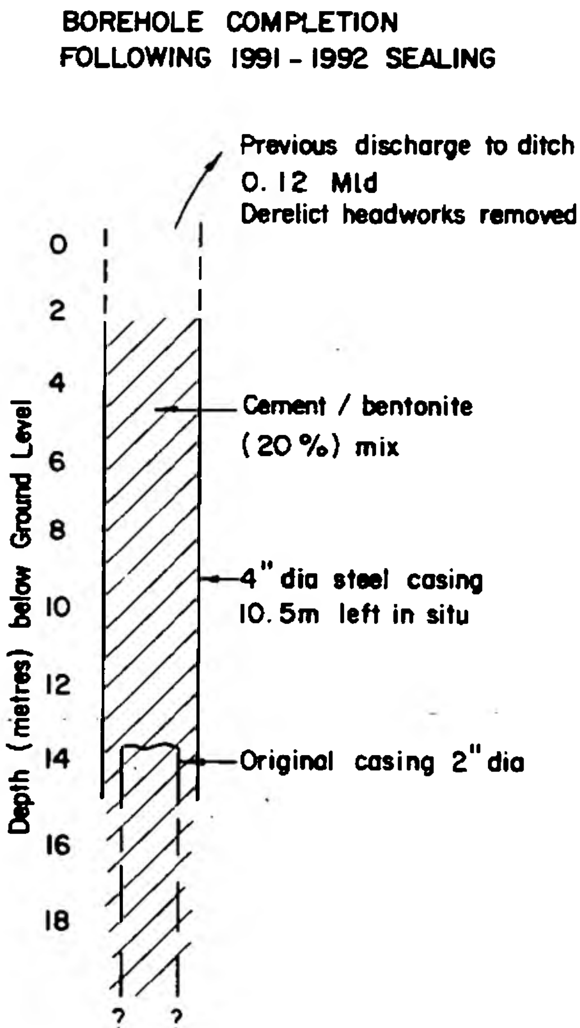


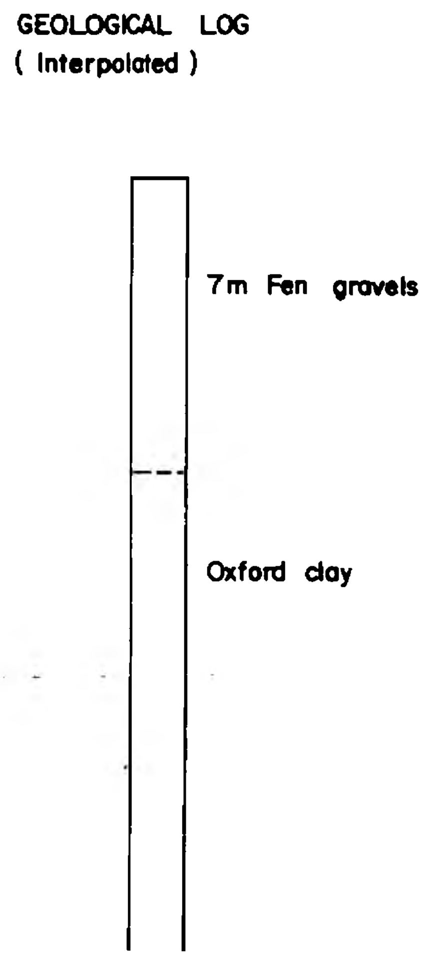
BOREHOLE HEREWARD CRESS BEDS (W5)
N.G.R. 103 188

