R. Bradford.

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE of HYDROLOGY

GROUNDWATER INVESTIGATION REPORT FOR
FEASIBILITY STUDY FOR WATER SUPPLIES
TO MOLEPOLOLE AND MOCHUDI VILLAGES, BOTSWANA

INSTITUTE OF HYDROLOGY
HOWBERY PARK
WALLINGFORD
BERKSHIRE

REPUBLIC OF BOTSWANA

DEPARTMENT OF WATER AFFAIRS

FEASIBILITY STUDY FOR WATER SUPPLIES TO MOLEPOLOLE AND MOCHUDI VILLAGES

GROUNDWATER INVESTIGATION REPORT

JUNE TO OCTOBER 1974

GROUNDWATER INVESTIGATION REPORT FOR FEASIBILITY STUDY FOR WATER SUPPLIES TO MOLEPOLOLE AND MOCHUDI VILLAGES

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PART 1

G E N E R A L

CHAPTER 1

INTRODUCTION

As part of a feasibility study for a water supply development for the villages of Molepolole and Mochudi in Botswana, the Institute of Hydrology carried out groundwater investigations at the request of Sir Alexander Gibb and Partners (Africa) for the Department of Water Affairs of the Government of Botswana.

In accordance with Section 4.2 of the Terms of Reference the investigation involved an assessment of the sustained yields of the most productive existing boreholes; the location and supervision of the drilling and testing of new boreholes, and the analysis of water quality aspects.

A brief reconnaissance study was carried out in early April, 1974 and the results presented in a Preliminary Report in May. The main investigation programme did not commence until mid-June and, due to difficulties with the equipment, was not completed until early October.

CHAPTER 2

PROCEDURES

2.1 Pumping Tests

Variable rate pumping tests, involving several consecutive stages at progressively increasing rates of pumping, were employed to ascertain sustained yields. These were carried out on the following boreholes:

Molepolole - Camp, Ntloedibe and 2126/2127
Mochudi - 38, 850, 1162, 1668 and 2035

Similar tests were made on the boreholes drilled as part of the investigation, except for borehole 3 at Molepolole and boreholes E and C at Mochudi, on which steady rate tests were employed.

The first two stages of each test continued for 2 to 3 hours. Each was pumped at a rate of about 50% and 75% respectively of the original reported yield where this was known. The third and usually the final stage was pumped for 24 hrs at the original yield to indicate any aquifer boundary conditions that could be encountered during the normal pumping regime. On some boreholes, eg 1162, a fourth stage was introduced to ascertain the relative productivity of different water bearing horizons, or to gauge any interference arising as a result of abstraction from nearby boreholes on the proposed production borehole being tested.

Electric submersible pumps were used to test all of the existing boreholes. Constant displacement pumps, operated by a cable-percussion drilling rig, were employed on most of the new boreholes. A meter was used to measure pumping rates, where this was not practical, a stopwatch and container were used. The error with the latter method may be as much as 10% at higher pumping rates. Outflow water was discharged some 300 m from the borehole site into a convenient watercourse, although at some sites this was not possible and re-circulation may have influenced the results.

Pumping water levels were measured below a chosen datum point at the well head to the nearest 0.5 cm at selected time intervals with electrical water-level indicators. Wherever the opportunity arose levels were similarly measured on nearby observation boreholes; the frequency of readings related to the distance from the production borehole. No corrections were made to the drawdown data for partial penetration, due to the limited drilling details available, or for changes in barometric pressure, as the total drawdown was usually large in comparison to the water level fluctuations produced by these changes.

Drawdown levels were plotted against time on a semi-logarithmic scale to construct time-drawdown graphs. For the short duration stages the data were extrapolated to estimate the drawdown that would occur after a period of 24 hours[1] pumping at the respective pumping rate, assuming conditions remained constant. These plots were used to ascertain selected aquifer parameters: the co-efficient of transmissivity (T), that is the ability of the aquifer to transmit water, and, where observation boreholes were available, the coefficient of storage (S), the yield per unit change in head.

The specific yield, that pumping rate which will avoid critical drawdown levels, was obtained from yield-drawdown curves. These were constructed by plotting the drawdown after 24 hours against the respective pumping rate. The yield for particular drawdown conditions can be read directly from these curves.

Graphical and mathematical procedures were used to estimate the efficiency of each borehole and that part of the total drawdown for each pumping rate that was caused by well losses, such as turbulent flow between the main supply and pump intake.

2.2 Water Quality

Although some groundwater chemistry data were available from Geological Survey records, a more comprehensive sampling of existing boreholes was made in April and additional samples were collected from the different stages of the pumping tests on those boreholes that were pump tested.

Analyses were carried out at the Geological Survey Laboratory for the major cations and anions, total dissolved solids, conductivity pH and fluoride. Iron and nitrate were included in some later determinations, the former because of the abundant iron oxide in the Waterberg sequence at Molepolole, and the latter as an additional indicator of contamination.

The accuracy of the chemical analyses was checked by comparing the difference in millequivalents per litre (meq/l) between the sum of the cations and the sum of the anions for each sample.

As comparatively few bacteriological analyses were available, additional samples were collected in April, although the results were inconclusive and subsequent resampling was made with a more reliable means of collection.

PART 2

MOLEPOLOLE GROUNDWATER INVESTIGATION

CHAPTER 3

EXPLORATION

Some 50 boreholes have been drilled in the Molepolole area, the majority into the Upper Waterberg shales. Only 36 could be located and of these, only 19 sites could be identified with certainty from Geological Survey borehole records.

The lack of reliable data restricted the assessment that could be made of the relative groundwater contribution and the present stage of development of the Waterberg aquifers. However, the available data indicated that the Lower Waterberg sandstones offered the most suitable opportunity for aquifer development.

An unexplored area about two kilometres south-west of the Government Camp and to the west of where the Molepolole river cuts through the Lower Waterberg formation, was selected as appossible well field. In this locality there is a large groundwater catchment area; the maximum aquifer thickness would be intersected at lowest cost; groundwater of good quality would probably be obtained, being near the main recharge area to the south; and it is within a reasonable distance of the present main storage tank. The northern boundary of the selected area is marked by a seepage line which is the result of upward leakage of groundwater from the Lower Waterberg sandstones as these pass beneath the less permeable Upper Waterberg shales.

The permeability of the Lower Waterberg sandstones is controlled by the development of major joints and fractures. These trend in a dominantly N.N.W. - S.S.E. direction. Three boreholes were located near the seepage line on separate fracture zones (1 to 3) identified by aerial-photo interpetation, whilst a further site (4) was located on the seepage line itself (Fig 3.1). The official numbers of these sites were: 1(not known), 2(2644), 3(2643) and 4(2645).

Drilling started in April at site 1 using a cable-percussion rig. Progress continued at only one metre per day and a private contractor with a pneumatic percussion, rotary rig was subsequently hired. During three weeks in June, sites 2, 3 and 4 were completed by the latter. Site 4 was abandoned due to an insufficient supply of water.

Considerable difficulty was encountered with an unexpectedly thick sequence of saturated clays and gravels at site 1, probably marking an abandoned channel of the Molepolole River, and five trial boreholes were drilled before this site was eventually completed (Fig 3.2).

The successful pilot boreholes were to be reamed to a diameter of 250 mm in order that electric submersible pumps capable of pumping the yields recommended could be installed. In addition, by reaming to below the main supply an increase in yield of about 5% could be obtained.

Although every effort was made to locate plain casing, only 55 m of 250 mm diameter and 40 m of 300 mm diameter were eventually available. The approximate total of the smaller diameter casing required at both Molepolole and Mochudi is about 75 m.

The second compressor necessary for reaming operations with the air-rig did not prove sufficiently reliable to enable this rig to be used for the Molepolole sites. It is envisaged that these sites will be reamed at a later date.

Drilling details were poorly recorded by the driller but available details, together with recommended final construction designs and reaming depths, are shown diagrammatically in Fig 3.3.

CHAPTER 4

PUMPING TEST RESULTS

4.1 Existing Boreholes

A summary of the pumping test details is set out in Table 4.1.1. Selected short pumping test reports and data summaries are given in Appendix A. Recommended yields and other relevant data are tabulated in Table 4.1.2. The available drawdown figures given in this table for both the Camp and Ntloedibe boreholes could only be estimated on the basis of subsurface geophysical logging carried out during the investigation using a simplified, short-normal sonde.

The Camp borehole derives its supply from fractures in the Upper Waterberg shales and sandstones. It was not possible with the logging device to identify separate fractures within the sequence. At a depth of 52 m there is apparently, however, a change in lithology (Fig 4.1.1). During the final stage of the test the pump stopped either as a result of the ingress of dirt or from rapid drawdown to the pump level due to dewatering of the main supply. We recommend therefore that the yield should not exceed 200 m^3/d with an available drawdown of 23 m, as indicated on the yield drawdown curve shown as Fig 4.1.2. Actual production may show whether dewatering actually occurs, at this level.

The Ntloedibe borehole is thought to draw its supply from the Lower Waterberg strata, which are overlain by Upper Waterberg shales and mudstones. This borehole was drilled just to the west of the major fracture zone tapped by borehole 1 and, like the Camp borehole, on the upslope side of a dolerite intrusion. This dolerite may act as a barrier to groundwater moving in the direction of the well field. During the pumping test it was shown that a rate of 180 m^3/d could be sustained for 24 hours. If, as the geophysical subsurface log suggests (Fig 4.1.3), the junction of the Upper and Lower Waterberg occurs at between 50 and 55 m below the surface the available drawdown would be 36 m (if a 3 m 'safety water level' is included). However, as a possible water bearing horizon was also indicated between 41 and 44 m, a yield of 200 m^3/d is recommended in order to maintain the pumping water level above this upper horizon, as shown in Fig 4.1.4.

Two of the boreholes selected for pump testing, 2126 and 2127, along the Thamaga road between the bridge and the lower dam, tap Basement Complex rocks. Although restricted by the pump characteristics of the submersible pumps available, both boreholes have very low specific capacities (Table 4.1.1 and Fig 4.1.5). They appear to be pumped at present at the maximum rates available but are compensated by short pumping regimes. We recommend that both boreholes should not be incorporated into the system and that the present equipment at the site could be more profitably used elsewhere. Data obtained during the test are not consistent with the Geological Survey records of these sites and consequently there is some doubt as to whether these boreholes have been correctly identified.

The efficiencies of the existing boreholes were generally about 50% and well losses were considerably higher than might be expected for uncased boreholes tapping fractured formations. The latter possibly results from turbulent flow between the main supply and the pump intake, particularly as the pumps used for carrying out the tests did not allow a sufficient annulus between the pump and the side of each borehole.

4.2 New Boreholes

Pumping test reports and data summaries are given in Appendix A and recommended yields and associated pumping details shown in Table 4.1.2.

Borehole 4 was abandoned due to an inadequate yield. Although a test was started with a submersible pump, proper cleaning of the borehole was neglected by the driller and consequently the test was abandoned to avoid damage to the pump.

A five hour, steady-rate test with a Mono constant-displacement pump. installed by the road contractor for the Molepolole roads scheme, was employed to indicate the yield of borehole 3. After 15 minutes of pumping a recharge boundary became apparent. This probably reflects the intersection of the cone of influence with a zone of higher transmissivity. The main supply is derived from a fracture at about 75 m below ground-level which resulted in flowing artesian conditions. The available drawdown has been taken as 60 m to allow a slight reduction in specific capacity with a longer pumping time, giving a calculated sustained yield of 690 m^3/d.

The yield drawdown curve for borehole 2, as shown in Figure 4.2.1, suggests that dewatering commenced almost immediately during the first stage, even though the main supply is reported to come from 16 to 21 m below the surface.

This level would be reached after 24 hours of pumping at a rate of 290 m^3/d, the maximum rate of which the pump employed is capable. Further dewatering would probably cause an increased rate of drawdown. The available drawdown has therefore been taken as 10 m allowing a sustained yield of 250 m^3/d. There is, however, some doubt as to the accuracy of the drilling details.

At the time of writing no test details were available from site 1, but, if a fracture connected to the major fault at this site is encountered, it is hoped that a high yield will be obtained.

The efficiencies of the new boreholes are higher than for the existing boreholes but are still rather low. In fractured formations, particularly with the type of drill employed, material is forced into fractures and the permeability is thereby reduced. Further development work could therefore be profitably carried out (as swabbing rather than surging), which by removing these fines could result in an increase in yield of up to 20%. In addition carefully placed charges of explosive could effectively open up fractures and give higher yields. These operations could be most profitably employed on borehole 1, if a low yield is obtained, and on borehole 4 before this is finally abandoned but must be carefully supervised.

CHAPTER 5

AQUIFER DEVELOPMENT

Excluding boreholes 2126 and 2127, the existing proposed supply boreholes draw their main supplies from fractures within the Upper Waterberg shales and mudstones and the new boreholes from the Lower Waterberg sandstones. The dolerite sill, between the existing and new boreholes, may play an important part in controlling groundwater movement although the formations are probably in hydraulic connection.

In both aquifers groundwater occurs under artesian conditions, the rest water level being higher than the depth at which water was encountered, and at borehole 3 actually overflowing at the surface.

Similar values of transmissivity, of about 20 m^2/d, were calculated from the time-drawdown graphs for the Camp and Ntloedibe boreholes. At the Camp borehole a storage coefficient of 4×10^{-6} was calculated. Transmissivities for the Lower Waterberg appear to be more variable but, particularly where fracturing is well developed, are higher than for the Upper Waterberg: a value of 70 m^2/d being recorded at borehole 2.

The lower transmissivity value calculated at borehole 3 may be compensated by a high storage co-efficient. Abstraction at borehole 3 does not appear to affect the rest water level on boreholes 2 or 4. This suggests discontinuity between the boreholes and reflects the markedly anisotropic nature of the aquifer in this area. Over a period of time, however, a multiple cone of influence may develop which could adversely affect the yields and result in a reduction in the base flow of the Molepolole River.

There are little data available to ascertain whether the aquifer as a whole can support the yields recommended, particularly in view of the sporadic recharge. The average annual rainfall at Molepolole is 500 mm with a 50% variation (Fig 5.1). Of this an annual average recharge of 36 mm has been estimated by comparing the monthly rainfall at Molepolole with the average monthly potential evaporation from a wet bare soil at Gaberone over the period 1960-74 (Tables 5.1 and 5.2). This does not take into account other factors influencing recharge, such as run-off, and the actual evaporation will be less than the potential evaporation. The groundwater catchment of the new well field is assumed to coincide with the surface water catchment which is about 96 km^2. The average recharge value over this area thus represents 1×10^4 m^3/d, which could be available for abstraction provided groundwater is easily transmitted through the catchment. This value exceeds the estimated 1985 demand of 1.9×10^3 m^3/d and suggests that further development of the aquifer could be made without mining of groundwater.

CHAPTER 6

WATER QUALITY

6.1 Chemical

Table 6.1 gives the results of water analyses carried out on samples obtained from the proposed supply boreholes. Other available analyses for the Molepolole area are given in Appendix B. Mixed bicarbonate to călcium-magnesium bicarbonate waters predominate (Fig 6.1) and total dissolved solids are less than 1000 mg/l. Of the specific ions analyzed, none exceed the World Health Organisation recommended limits except for iron. These waters are thus considered to be of suitable quality for drinking purposes.

Iron concentrations range from 0.6 mg/l to 2.5 mg/l which exceed the recommended World Health Organization limit of 0.3 mg/l. These concentrations, however, do not constitute a health risk but may cause undesirable discolouration of clothes or fittings. The iron is more likely to be derived from the Upper Waterberg shales, due to their lower permeability, than from the Lower Waterberg sandstones, even though disseminated iron oxide occurs in the cementing material of the latter.

In the Molepolole area both total dissolved solids and chloride concentrations increase towards the Boribamo area due to a shallow hydraulic gradient and as a result of the lower permeability of the Upper Waterberg sequence.

An unusual analysis was recorded from a water sample taken from the borehole supplying the Secondary School, which derives its supply from the Lower Waterberg sandstones. This water has a total dissolved solids of only 36 mg/l with a pH of 4.9 and a magnesium bicarbonate composition. It is reported to corrode metal fittings and cause undesirable iron discolouration.

Borehole 3 has water of a similar pH and total dissolved solids to the Secondary School borehole. It would appear that the partial pressure of carbon dioxide in the deeper supplies is high (as indicated by gas bubbles rising during normal artesian flow at this borehole). Under pumping conditions the sharp reduction in pressure affects the stability of the carbon dioxide-bicarbonate equilibrium; calcium bicarbonate being lost from solution as carbon dioxide is released, thereby lowering the pH. The low pH represents an excess of hydrogen ions in relation to other ions and such waters are usually aggressive.

Although this effect is probably of localized occurrence, the water may require treatment to increase the pH if corrosion becomes apparent and yields are to be maintained but may be less apparent after mixing with groundwater from the other abstraction boreholes.

6.2 Bacteriological

Widespread contamination of groundwater was suggested by the samples collected for analysis in April. High coliform counts were measured in samples taken from the Molepolole tributaries but these probably reflect contamination from surface sources. The nil coliform counts recorded from all the re-sampled sources and also the new boreholes (Table 6.2), suggest that the original sampling did not reflect groundwater conditions but contamination of pipes or storage tanks.

Fractured rock formations do not effectively filter out harmful bacteria and, although the main recharge area lies in the uninhabited hills to the south of the new well field, there exists a potential source of contamination via the fractured rock outcrops in the immediate vicinity of each borehole. The recommended borehole construction designs (see Fig 3.2) take this possibility into account. It is intended, however, to install a chlorination plant in the distribution network.

PART 3

MOCHUDI GROUNDWATER INVESTIGATION

CHAPTER 7

EXPLORATION

7.1 Geophysical Survey at Mochudi

Drilling details of many of the 50 boreholes reported to have been drilled in the Mochudi area were either ambiguous or inadequate. However an examination of the available borehole records suggested that higher yields could be obtained from areas of deeper weathering in the Central Eastern Mochudi area. These more deeply weathered areas could occur as either 'basins' of decomposition of the granitoid gneises or as preferred zones along fractures and/or dolerite dykes.

To provide a basis for the location of new boreholes electrical resistivity traverses were employed to indicate the depth of weathering and magnetic traverses to show the distribution of dolerite dykes. The survey encompassed the lower ground astride the Notwane River from the Community Centre to, and along, the Makakatela valley (Fig 7.2) and was completed in three weeks during June. The results are presented in a report by McDowell (1974).

Seven depth probes were made over selected existing boreholes in the survey area using a Schlumberger arrangement capable of penetrating to 80 m. These suggested that weathering might be shallower than indicated by driller's logs; that low yielding boreholes had a higher resistivity for the second layer; and that there is an inverse correlation between yield and the resistivity values.

Fourteen resistivity traverses involving 377 stations were then made over the selected area. These employed an electrode spacing and station interval of 30 m with a Wenner configuration using an ABEM Terrameter. An isoresistivity map was drawn from the data. This showed a zone of low resistivity along the Notwane alluvium; that the more productive boreholes were located in low resistivity zones; and that several elongated zones of low resistivity traversed the area in a NW-SE direction. Sharp resistivity contrasts along these zones suggested faulted contacts.

A proton magnetometer was used to carry out 23 traverses involving 800 readings at a station interval of 20 m. Where a steep gradient was encountered the interval was reduced to 10 m. An isogamma map was constructed from the results. Several linear magnetic highs and one wide magnetic low, trending in a NNW-SSE direction were clearly shown, indicating the presence of dolerite dykes.

The highest yielding boreholes, such as 850 and 38, were shown to be located on structural features, particularly where these coincided with low resistivity zones. On this basis four similar undeveloped areas were selected for detailed traverse work using a Chlumberger arrangement with electrodes spaced at 45 m and a station interval of 5 m. Two other sites were marked but not investigated in the same detail. Details of the surveys at these sites are shown in Table 7.1.

7.2 Drilling

Drilling did not commence at the four selected sites until the 11th September. The official numbers given to the sites were: A(2786), B(2784), C(2787) and E(2785). All were drilled at 150 mm diameter by an air-percussion, rotary rig. Drilling details are shown on the yield-drawdown curves (Figures 8.1 to 8.7).

Site A is located in the lower part of the Makakatela valley some 75 m north of its confluence with the Notwane River. This valley has a comparatively large catchment area and the initial reconnaissance indicated that this particular area could be of significance in groundwater development. Contrary to expectations a water bearing horizon in the Notwane alluvium was not encountered. Instead water was initially met at 19.8 m in granite which gave approximately 20 m^3/d. A second supply was met at 33.5 m but the main supply is derived from a fracture zone, still in granite, at a depth of 39.7 m. Drilling was stopped at 42 m.

Water was struck at 12.2 m at site B in the alluvial deposits of the River Notwane, the present channel of which is about 40 m east of the site. About 14 m^3/d was obtained from this water bearing horizon. A second supply of about 100 m^3/d was obtained from the weathered junction of the dolerite and overlying alluvium at 18.3 m. A lower supply contributing about 110 m^3/d was encountered at 27.5 m in fractured dolerite. A further fracture was reported at 30.5 m but gave no additional supply. The total depth of the borehole is 38.5 m.

Sites E and C were abandoned due to inadequate yields. Site E was drilled to 38 m encountering dolerite at 13.7 m but only a small supply was obtained from the weathered top of the dolerite. This site was drilled some 30 m west of the River Notwane into a low resistivity area overlying a wide dolerite dyke that passes through the high yielding borehole 850.

At site C water was encountered in weathered dolerite at 19 m but which supplied only about 20 m^3/d. Further seepages were met in fractures in the upper dolerite between 25.5 and 33 m. The borehole passed through granite between 56.5 and 59.5 m, possibly separating two dolerite dykes or sills, but no additional supplies were encountered at the junctions, and drilling was finally stopped at 62.5 m.

Sites A and B were reamed to a diameter of 250 mm by cable-percussion rig to depths of 33.5 m and 27.5 m respectively, but the results of the pumping tests to ascertain any increases in yields resulting from the reaming are not yet available.

CHAPTER 8

PUMPING TEST RESULTS

Pumping tests were carried out on five existing boreholes during June and July. Pumping test reports are given in Appendix A and a summary of the pumping tests in Table 8.1. Yield-drawdown curves are shown as Figures 8.1 to 8.7 and recommended abstraction rates and relevant pumping details are set out in Table 8.2.

Weathered and/or fractured dolerite forms the principal aquifer of boreholes B,1162, 850 and 2035, whilst fractures in the granitic gneisses supply groundwater to sites A,38 and 1668.

8.1 Boreholes in Dolerite Aquifers

Borehole 1162 and site B have similar drilling details and both may derive their supplies from the same, or interconnected, dolerite dykes. The lower water bearing horizon of fractured dolerite appears to contribute almost the whole supply in both boreholes, although there may have been some unavoidable re-circulation during the test carried out at site B. Extrapolation of the yield drawdown curve for borehole 1162 beyond the maximum pumping rate of 190 m^3/d is uncertain but as the lower supply appears to be the most important a sustained yield of 260 m^3/d is thought to be available. Similarly a yield of 360 m^3/d should be available from site B. The two sites are only 250 m apart but site B was not apparently affected by abstraction at borehole 1162, although interference could occur at the higher rates recommended, nor was the latter greatly affected by normal pumping at borehole Z720 some 60 m to the south.

Almost the whole supply of borehole 850 is derived from fractured dolerite at 18.3 m, which was intersected during the high yield test at 366 m^3/d carried out in order to ascertain the relative productivity of the water bearing horizons. To maintain the pumping water level at 3 m above this horizon a yield of 250 m^3/d is recommended.

Borehole 2035, one of a group of three boreholes drilled to the east of Mochudi, was tested in order to determine if a supply could be obtained at lower cost than bringing a piped water supply from Central Mochudi. The top of the upper water bearing horizon was encountered during the first stage and consequently the yield drawdown curve (Fig 8.4) represents the lower horizon. This horizon was met during the final stage of the first test with a pumping rate of 143 m^3/d at which point rapid drawdown occurred due to dewatering. The specific capacity is low and well losses are very high for this borehole and consequently a yield of 94 m^3/d is recommended. Borehole 2052 of the same group was not pump tested as planned as this was found to be severely out of alignment.

8.2 Boreholes in Gneissic Aquifers

The upper water bearing horizon at 23 m in borehole 38 in the middle part of the Makakatela valley, was reached during the third stage of the pumping test whilst pumping at 233 m^3/d. Rapid drawdown occurred at this level suggesting that almost the whole supply is derived from this horizon. As at borehole 850 it is essential that the pumping water level is maintained above this horizon to avoid damage to the pump. This recommended sustained yield of 208 m^3/d incorporates a 3 m water-level 'safety margin'.

Unfortunately, the maximum pumping test rate on site A was restricted to about 345 m^3/d by the equipment available and projection of the yield-drawdown curve (Fig 8.5) beyond this rate is uncertain. In addition, although the main supply is derived from the lower horizon, the productivity of the two horizons could not be ascertained. Nevertheless, a sustained yield of 505 m^3/d is recommended to maintain the pumping water level above the middle water bearing horizon at 33.5 m.

A disused borehole, 1668, on the eastern bank of the Notwane River opposite site A, was tested primarily to ascertain the order of yields available from underflow along the Notwane River, if in connection with the aquifer. A recharge boundary became apparent during the first stage of the test although specific capacities are low. To maintain the pumping water level above the upper water bearing horizon a yield of 63 m^3/d is recommended.

CHAPTER 9

AQUIFER DEVELOPMENT

In the past groundwater exploitation in the Mochudi area has been sporadic and uncoordinated. Although seepages arise at the junction of the Waterberg and Basement Complex rocks the original water supplies were probably obtained from hand-dug wells in the alluvium adjacent to the Notwane River, eg near borehole B. In contrast to Molepolole, Mochudi township lies along the base of the Waterberg escarpment and consequently the Waterberg sandstone extending northwards have remained relatively unexplored. For economic reasons they will probably continue to remain so. Exploration and exploitation has therefore been mainly restricted to the Basement Complex rocks.

The aquifers tapped by the proposed supply boreholes are widely spaced and for the most part discrete. Not surprisingly transmissivity values were variable but where fracturing was well developed they are as high as 115 m^2d for the dolerites. The gneissic aquifers have lower transmissivities ranging from less than 1 m^2d to about 50 m^2d and supplies are usually encountered at greater depth. A value for storage coefficient could only be ascertained at borehole 1162, for which an average value to 1×10^{-4} was calculated.

The mean annual rainfall at Mochudi is 500 mm with a 30% variation (Fig 9.1). An average annual recharge value of 32 mm was calculated by comparing monthly rainfall at Mochudi with potential evaporation at Gaberone (Table 9.1) without any allowance for other factors influencing infiltration. The groundwater catchment of the proposed supply boreholes is less easily ascertained than at Molepolole due in part to the influence of the Notwane River as a recharge source and the utilization of several aquifers that may not be interconnected. It is not known therefore whether the recommended abstraction rates will exceed the long term mean annual recharge.

CHAPTER 10

WATER QUALITY

10.1 Chemical

Analyses of groundwater from the proposed supply boreholes are given in Table 10.1. No analysis is available for borehole 38. Other available chemical data are set out in Appendix B. All the samples showed a mixed bicarbonate to a calcium-magnesium bicarbonate composition as shown by the trilinear diagram (Figure 10.1). The proposed supply sources have groundwater of suitable chemical quality for drinking purposes.

Concentrations of specific ions are generally within the limits suggested by the World Health Organization. Chloride values are higher at borehole 1162 and some of the high nitrate values may suggest contamination, however, the concentrations of the latter are suspect as they varied widely during the test and were apparently greater at borehole 850 from the groundwater than from the open tank. Iron concentrations are low and fluoride values, even through high to the east and west of the township, are also well within potable limits in the proposed supply sources.

Total dissolved solids in the supply boreholes range from about 300 mg/l to nearly 1300 mg/l. The higher total dissolved solids are found in the western Mochudi area and probably result from a longer travel time from the recharge area to the north through deposits of lower permeability. This is supported by the lower ratio of calcium and magnesium to sodium in these waters.

10.2 Bacteriological

Coliform counts of samples collected throughout the Mochudi area are given in Table 10.2. Previously collected samples suggested groundwater contamination. However, later re-sampling, where possible, recorded nil counts for the groundwater but indicated contamination in the open reservoirs or stand pipes, eg boreholes 216 and 35.

High counts were recorded in samples of the Notwane River and although the boreholes near to the river could therefore be contaminated, the alluvial deposits will probably filter out harmful bacteria.

Should future contamination arise the proposed installation of a simple chlorination plant will effectively reduce any health hazard.

PART 4

RECOMMENDATIONS

AND

SUMMARY

CHAPTER 11

FUTURE MANAGEMENT

The proposed supply boreholes can meet the estimated 1985 maximum demands at both Molepolole and Mochudi, which are as follows:

	1975	1980	1985
Molepolole (m^3/d)	800	1300	1900
Mochudi (m^3/d)	500	900	1400-1500 (excluding demand at Pilane)

However, continuous pumping will be required during the winter period between 1980 and 1985. To provide for standby pumping capacity and to reduce pumping times, and thereby spread the demand on the various aquifers, we recommend that at least one other high yielding borehole be constructed at each village by 1980. We suggest the following sites should be explored:

Molepolole

1. Two reserve sites at the junction of the Upper and Lower Waterberg to the south of the main tank.

2. On the major fracture zone through site 1 near the junctions of the dolerite and Waterberg formations south of the Molepolole dam (see Fig 3.1).

3. At the junction of the Upper and Lower Waterberg in the fracture zone to the west of borehole 4 (Fig 3.1).

Mochudi

In the vicinity of site F to the west of the Secondary School (Fig 7.2).

2. Further exploration at sites C or E (Fig 7.2).

Detailed geophysical and geological surveys should be carried out in the immediate area of these locations, as the abandoned boreholes drilled during the investigation show the marked anisotropic nature of the aquifers and that several exploratory boreholes may be required at each site before a water bearing fracture zone of high permeability is encountered.

In semi-arid environments groundwater recharge is commonly sporadic and constitutes only a small proportion of the total annual rainfall, which is variable in both distribution and intensity. Table 11.1 illustrates how the higher than average rainfall of the wet season 1973/74 has resulted in considerably higher water levels than, for example, 1964 which had a low rainfall associated with a drought period from 1961-66. As an approximation, it appears that there is a change in water level of about 1 m in the Mochudi area for a change in the total annual rainfall of about 50 mm. This correlation will reflect the influence of present abstractions and may be modified by the new supply scheme.