Figure E28

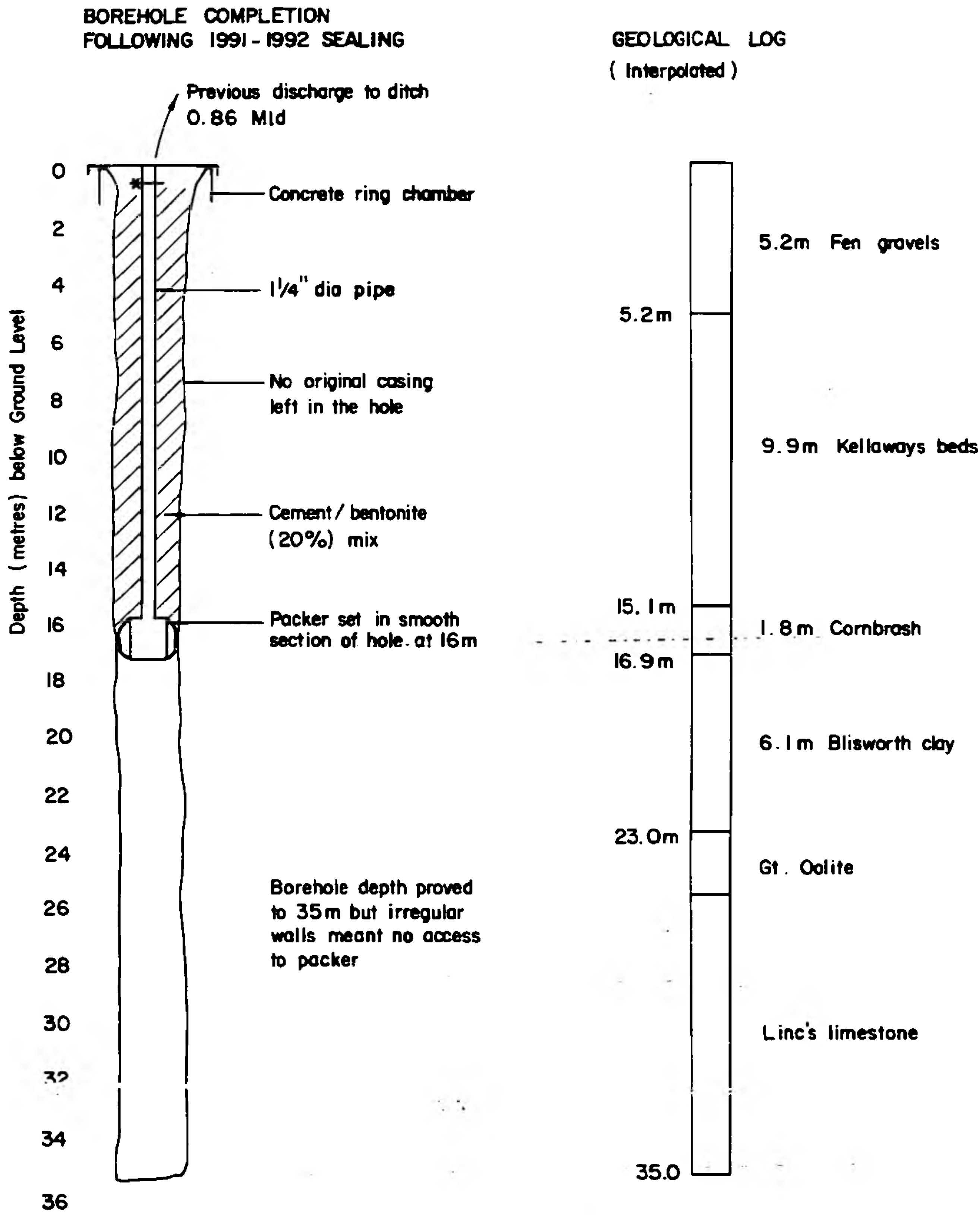


BOREHOLE CAR DYKE THURLBY (W27)
N.G.R. 104 166



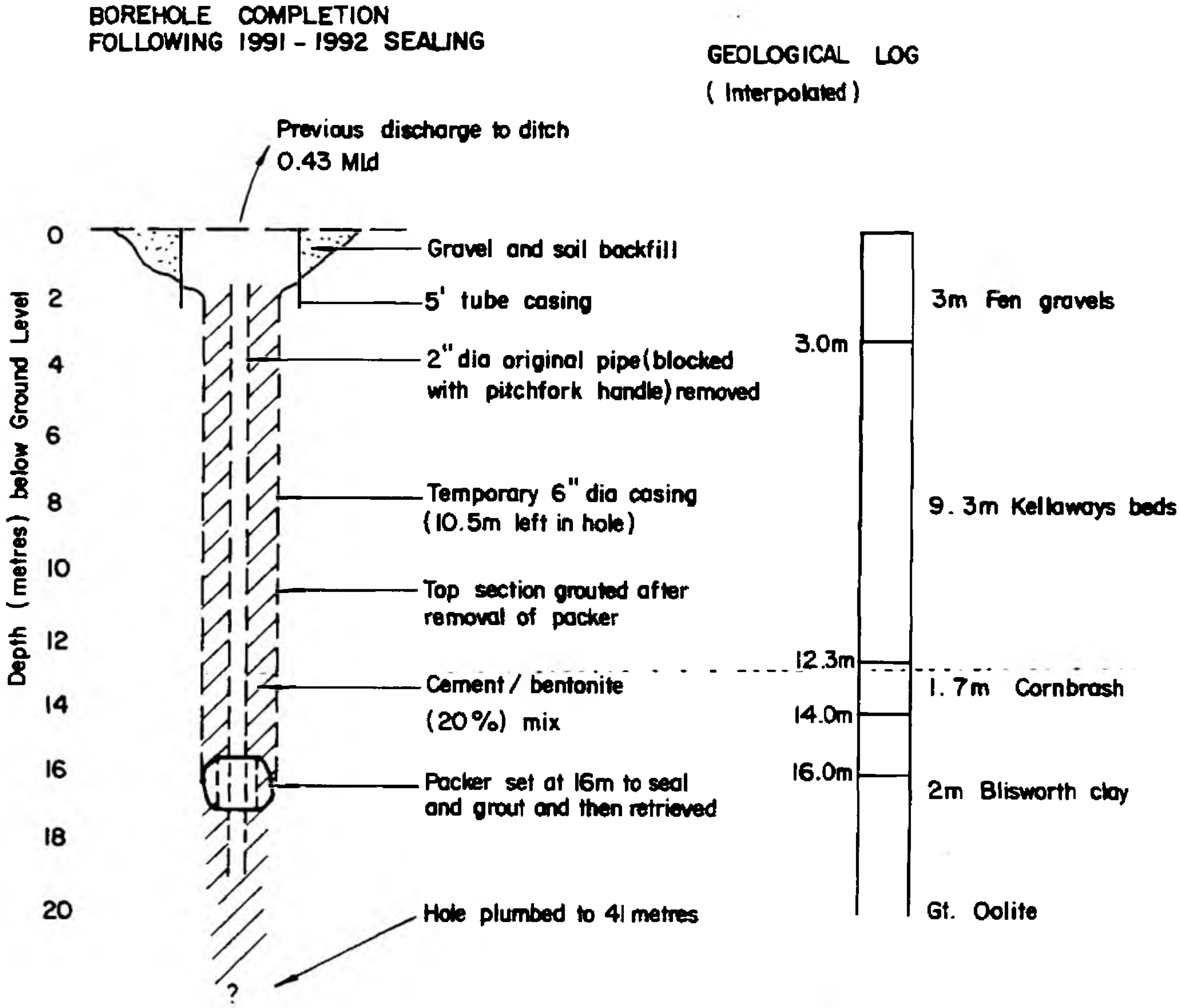


BOREHOLE MAXEY HOUSE (W4)
N.G.R. 141 095



BOREHOLE THURLBY FEN DUTCH BARN (W58)
N.G.R. 124 173

Figure E31



BOREHOLE THURLBY FEN FIELD (W59)
N.G.R.123 169

Appendix F

FURTHER WORKS

APPENDIX F - FURTHER WORKS

A number of wild boreholes have been identified for future work. These include:

Four boreholes from the present project requiring additional remedial work, at Quadring High Fen (L12), Sycamore Farm (L57), Walkers Barn (L57) and Barnes Farm, Helpringham (L59).

Two major boreholes identified at the site of the old watercress beds at Kates Bridge.

Two boreholes, omitted from the present project, at Langtoft Common (W12) and Dunsby Fen (L25)

Four boreholes in the Quadring Fen area, as reported by the owner at Robinson Farm, Quadring Fen. Amongst these holes is likely to be the already recorded Quadring Low Fen but the other locations are not known at this stage.

At least two boreholes in the northern outskirts of Peterborough, Dysons, Werrington (W31) and Foxcovert Road, Flinton (W55). Two others, Mancetters, Walton (W3) and Lincoln Road, Werrington (W32) are reported to exist but have not been positively identified.