It is therefore important to monitor fluctuations in the rest water level in order that each years recharge can be assessed. These levels should be taken as accurately as possible by a simple measuring device. We suggest that borehole number 4 at Molepolole and borehole 1096(?) at Mochudi (just to the east of the track joining site A and borehole 38 and midway between them) could be used for measuring water levels on a monthly or fortnightly basis provided they are unaffected by future continuous abstraction at the nearby boreholes. Routine levels collected during the investigation are shown in Fig 11.2.

The available drawdown data are given for the period June to October 1974. It would appear that the water level conditions on which this data is based may not be representative of average conditions. Even though a 3 m water level 'safety limit' has been incorporated in the recommended sustained yields, a period of below average rainfall may provide insufficient recharge to maintain the recommended yields. Under such conditions it may become necessary to adjust the rate or duration of pumping, depending upon the type of pump employed, in relation to the specific capacity for each metre decline in the steady-state pumping water level.

If a variable displacement pump is used on each borehole the yield may be adjusted in multiples of the specific capacity. For constant displacement pumps the duration of pumping is altered. A hypothetical example is illustrated below:

Pumping rate 200 l/min for 10 hours/d (600 mins) with 10 m drawdown specific capacity, $\frac{Q}{s} = \frac{200}{10} = 20$ l/min/m

Due to overabstraction, associated with low recharge, the steady-state pumping water level has declined by 1 m and is approaching the critical drawdown level, ie only 9 m of drawdown now remain available:-

Variable displacement pump

Reduction in pumping rate to maintain level at the original level, whilst keeping the pumping duration constant - $= 9 \times \frac{Q}{s} =$ 180 l/min

2. Constant displacement pump

Impractical to reduce pumping rate, therefore reduce the duration of pumping to maintain original pumping water level -

$$= \frac{(10 \times \frac{Q}{s} \times 600) - (9 \times \frac{Q}{s} \times 600)}{200} = \underline{60} \text{ mins}$$

It is necessary to measure pumping water levels on all of the proposed supply boreholes just before shutdown following each days pumping. These levels could be measured by an air-line consisting of a thin, airtight tube extending to about 3 m below the normal pumping water level (or alternatively to 2 m above or below the pump intake) and connected to a pressure gauge at the well head.

In order to maintain essential supplies in periods of drought or failure of the system, standby supplies should be provided. Boreholes 35 and 1018 could provide an additional 130 and 85 m^3/d respectively. Borehole 792 could be retained as a standby for Segale School and borehole 2108 for the Secondary School on the Deederpoort road. The hospital supply could be maintained by the new supply system by diversion from other areas if necessary.

There are fewer suitable alternative supplies at Molepolole and borehole 2442 is already incorporated in the proposed system and therefore greater attention should be given to the construction of a new borehole at one of the above suggested sites.

In order to maintain yields and reduce well losses, periodic maintenance will be required by simple swabbing or surging. Consideration should also be given to carrying this out before putting the boreholes into production.

The use of hand-operated pumps in some locations could provide an economic alternative to motorized standby supplies or to the installation of long, expensive pipelines and standpipes to outlying areas. These pumps are not in general use in Botswana, but are favoured in other African countries as a low-cost, easily maintained means of groundwater abstraction from lower yielding boreholes for small communities. Available designs (see Appendix C) can cope with groundwater conditions at Molepolole and Mochudi. Government boreholes where handpumps could be suitably installed could include:

Molepolole: 2127 or 2126, and 1339
Mochudi: 2035, 216, 31, 1668, 789 and 2187

SUMMARY

Pumping Tests

Although technical difficulties, and in some cases a lack of reliable drilling details, restricted the accuracy of the data obtained from the variable-rate tests, sustained yields have been calculated and the indicated areas of groundwater exploitation proved.

A more unified water supply system is now available to meet future demands. However, at least one further high-yielding borehole at each village together with responsible management, particularly at Mochudi, will be required to maintain water supplies during periods of insufficient recharge.

High well losses and comparatively low efficiencies were indicated by the results. Regular re-habilitation should be considered in order to maintain, or even improve, the yields suggested.

2. Water Quality

The future production boreholes tap groundwater of suitable drinking quality. However, there are indications that the deeper aquifers in the Molepolole well field may yield aggressive water which could necessitate treatment to raid the pH, if the aggressiveness is not naturally reduced by mixing with water from shallower aquifers.

An initial water sampling programme of bacteriological quality suggested widespread groundwater contamination which has not been proved by later sampling. Nevertheless, for a public water supply it is essential that a treatment plant is installed and maintained.

REFERENCES

Pike, J. G., 1971. Rainfall and Evaporation in Botswana - UNDP FAO Tech Doc 1

McDowell, P. W., 1974. Feasibility Study for Water Supplies to Molepolole and Mochudi villages: Geophysical Survey of Mochudi.

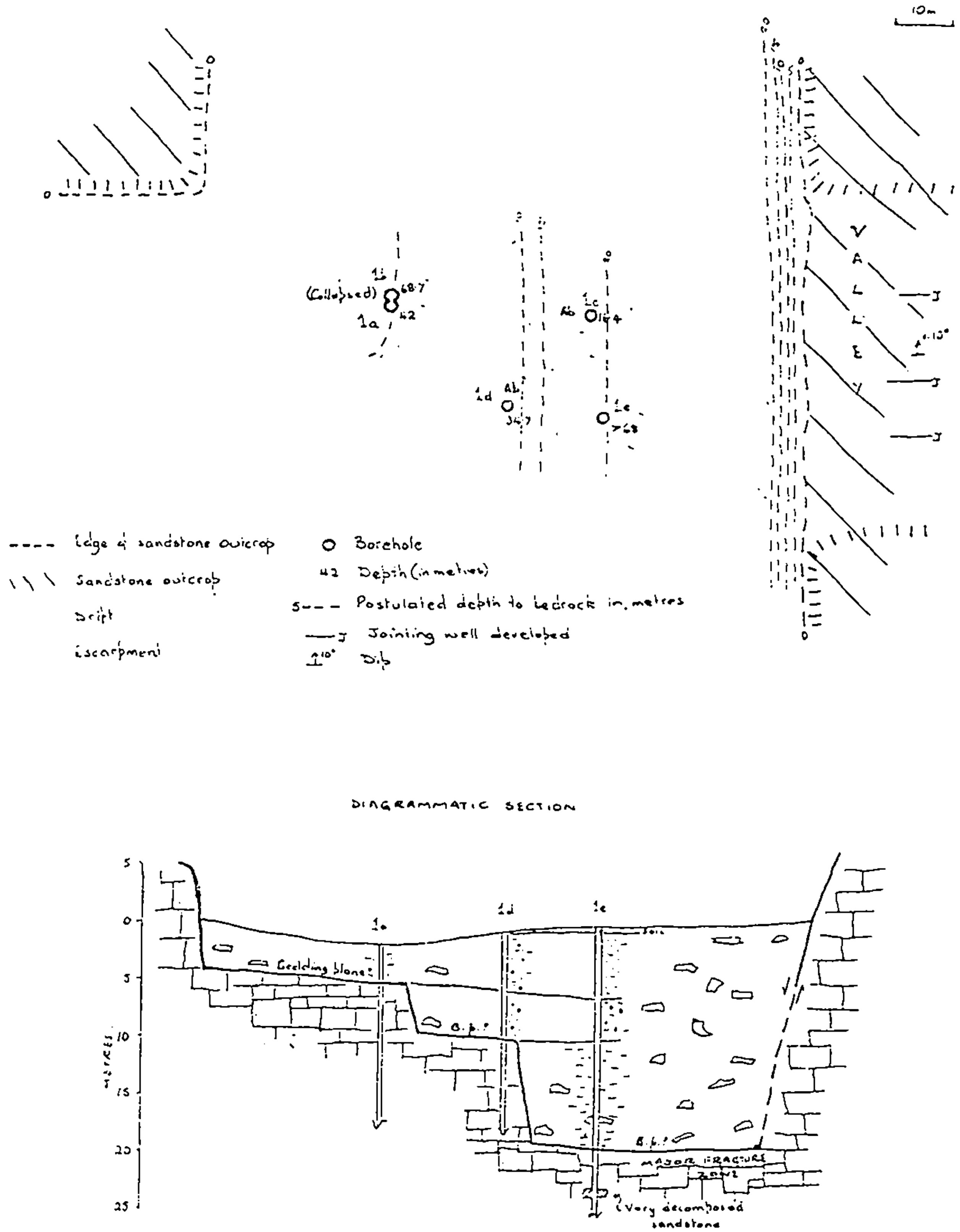
B. G. A. Lund and Partners (Cons. Eng.) 1967. Report on proposed Molepolole Water Supply Scheme.

FIGURES AND TABLES

FIG 3.1

'OLEPOLE WELL FIELD MAJOR FRACTURES A N WATER SOURCES

(based ... otographs)



silt

Sandy or gravelly silt

Gravelly sand

clay

Clay

Sandstone bedrock

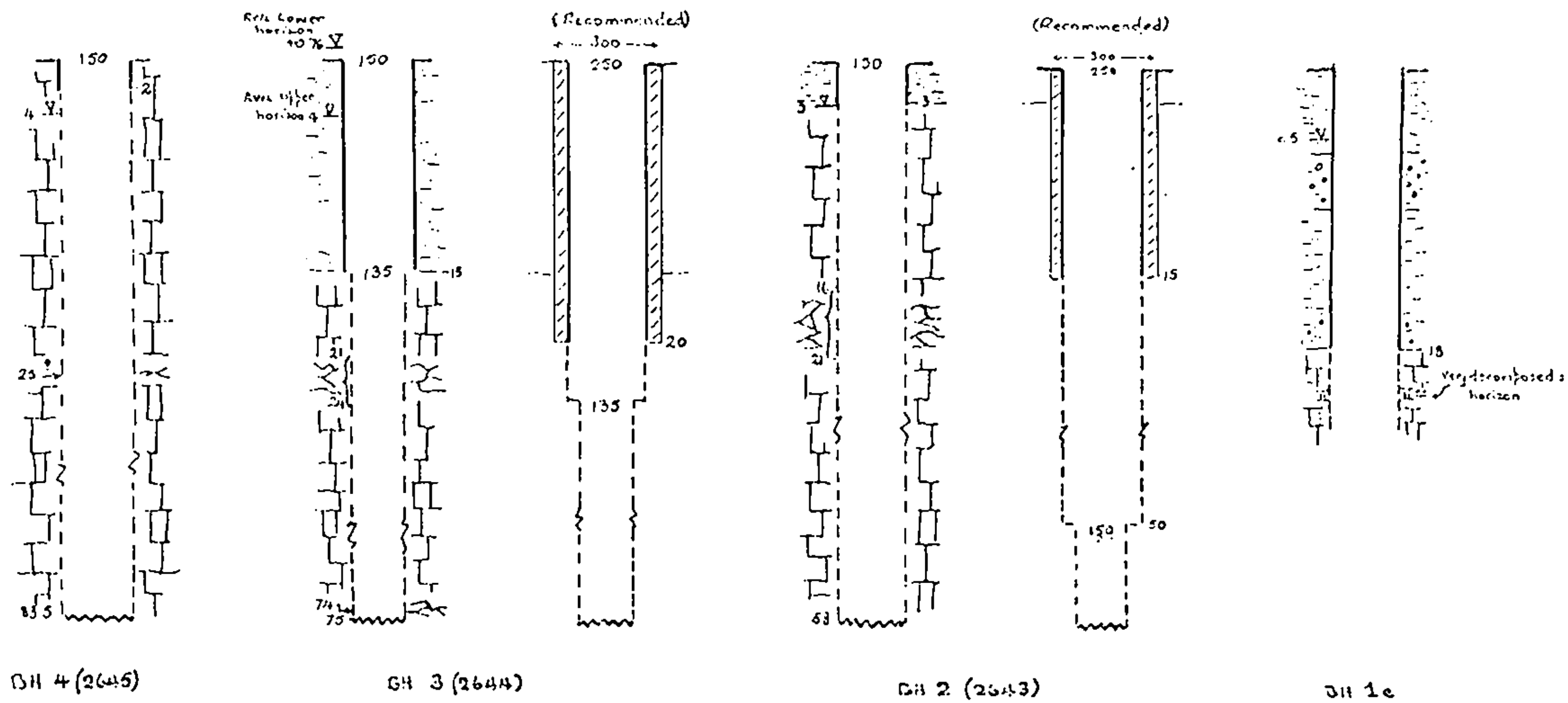
boulders

FIG. 3.2

SITE 1, MOLEPOLOLE
EXPLORATORY BOREHOLE LOCATIONS
AND DIAGRAMMATIC SECTION

FIG. 3.3

DIAGRAMMATIC SUMMARY OF BOREHOLE CONSTRUCTION DETAILS



KEY

150 Casing or hole diameter in millimetres

Temporary casing

Permanent or present casing

Open hole

Cement grout

Rest Water Level

Water struck

Silt

Gravelly clay

Clay

Bedrock sandstone

Fracture zone

Full details for site 1 not available.

1. As economic alternative to cement grout 300mm casing installed permanently and reaming continued at 250mm

2. Verbal report from driller that fractures extend to depths of more than 21m at site 2

TABLE 4.1.1

MOLEPOLOLE PUMPING TESTS: SUMMARY SHEET

BOREHOLE No.	Total Depth (m)	DEPTH W.S. (m)	RWL m(bct)	PROCEDURE (mins)	PUMPING RATES (l/min)	APPARENT DRAWDOWN (m)	SPECIFIC CAPACITIES (l/min/m)	WELL LOSSES AND EFFICIENCY	AQUIFER PARAMETERS
CAMP (1 ow)	72	NR	14.96	VR 1.) 150 2.)each 3. 996	45.8 90.6 142	5.75 13.09 23.94	7.97 6.92 5.93	C5400 sec^2/ft^5 70-52%	T ? 19 m^2d S 4×10^{-6} U Wbg r = 33 m
NTLOEDIBE	88.5	NR	6.8	VR a) 1.)150 2.)each b) 3.)150 4.)each 5. 1440	44.1 67.6 90.5 124.4 137.3	8.57 13.02 18.27 29.62 35.27	5.15 5.19 4.95 4.2 3.9	C10,000 - 13,000 sec^2/ft^5	T ? 19 m^2d
2127 (1 ow)		59.9 95.7)main 98.15)supply	17.76 (?)	VR a) 1.)150 2.)each b) 3. 117	(Av) 41.5 22.2 21.1	36	<1.0		T 0.75 m^2d S (not calculated) Dol r = 245
2126		10.0 12.5	17.82	SR 1.95	(Av) 41	90	<<0.45	(high)	T 0.25 m^2d Drift & weathered granite[2]

TABLE 4.1.2

MOLEPOLOLE BOREHOLES: RECOMMENDED YIELDS AND ASSOCIATED PUMPING DATA

Borehole	Aquifer	Total Depth m	*RWL b.d. m	PWL b.d. m	Available Drawdown m	**Yield (m^3d)	Pump Setting b.d. m	Specific Capacity m^2d @ t = 1440 mins
Camp	U. Wbg	73	15	38	23	200	50	8.6
Ntloedibe	U. + L. Wbg	88.5	7	41	35	200	64	5.8
2127	B. Cx.	99.4	17.5	39	c.21	Less than 75	60	1.7
†2442	U. Wbg	148.4	9	NK	NK	75	NK	NK
(1)	L. Wbg							
2644 (2)	L. Wbg	57.9	3	13	10	250	25	25
2643 (3)	L. Wbg	76	+0.7	60	60	690	75	11.5
2645 (4)	L. Wbg	8.4	4.5			(Ab)		
						Total:		

* For the period Jun - Oct., 1974

** For available drawdown shown.

† Not test pumped.

b.d. Below datum point.

O

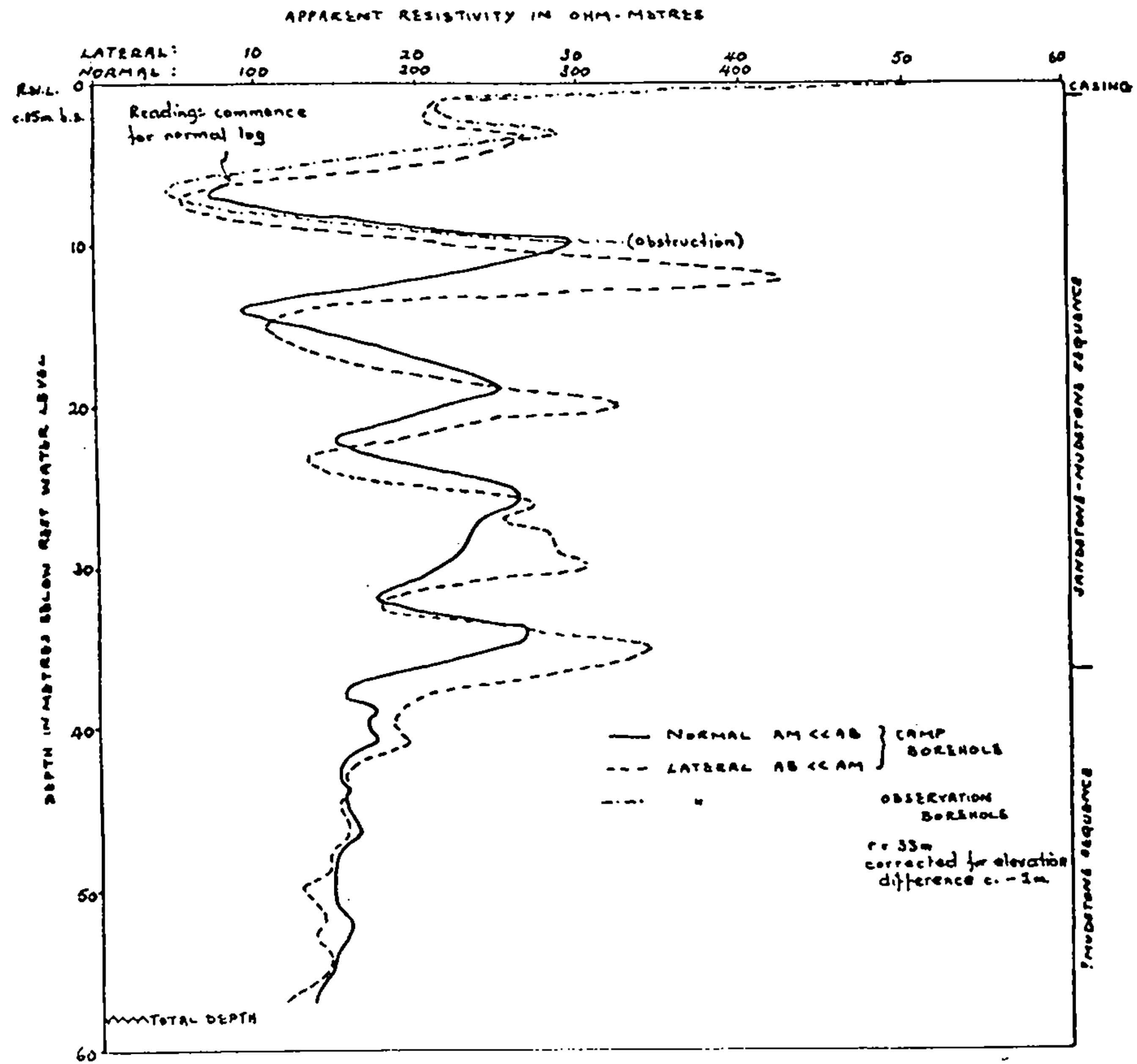
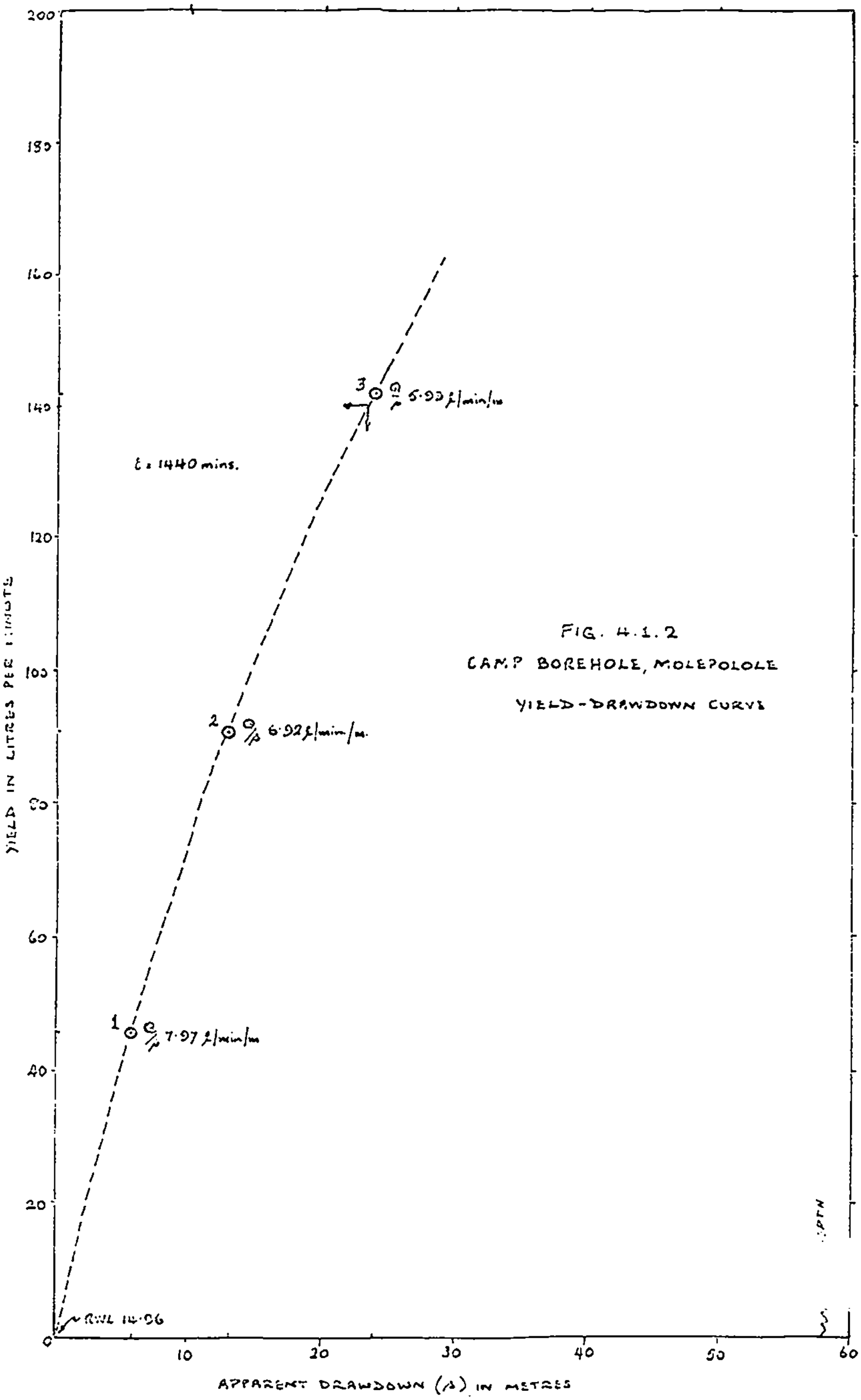


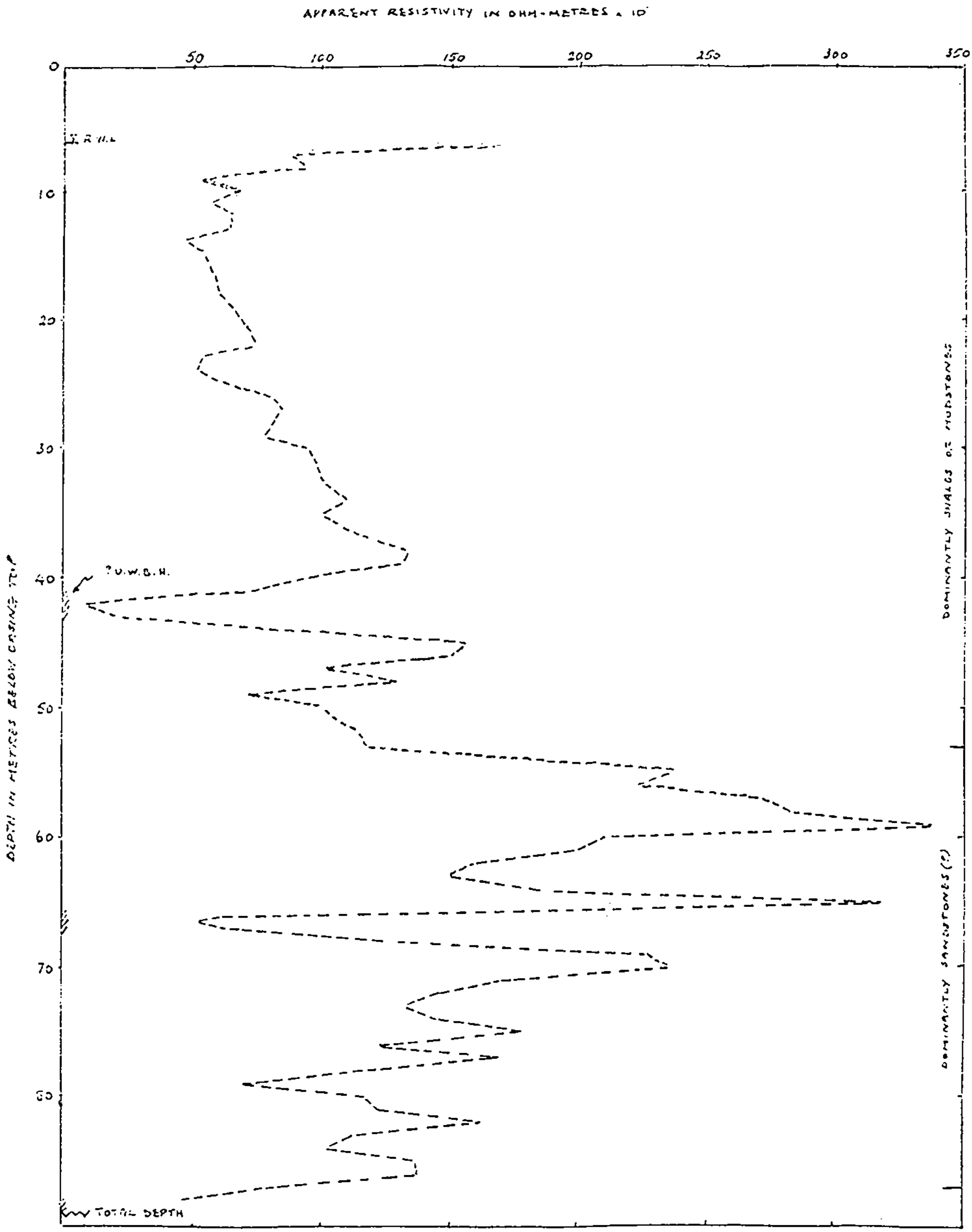
FIG. 4.1.1

SUBSURFACE RESISTIVITY LOGS
FOR CAMP BOREHOLE, MOLEPOLOLE



200
180
160
140
120
100
80
60
40
20
0
10
20
30
40
50
60
YIELD IN LITRES PER MINUTE
APPARENT DRAWDOWN (s) IN METRES
t = 1440 mins.
1 Q/s 7.97 l/min/m
2 Q/s 6.92 l/min/m
3 Q/s 5.93 l/min/m
RWL 14.96
FIG. 4.1.2
CAMP BOREHOLE, MOLEPOLOLE
YIELD-DRAWDOWN CURVE