Swaton Road, Horbling (L39) has been located and appears to be a wild bore although its relatively high elevation above OD, 9 m, is inconsistent and puzzling. A wild bore reported at Eau Farm, Swaton, could not be identified and is presumed to be seasonal or ephemeral.

Wild bores at Birthorpe Road, Billingborough (L2), Sempringham House (L8) and Mallard Farm (L7) were considered too minor to warrant remedial work at present, though the situation at each borehole could deteriorate and should therefore be monitored.

A second as yet unidentified wild bore is rumoured to exist on Helpringham Fen. One wild bore, possibly two, certainly exists in the vicinity of Spinney Farm, Bourne North Fen but attempts to locate them have been unsuccessful.

At least eight wild bores, some minor and other seasonal, have been identified or located within the Bourne urban area (W6, W11, W19, W21, W24, W26, W51 and W53) but are likely to prove difficult to work on due to lack of access or close proximity to buildings. Two other boreholes, at Mays Works (W15 and W52) on the eastern outskirts of Bourne, although located could not be included in the recently completed programme due to a refusal of cooperation by the landowner - the only instance encountered.

Given the above average rainfall that has characterised this Autumn together with reports after the end of the 1976 drought of an increase in borehole failures, it is likely that further, as yet unrecorded, holes will be reported to the NRA over the next few months as having failed and gone wild.