FIG. 4.1.3



NTLOEDIBE BOREHOLE, MOLEPOLOLE: LATERAL RESISTIVITY LOG

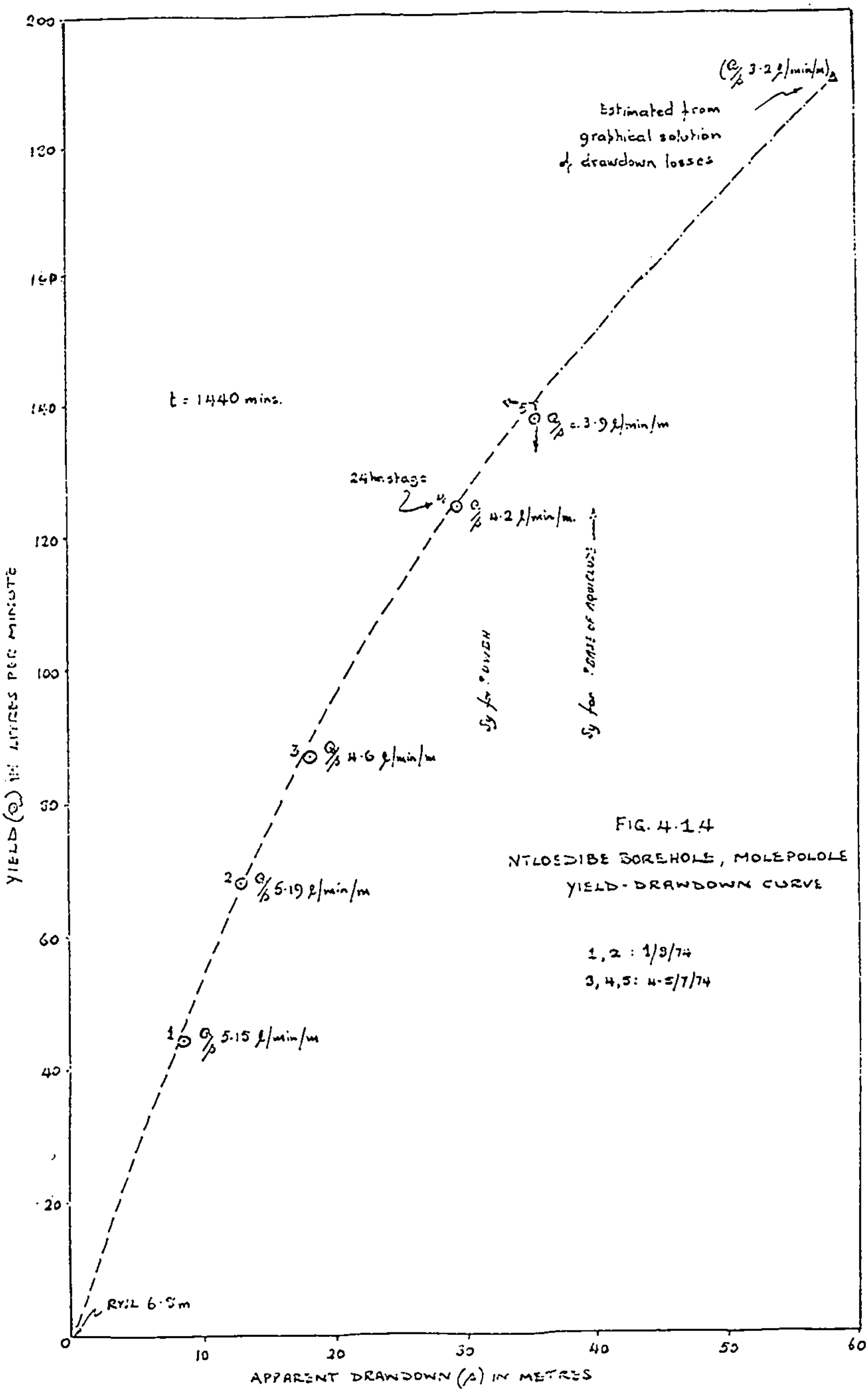


FIG. 4.14

NTLOEDIBE BOREHOLE, MOLEPOLOLE
YIELD-DRAWDOWN CURVE

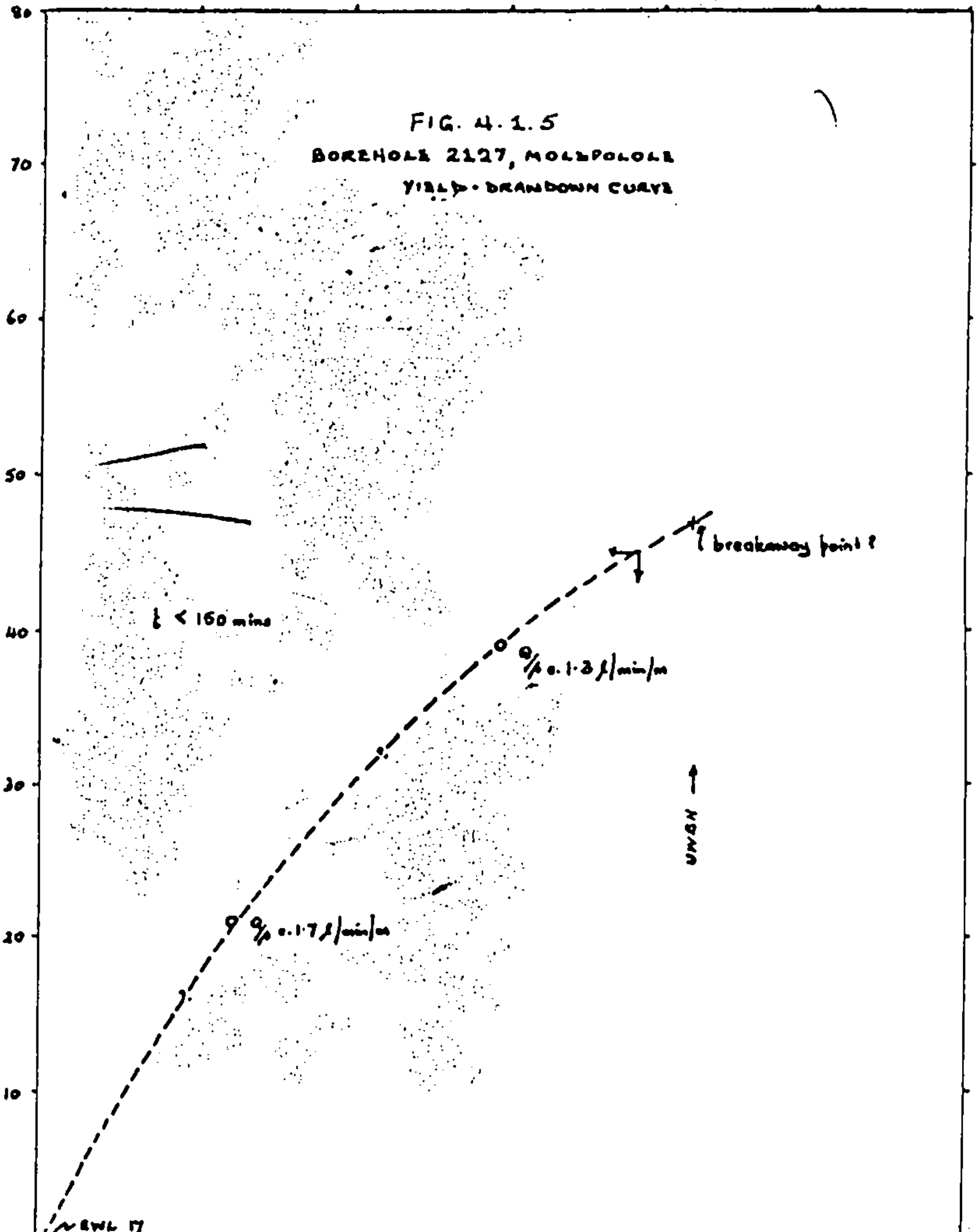


FIG. 4.1.5
BOREHOLE 2127, MOLEPOLOLE
YIELD - DRAWDOWN CURVE
? breakaway point ?
Q/s c.1·3 l/min/m
Q/s c.1·7 l/min/m
t < 160 mins
RWL 17
0
10
20
30
40
50
60
70
80
0
10
30
30
40
50
60

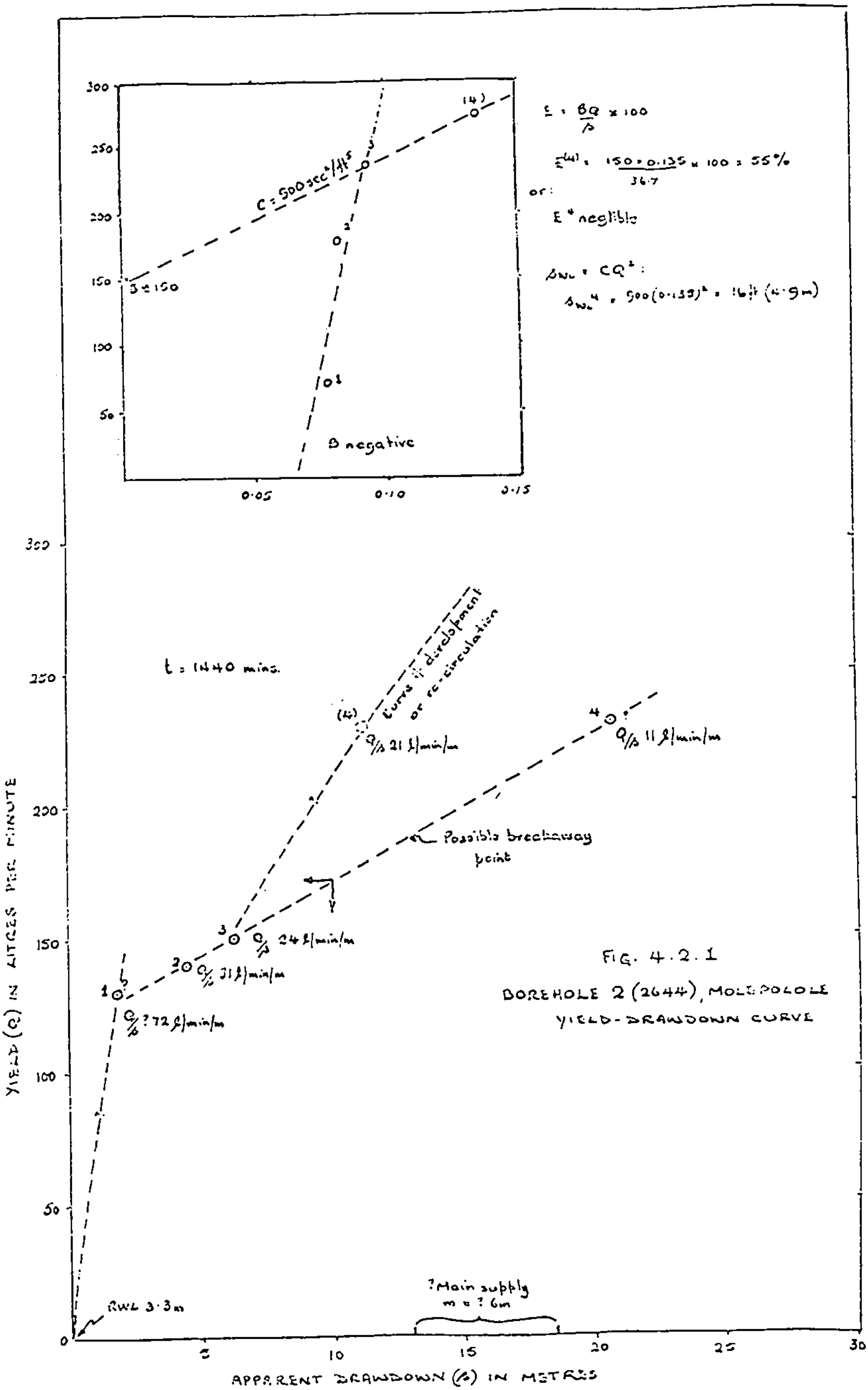
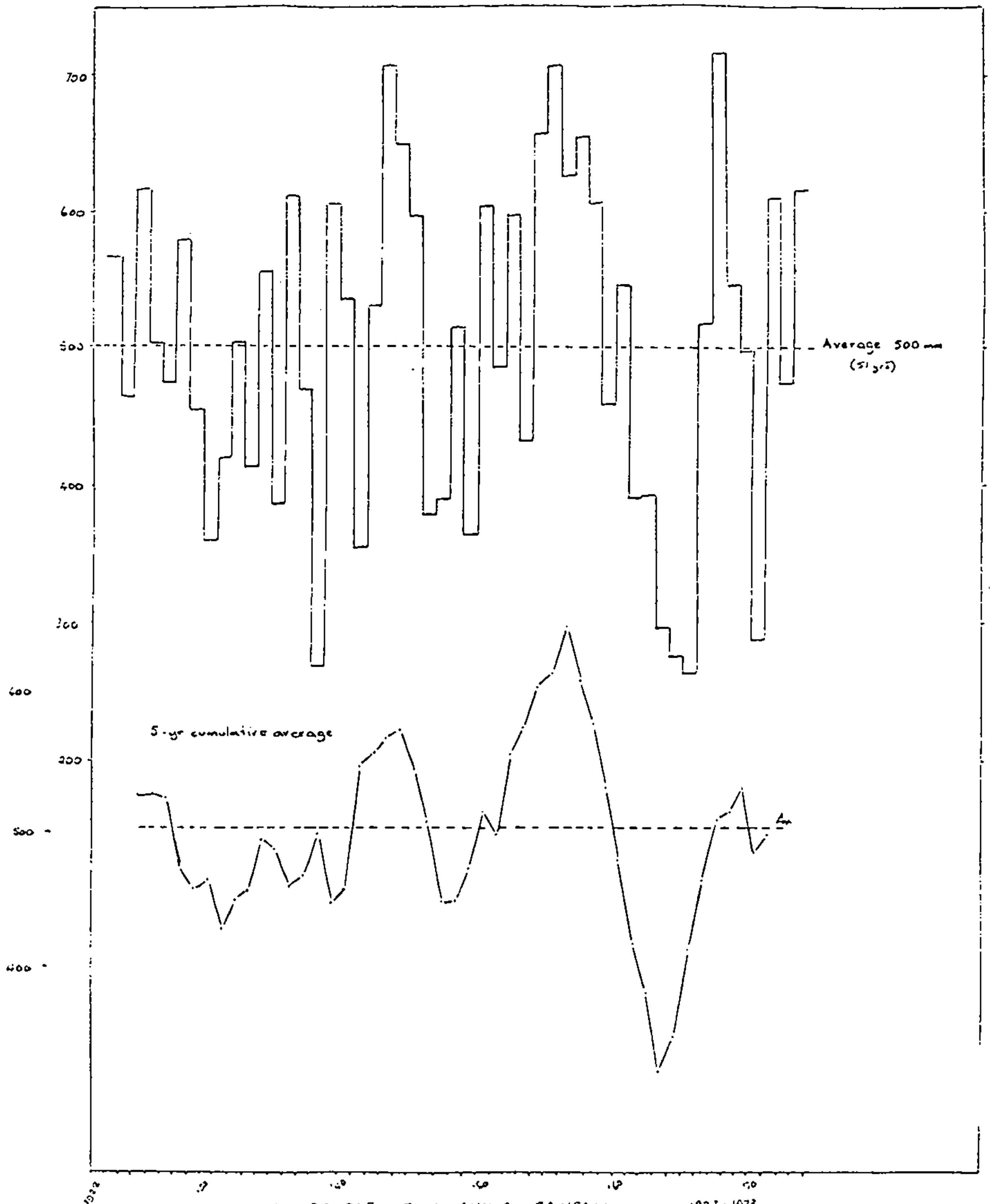


FIG. 4.2.1

BOREHOLE 2 (2644), MOLEPOLOLE
YIELD-DRAWDOWN CURVE

FIG. 5.1



MOLEPOLOLE - TOTAL ANNUAL RAINFALL in mm, 1923-1973

TABLE 5.1

AVERAGE MONTHLY POTENTIAL EVAPORATION FROM A WET BARE SOIL AT GABERONE (1957/58 to 1967/68)

MONTH	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
AVERAGE POTENTIAL EVAPORATION (mm)	142	147	153	155	128	103	76	49	33	40	64	102

TABLE 5.2

POTENTIAL RECHARGE AT MOLEPOLOLE AND MOCHUDI IN MILLIMETRES

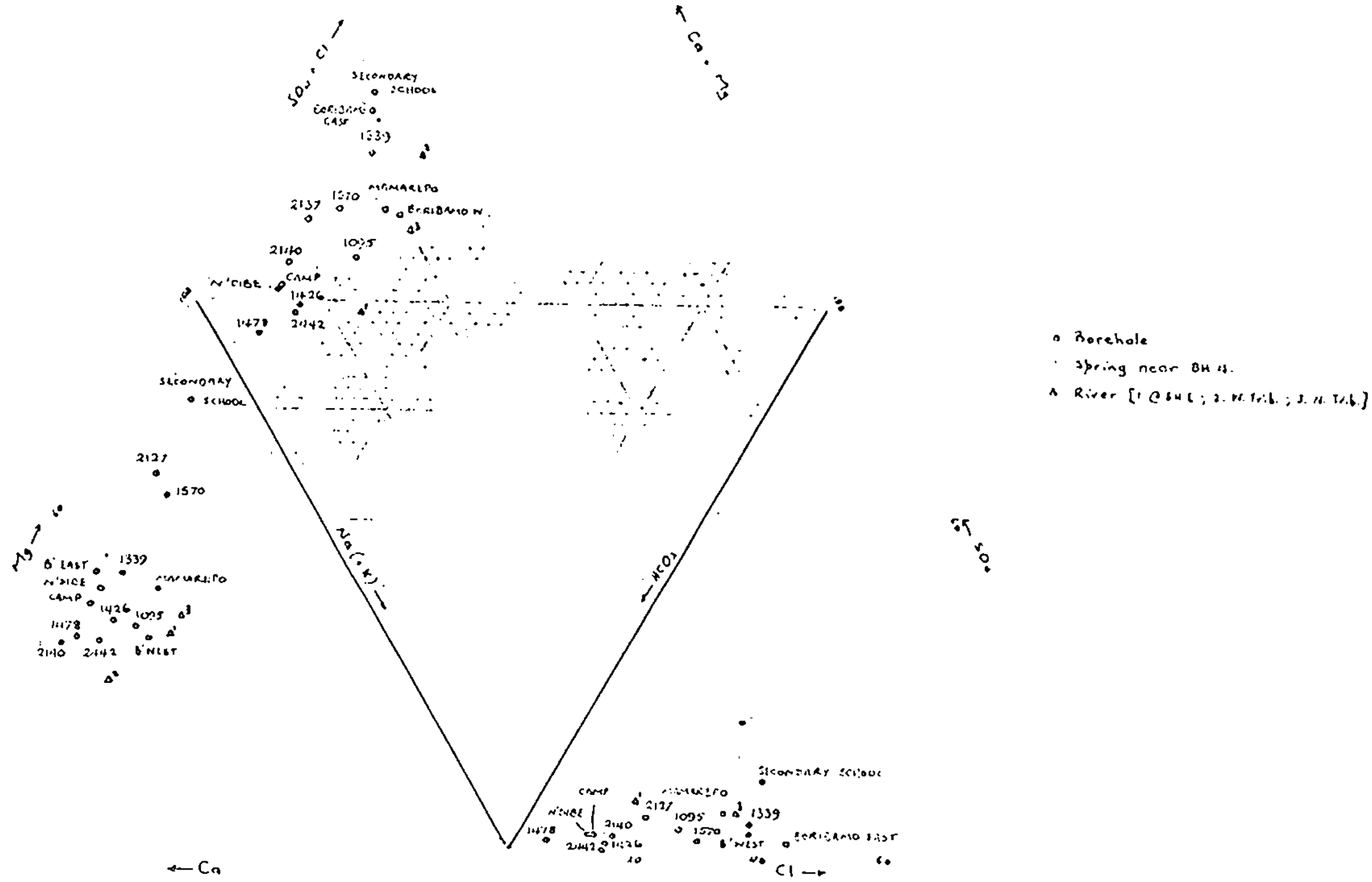
FOR THE PERIOD 1960-1974

Year	Months during which rainfall exceeded potential evaporation		Rainfall minus potential evaporation from wet bare soil	
	Mol.	Moch.	Mol.	Moch.
1960-61	Nov., Dec., Apr	Nov., Apr	31, 3, 15	49,41
1961-62	Nil	Nil		
1962-63	Nil	Nil		
1963-64	Nil	Nil		
1964-65	Apr	Nil	19	
1965-66	Feb	Nil	75	
1966-67	Feb, Apr	Jan, Feb, Mar, Apr	45, 135	49, 13, 45, 134
1967-68	Apr	Apr	81	36
1968-69	Apr	Apr	34	6
1969-70	Nil	Dec		26
1970-71	Nil	Apr		6
1971-72	Nov, Jan	Jan	22,104	5
1972-73	Nil	Nil		
1973-74	Dec, Jan	Mar	27,12	32
		Average recharge per year	36	32

FIGURE 6.1

GROUNDWATER QUALITY

MOLEPOLOLE



<u>TABLE 6.1</u>

<u>GROUNDWATER SAMPLES FROM MOLEPOLOLE SUPPLY BOREHOLES</u>

Analyses carried out by Geological Survey Department

Borehole Number	CAMP		P.T. St.2		NTLOEDIBE				P.T. St.4		2127			
Date of collection	4.74			25.7.74	1.73		4.74			2.8.74	2.68		4.74	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	75	3.74	90	4.49	55	2.74	80	3.99	41	2.05	43	2.15	21	1.05
Magnesium	45	3.70	47	3.87	29	2.39	56	4.61	83	6.83	17	1.4	40	3.29
Sodium	23	1.00	55	2.39	40	1.74	25	1.09	70	3.04	12	0.52	11	0.48
Potassium	1	0.026	3	0.08	2	0.05	2.5	0.06	2.7	0.07	3	0.08	2.2	0.06
Total Cations		8.47		10.83		6.92		9.75		11.99		4.15		4.87
Bicarbonate	444	7.28	505	8.28	330	5.41	485	7.95	575	9.72	170	2.79	202	3.31
Sulphate	13	0.27	17	0.35	35	0.73	13	0.27	34	0.71	9	0.19	13	0.27
Chloride	37	1.04	43	1.21	50	1.41	37	1.04	29	0.82	32	0.9	29	0.82
Fluoride	0.25	0.01	0.65	0.03	0.07	0.04	0.25	0.01	0.65	0.03	1.0	0.05	0.25	0.01
Total Anions		8.61		9.88		7.59		9.28		11.28		3.93		4.41
Conductivity (micromhos @ 20°C)	710		930		600		770		1050		390		250	
Total dissolved solids @ 120°C	564		660		336		540		920		224		100	
Theoretical dissolved solids	412		504		374		452		551		201		215	
pH	7.2		7.2		7.0		7.5		7.9		7.5		7.8	
Fe			0.6						0.9					

*Not pump tested during investigation

				2126				3		1		2442*	
P.T.	13.8.74	6.68		11.70		P.T.	13.8.74	P.T.	30.8.74	P.T.		4.74	
mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
30	1.50	28	1.4	26	1.28	39	1.95	8	0.40			72	3.59
22	1.81	10	0.82	29	2.39	16	1.32	2	0.16			36	2.96
13	0.57	6	0.26	10	0.44	9	0.39	25	1.09			25	1.09
4	0.10	3	0.08	2	0.05	2	0.05	2	0.05			4.8	0.12
	3.97		2.56		4.16		3.70		1.70				7.77
196	3.21	79	1.29	148 (carbonate 7/0.23)	2.43	161	2.64	56	0.92			350	5.76
13	0.27	9	0.19	56	1.16	10	0.21	6	0.13			3	0.06
43	1.2[illegible]	29	0.82	18	0.51	32	0.90	14	0.40			37	1.04
0.65	0.03	1	0.05	1	0.05	0.65	0.03	0.65	0.03			0.25	0.01
	3.73		2.35		4.38		3.78		1.46				6.86
385		245		285		345		65				770	
220		140		288		224		52				536	
221		125		224		187		84				350	
5.65		6.4		7.6		5.6		5.6				7.6	
2.5						0.9		NR					

TABLE 6.2

BACTERIOLOGICAL ANALYSES OF WATER SAMPLES

FROM MOLEPOLOLE AREA.

Analyses by Veterinary Diagnostic Laboratory

Borehole Number	Sample Point Description	Date	Presumptive Coliform Count/100 ml	Faecal coliform count
Camp BH	Air trap	4/74	3	0
Ntloedibe BH	Stand pipe	4/74	Nil	Nil
2127	Discharge pipe during pump test (unheated)	8/74	50	Nil
2126	1. Reservoir	4/74	160	160
	2. Discharge pipe during pump test (unheated)	8/74	Nil	Nil
1095	1. Air trap	4/74	180	Nil
	2. Air trap	8/74	Nil	Nil
1478	Air trap	4/74	Nil	Nil
2140	1. Tap by pump	4/74	180	3
	2. Tap by pump	9/74	Nil	Nil
1426	1. Air trap	4/74	180	35
1570	Reservoir	4/74	14	0
2442	1. Stand pipe	4/74	180	0
	2. Stand pipe	8/74	Nil	Nil
1339	1. Reservoir	4/74	180	35
Boribamo West	Air trap	4/74	13	0
Boribamo East	Air trap	4/74	7	1
Secondary School BH	Air trap	4/74	Nil	Nil
Mamarebo BH	1. Stand pipe after reservoir	4/74	160	160

TABLE 6.2 (contd)

(1)				
2644 (2)	Outflow pipe during pumping test.	9/74	Nil	Nil
2643 (3)	Outflow pipe during pumping test.	8/74	Nil	Nil
	*Spring by BH 4	4/74	180 +	180 +
	*Western tributary of Molepolole R.	4/74	180 +	180 +
	*Northern tributary of Molepolole R.	4/74	180 +	180 +
	*Molepolole R. by BH 1	4/74	180 +	180 +

*Sampled following about 20 mm rain when base flow about 20%

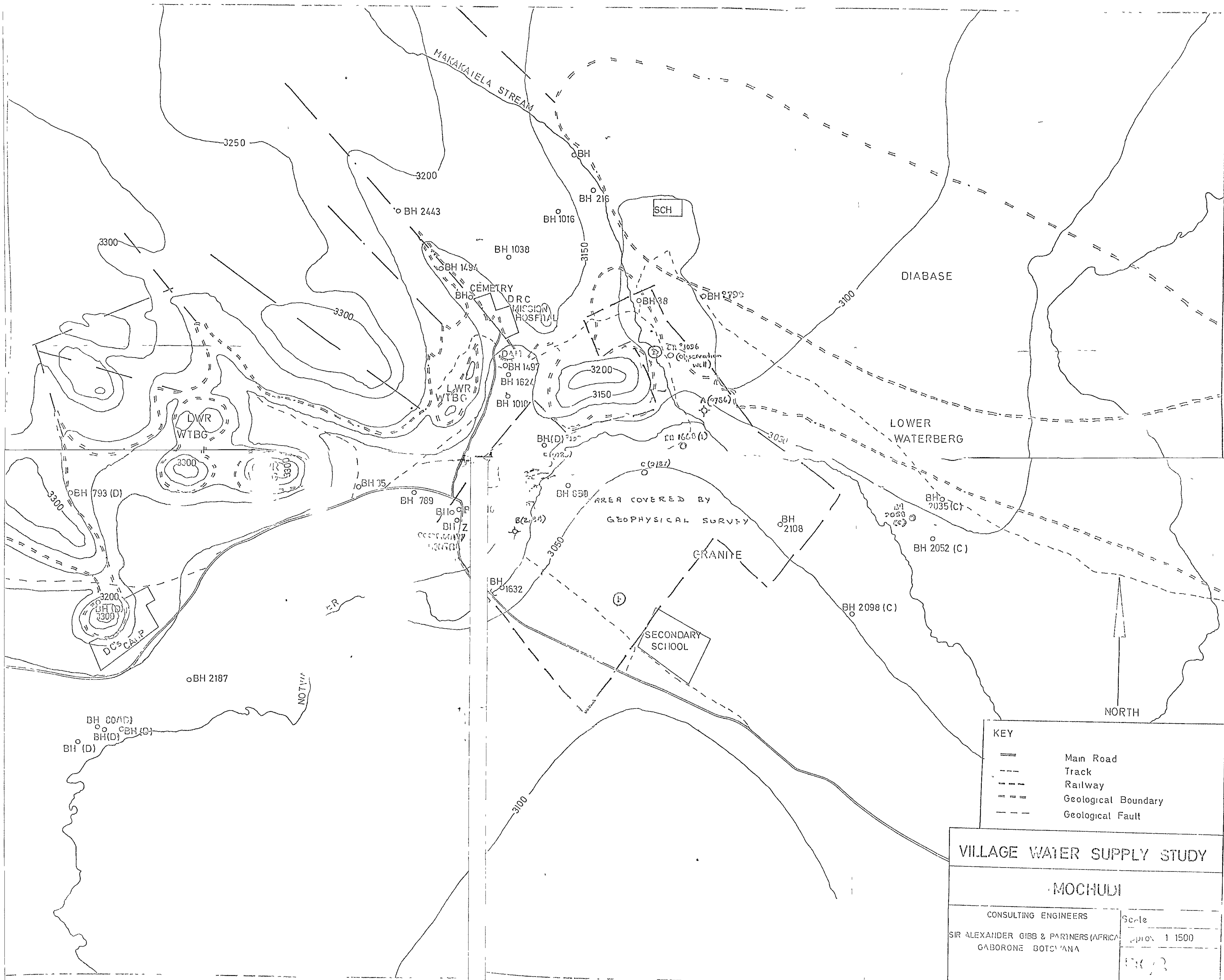

MAKAKATELA STREAM
3250
3200
3300
BH 2443
BH 1016
BH 216
BH
SCH
BH 1038
BH 1494
CEMETRY
BH
D R C
MISSION
HOSPITAL
DIABASE
3100
3150
BH 38
BH 2799
DAM
BH 1497
BH 1624
BH 1010
3200
3150
LWR
WTBG
LWR
WTBG
3300
BH(D)
A(2786)
LOWER
WATERBERG
3050
C(2787)
BH 35
BH 789
BH 793 (D)
BH 650
AREA COVERED BY
GEOPHYSICAL SURVEY
BH
2108
BH
2035 (C)
BH 2052 (C)
GRANITE
B(2784)
BH
1632
SECONDARY
SCHOOL
BH 2098 (C)
DC's CAMP
BH(D)
BH 2187
BH (D)
NORTH
KEY
Main Road
Track
Railway
Geological Boundary
Geological Fault
3100
VILLAGE WATER SUPPLY STUDY
MOCHUDI
CONSULTING ENGINEERS
SIR ALEXANDER GIBB & PARTNERS (AFRICA)
GABORONE BOTSWANA
Scale
approx 1 1500

TABLE 7.1

SUMMARY OF RESISTIVITY DEPTH PROBE RESULTS, MOCHUDI

Site or Borehole No.	ρ_1 (ohm-m)	λ_1 (m)	ρ_2	λ_2	ρ_3	λ_3	ρ_4	Comments
A	190	0.66	8	4.0	40*	40	∞	G
B	40	0.85	13	18	∞*			D
C	24	0.26	17	2.2	∞			D, Ab
E	110	0.54	4	4.8	∞			D, Ab
850	40	0.4	4	3.6	1000*			D
1036	110	0.54	4	4.8	∞*			G, d, saline
2720	300	0.4	22*	40	40	410		WG
2108	210	0.2	70	6.0	210*	100	0	D
2098	2500	1.3	100	3.3	0	6.0	∞*	D, d
1632	40	?	40	13	200*			G, d
1668	45	0.33	22	4.7	68	28.2	∞*	G, d

ρ = apparent resistivity; λ = depth to layer interfaces.

G = granite; WG = weathered granite; D = dolerite; d = disused;

Ab = abandoned.

Asterisk indicates layer in which main supply was encountered

n.b. Depth probes on existing boreholes sometimes offset by up to 20 m and were generally parallel to the structural trend.

TABLE 8.1

MOCHUDI PUMPING TESTS: SUMMARY SHEET

No.	DEPTH W.S.	RWL	PROCEDURE	PUMPING RATES (l/min)	APPARENT DRAWDOWN (m)	SPECIFIC CAPACITIES (l/min/m)	WELL LOSSES AND EFFICIENCY	AQUIFER PARAMETERS
|2ow| 1162	18.3 30.5	12.5	VR (a) 1.) 180 mins 2.) each 3. 1140 " (b) 4. 90 mins (+2720)	 64 96.5 130.4 72.2	 3.05 5.05 7.95 (+0.06)	 21.0 18.7 16.4	$C=1900\ sec^2/ft^5$ 1. 27% 2. 37% 3. 43% E c. 55%	T = 115 m^2/d S = 1×10^{-4} cone of influence: 1200 m @ 1475 mins rate 3 Fract. dol. + granite
|3ow| 850	18.3 29.3	9.2	VR (a) 1.) 1440 mins 2.) each (b) 3.) 120 " 4.) each 5.) 1440 " (c) 6. 60 " 7. 100 "	 102 - 83.2 142.5 185 206 254	 2.85 - 2.4 4.28 6.8 (8.2) (720)	 37.4 - 34.7 33.3 27.2 (25.1)	$C=1400\ sec^2/ft^5$ WL 70%/E 40%	T = 61 - 66 m^2/d (residual s 44 ") No significant s on 1668, 1632 and 792 Fractured dol + granite
38	23.8 37.8	3.54	VR (a) 1. 1440 " 2. Ab (b) 3. 1440 " 4. Ab	 137 - 108 155	 12.37 - 15.6 (19.6)/32+	 8.8 c.8.8 -	$C=7300\ sec^2/ft^5$ 1. 75% 3. 94% E c. 70%	T = 5 - 8 m^2/d (residual s 4 m^2/d) Fractured granite
1668	32.3-45.7	9.5	VR (a) 1. Ab (b) 2.) 120 " 3.) each 4. 1440 "	 23.75 35.5 44.4	 7.5 13.1 21.6	 3.3 2.7 2.05	$C=77500\ sec^2/ft^5$ 65% E c. 30%	T = 0.7 m^2/d k = 0.05 " Recharge boundary effective from t = c. 20 mins Granite

/contd

TABLE 8.1 (CONTD)

No.	DEPTH W.S.	RWL	PROCEDURE	PUMPING RATES (l/min)	APPARENT DRAWDOWN (m)	SPECIFIC CAPACITIES (l/min/m)	WELL LOSSES AND EFFICIENCY	AQUIFER PARAMETERS
|2ow| 2035	32.9 - 40 m = 7.1 58.2	24.1	VR (a) 1.)180 mins 2.) each 3. Ab (b) 4. 180 mins 5. 1440 "	48.2 69.5 (99.3) 56.5 67.7	10.3 27.7 - 17.6 27.6	(c.5) 2.1 - 3.0 -	C = 104000 sec^2/ft^5 W.L. v. high E v low	T(UWBH) 8.4 m^2/d (LWBH) 1.5 " No significant drawdown on 2052 and small on 2058 Dolerite and granite

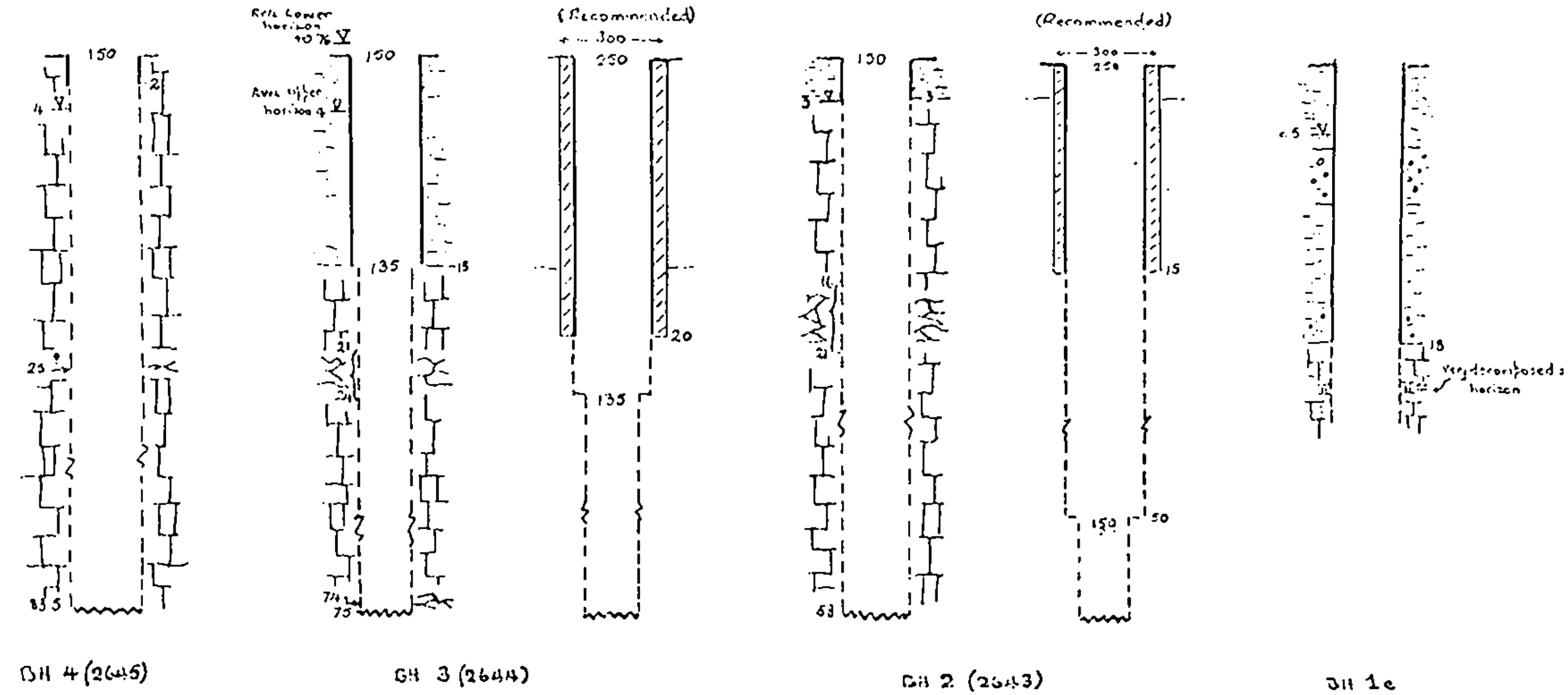
FIG 3.1

'OLEPOLE WELL FIELD MAJOR FRACTURES A N WATER SOURCES

(based ... otographs)

FIG. 3.3

DIAGRAMMATIC SUMMARY OF BOREHOLE CONSTRUCTION DETAILS



KEY

150 Casing or hole diameter in millimetres

Temporary casing

Permanent or present casing

Open hole

Cement grout

Rest Water Level

Water struck

Silt

Gravelly clay

Clay

Bedrock sandstone

Fracture zone

Full details for site 1 not available.

1. As economic alternative to cement grout 300mm casing installed permanently and reaming continued at 250mm

2. Verbal report from driller that fractures extend to depths of more than 21m at site 2

TABLE 4.1.1

MOLEPOLOLE PUMPING TESTS: SUMMARY SHEET

BOREHOLE No.	Total Depth (m)	DEPTH W.S. (m)	RWL m(bct)	PROCEDURE (mins)	PUMPING RATES (l/min)	APPARENT DRAWDOWN (m)	SPECIFIC CAPACITIES (l/min/m)	WELL LOSSES AND EFFICIENCY	AQUIFER PARAMETERS
CAMP (1 ow)	72	NR	14.96	VR 1.) 150 2.)each 3. 996	45.8 90.6 142	5.75 13.09 23.94	7.97 6.92 5.93	C5400 sec^2/ft^5 70-52%	T ? 19 m^2d S 4 x 10^{-6} U Wbg r = 33 m
NTLOEDIBE	88.5	NR	6.8	VR a) 1.)150 2.)each b) 3.)150 4.)each 5. 1440	44.1 67.6 90.5 124.4 137.3	8.57 13.02 18.27 29.62 35.27	5.15 5.19 4.95 4.2 3.9	C10,000 - 13,000 sec^2/ft^5	T ? 19 m^2d
2127 (1 ow)		59.9 95.7)main 98.15)supply	17.76 (?)	VR a) 1.)150 2.)each b) 3. 117	(Av) 41.5 22.2 21.1	36	<1.0		T 0.75 m^2d S (not calculated) Dol r = 245
2126		10.0 12.5	17.82	SR 1.95	(Av) 41	90	<<0.45	(high)	T 0.25 m^2d Drift & weathered granite[2]

TABLE 4.1.2

MOLEPOLOLE BOREHOLES: RECOMMENDED YIELDS AND ASSOCIATED PUMPING DATA

Borehole	Aquifer	Total Depth m	*RWL b.d. m	PWL b.d. m	Available Drawdown m	**Yield (m^3d)	Pump Setting b.d. m	Specific Capacity m^2d @ t = 1440 mins
Camp	U. Wbg	73	15	38	23	200	50	8.6
Ntloedibe	U. + L. Wbg	88.5	[illegible]	41	35	200	64	5.8
2127	B. Cx.	99.4	17.5	39	c.21	Less than 75	60	1.7
†2442	U. Wbg	148.4	9	NK	NK	75	NK	NK
(1)	L. Wbg							
2644 (2)	L. Wbg	57.9	3	13	10	250	25	25
2643 (3)	L. Wbg	76	+0.7	60	60	690	75	11.5
2645 (4)	L. Wbg	8.4	4.5			(Ab)		
						Total:		

* For the period Jun - Oct., 1974

** For available drawdown shown.

† Not test pumped.

b.d. Below datum point.

U

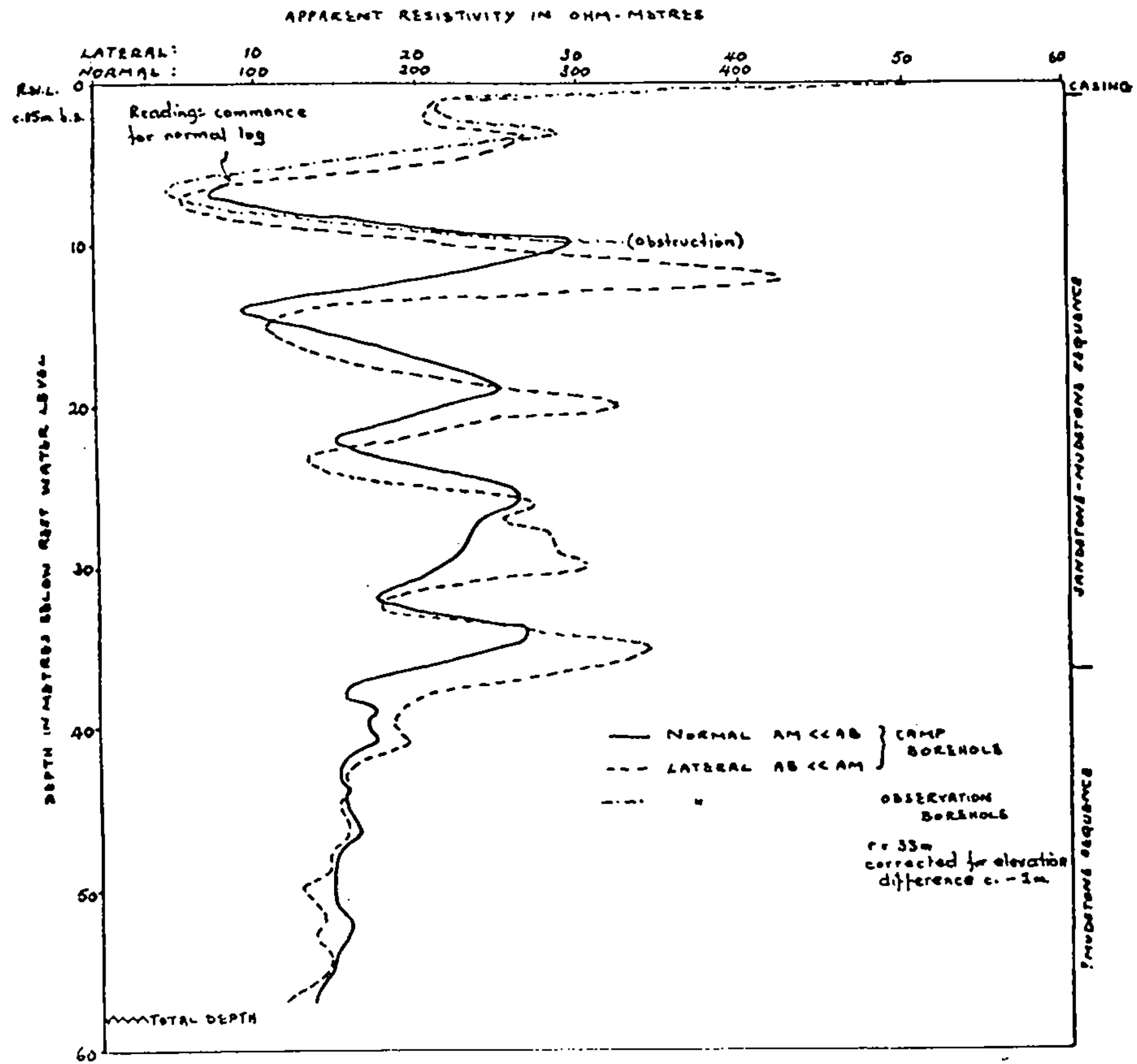


FIG. 4.1.1

SUBSURFACE RESISTIVITY LOGS FOR CAMP BOREHOLE, MOLEPOLOLE

TABLE 5.2

POTENTIAL RECHARGE AT MOLEPOLOLE AND MOCHUDI IN MILLIMETRES

FOR THE PERIOD 1960-1974

Year	Months during which rainfall exceeded potential evaporation		Rainfall minus potential evaporation from wet bare soil	
	Mol.	Moch.	Mol.	Moch.
1960-61	Nov., Dec., Apr	Nov., Apr	31, 3, 15	49,41
1961-62	Nil	Nil		
1962-63	Nil	Nil		
1963-64	Nil	Nil		
1964-65	Apr	Nil	19	
1965-66	Feb	Nil	75	
1966-67	Feb, Apr	Jan, Feb, Mar, Apr	45, 135	49, 13, 45, 134
1967-68	Apr	Apr	81	36
1968-69	Apr	Apr	34	6
1969-70	Nil	Dec		26
1970-71	Nil	Apr		6
1971-72	Nov, Jan	Jan	22,104	5
1972-73	Nil	Nil		
1973-74	Dec, Jan	Mar	27,12	32
		Average recharge per year	36	32

FIGURE 6.1

GROUNDWATER QUALITY

MOLEPOLOLE

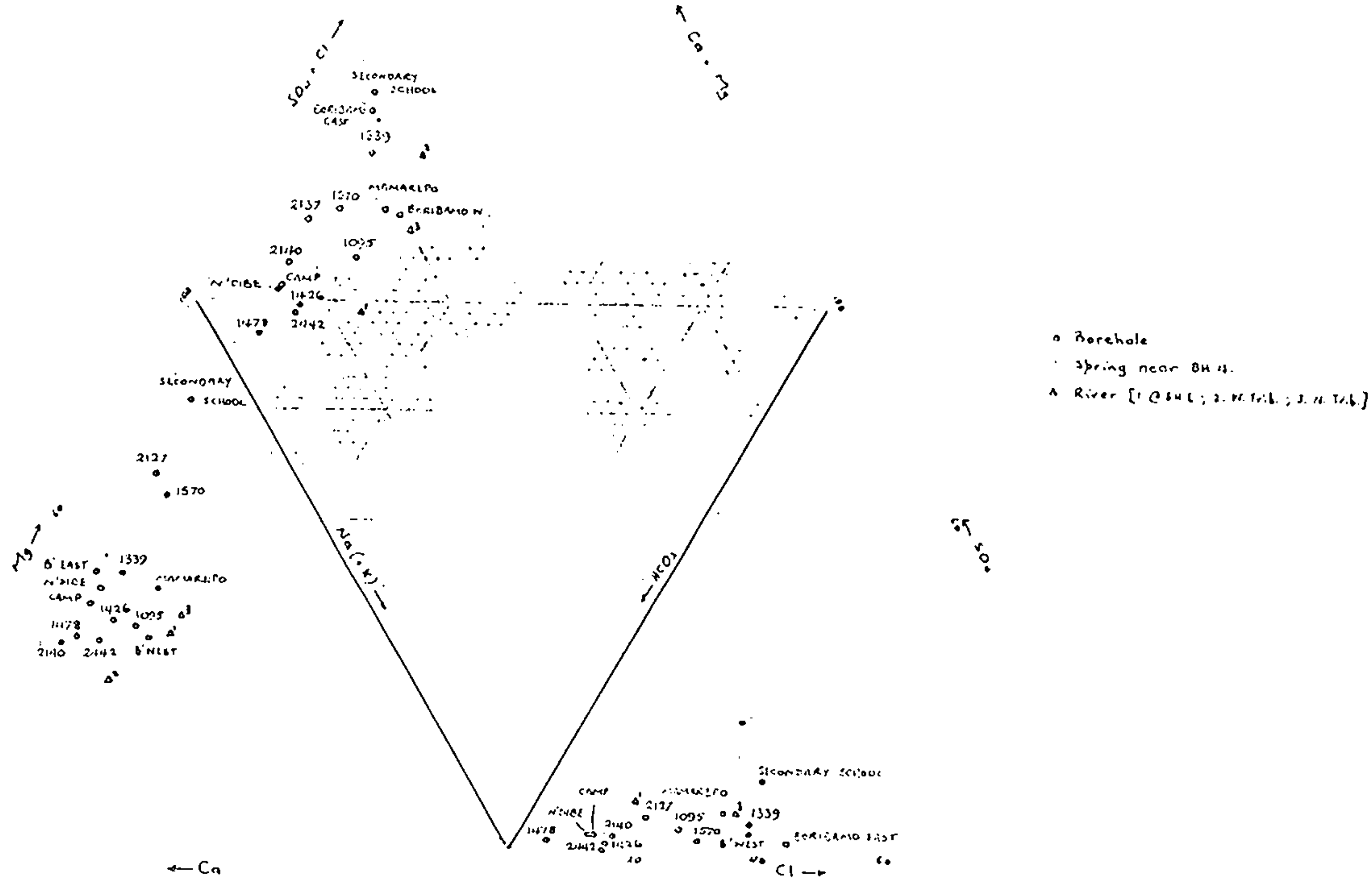


TABLE 6.1

GROUNDWATER SAMPLES FROM MOLEPOLOLE SUPPLY BOREHOLES

Analyses carried out by Geological Survey Department

Borehole Number	CAMP		P.T. St.2		NTLOEDIBE				P.T. St.4		2127			
Date of collection	4.74		25.7.74		1.73		4.74		2.8.74		2.68		4.74	
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	75	3.74	90	4.49	55	2.74	80	3.99	41	2.05	43	2.15	21	1.05
Magnesium	45	3.70	47	3.87	29	2.39	56	4.61	83	6.83	17	1.4	40	3.29
Sodium	23	1.00	55	2.39	40	1.74	25	1.09	70	3.04	12	0.52	11	0.48
Potassium	1	0.026	3	0.08	2	0.05	2.5	0.06	2.7	0.07	3	0.08	2.2	0.06
Total Cations		8.47		10.83		6.92		9.75		11.99		4.15		4.87
Bicarbonate	444	7.28	505	8.28	330	5.41	485	7.95	575	9.72	170	2.79	202	3.31
Sulphate	13	0.27	17	0.35	35	0.73	13	0.27	34	0.71	9	0.19	13	0.27
Chloride	37	1.04	43	1.21	50	1.41	37	1.04	29	0.82	32	0.9	29	0.82
Fluoride	0.25	0.01	0.65	0.03	0.07	0.04	0.25	0.01	0.65	0.03	1.0	0.05	0.25	0.01
Total Anions		8.61		9.88		7.59		9.28		11.28		3.93		4.41
Conductivity (micromhos @ 20°C)	710		930		600		770		1050		390		250	
Total dissolved solids @ 120°C	564		660		336		540		920		224		100	
Theoretical dissolved solids	412		504		374		452		551		201		215	
pH	7.2		7.2		7.0		7.5		7.9		7.5		7.8	
Fe			0.6						0.9					

*Not pump tested during investigation

P.T.	13.8.74	6.68		2126 11.70		P.T.	13.8.74	P.T. 3	30.8.74	P.T. 1		2442* 4.74	
mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
30	1.50	28	1.4	26	1.28	39	1.95	8	0.40			72	3.59
22	1.81	10	0.82	29	2.39	16	1.32	2	0.16			36	2.96
13	0.57	6	0.26	10	0.44	9	0.39	25	1.09			25	1.09
4	0.10	3	0.08	2	0.05	2	0.05	2	0.05			4.8	0.12
	3.97		2.56		4.16		3.70		1.70				7.77
196	3.21	79	1.29	148 (carbonate 7/0.23)	2.43	161	2.64	56	0.92			350	5.76
13	0.27	9	0.19	56	1.16	10	0.21	6	0.13			3	0.06
43	1.20	29	0.82	18	0.51	32	0.90	14	0.40			37	1.04
0.65	0.03	1	0.05	1	0.05	0.65	0.03	0.65	0.03			0.25	0.01
	3.73		2.35		4.38		3.78		1.46				6.86
385		245		285		345		65				770	
220		140		288		224		52				536	
221		125		224		187		84				350	
5.65		6.4		7.6		5.6		5.6				7.6	
2.5						0.9		NR					

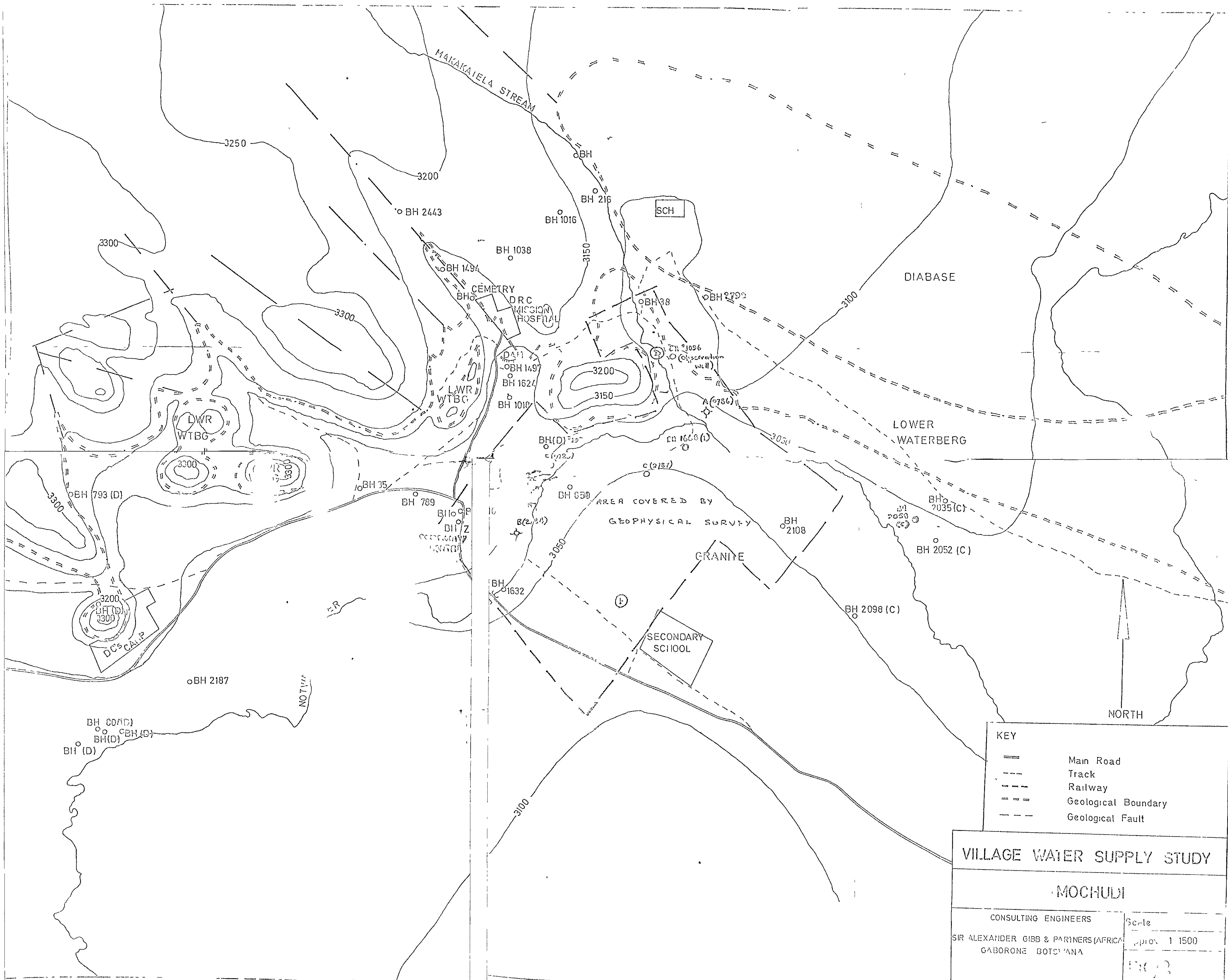

VILLAGE WATER SUPPLY STUDY
MOCHUDI
CONSULTING ENGINEERS
SIR ALEXANDER GIBB & PARTNERS (AFRICA)
GABORONE BOTSWANA
Scale
approx 1 1500
KEY
Main Road
Track
Railway
Geological Boundary
Geological Fault
NORTH
MAKAKATELA STREAM
DIABASE
LOWER WATERBERG
GRANITE
LWR WTBG
AREA COVERED BY GEOPHYSICAL SURVEY
SECONDARY SCHOOL
SCH
CEMETERY
D R C MISSION HOSPITAL
DC's CAMP
BH 2443
BH 216
BH 1016
BH 1038
BH 1494
BH 38
BH 1497
BH 1624
BH 1010
BH 650
BH 2108
BH 2052 (C)
BH 2035 (C)
BH 2098 (C)
BH 1632
BH 789
BH 35
BH 793 (D)
BH 2187
BH (D)
3100
3150
3200
3250
3300
3050

TABLE 8.1

MOCHUDI PUMPING TESTS: SUMMARY SHEET

No.	DEPTH W.S.	RWL	PROCEDURE	PUMPING RATES (l/min)	APPARENT DRAWDOWN (m)	SPECIFIC CAPACITIES (l/min/m)	WELL LOSSES AND EFFICIENCY	AQUIFER PARAMETERS
|2ow| 1162	18.3 30.5	12.5	VR (a) 1.)180 mins 2.) each 3. 1140 " (b) 4. 90 mins (+2720)	64 96.5 130.4 72.2	3.05 5.05 7.95 (+0.06)	21.0 18.7 16.4	C=1900 sec^2/ft^5 1. 27% 2. 37% 3. 43% E c. 55%	T = 115 m^2/d S = 1 x 10^{-4} cone of influence: 1200 m @ 1475 mins rate 3 Fract. dol. + granite
|3ow| 850	18.3 29.3	9.2	VR (a) 1.)1440 mins 2.) each (b) 3.) 120 " 4.) each 5.)1440 " (c) 6. 60 " 7. 100 "	102 - 83.2 142.5 185 206 254	2.85 - 2.4 4.28 6.8 (8.2) (720)	37.4 - 34.7 33.3 27.2 (25.1)	C=1400 sec^2/ft^5 WL 70%/E 40%	T = 61 - 66 m^2/d (residual s 44 ") No significant s on 1668, 1632 and 792 Fractured dol + granite
38	23.8 37.8	3.54	VR (a) 1. 1440 " 2. Ab (b) 3. 1440 " 4. Ab	137 - 108 155	12.37 - 15.6 (19.6)/32+	8.8 c.8.8 -	C=7300 sec^2/ft^5 1. 75% 3. 94% E c. 70%	T = 5 - 8 m^2/d (residual s 4 m^2/d) Fractured granite
1668	32.3-45.7	9.5	VR (a) 1. Ab (b) 2.) 120 " 3.) each 4. 1440 "	23.75 35.5 44.4	7.5 13.1 21.6	3.3 2.7 2.05	C=77500 sec^2/ft^5 65% E c. 30%	T = 0.7 m^2/d k = 0.05 " Recharge boundary effective from t = c. 20 mins Granite

/contd

TABLE 8.1 (CONTD)

No.	DEPTH W.S.	RWL	PROCEDURE	PUMPING RATES (l/min)	APPARENT DRAWDOWN (m)	SPECIFIC CAPACITIES (l/min/m)	WELL LOSSES AND EFFICIENCY	AQUIFER PARAMETERS
|2ow| 2035	32.9 - 40 m = 7.1 58.2	24.1	VR (a) 1.) 180 mins 2.) each 3. Ab (b) 4. 180 mins 5. 1440 "	48.2 69.5 (99.3) 56.5 67.7	10.3 27.7 - 17.6 27.6	(c.5) 2.1 - 3.0 -	C = 104000 sec^2/ft^5 W.L. v. high E v low	T(UWBH) 8.4 m^2/d (LWBH) 1.5 " No significant drawdown on 2052 and small on 2058 Dolerite and granite

TABLE 8.2

MOCHUDI BOREHOLES: RECOMMENDED YIELDS AND ASSOCIATED PUMPING DATA

BOREHOLE	AQUIFER	TOTAL DEPTH m.b.d.	*R.W.L. b.d. m	PWL b.d. m	*AVAILABLE DRAWDOWN m	*YIELD m^3d	Pump Setting b.d. m.	SPECIFIC CAPACITY m^2d @ t = 1440 mins
1162	DOLERITE	40.5	12.5	26	13.5	260	31	<.20
850	DOLERITE	30.5	9.2	15	6	250	20	41.6
38	GRANITE	65.7	3.5	20.5	17.5	210	24	12
2035	DOLERITE AND GRANITE	70.1	24.1	49	25	94	60	3.6
1668	GRANITE	54.9	9.5	29.5	20	63	40	3.2
A (2786)	GRANITE	42	6.0	31	25	500	40	20
B (2784)	DOLERITE	38.5	8.1	23	15	360	28	24
C (2787)	Abandoned							
E (2785)	Abandoned							
						TOTAL: 1737		

* For the period Jun-Oct, 1974.

b.d. Below datum point.

TABLE 8.2

MOCHUDI BOREHOLES: RECOMMENDED YIELDS AND ASSOCIATED PUMPING DATA

BOREHOLE	AQUIFER	TOTAL DEPTH m.b.d.	*R.W.L. b.d. m	PWL b.d. m	*AVAILABLE DRAWDOWN m	*YIELD m^3d	Pump Setting b.d. m.	SPECIFIC CAPACITY m^2d @ t = 1440 mins
1162	DOLERITE	40.5	12.5	26	13.5	260	31	$<$.20
850	DOLERITE	30.5	9.2	15	6	250	20	41.6
38	GRANITE	65.7	3.5	20.5	17.5	210	24	12
2035	DOLERITE AND GRANITE	70.1	24.1	49	25	94	60	3.6
1668	GRANITE	54.9	9.5	29.5	20	63	40	3.2
A (2786)	GRANITE	42	6.0	31	25	500	40	20
B (2784)	DOLERITE	38.5	8.1	23	15	360	28	24
C (2787)	Abandoned							
E (2785)	Abandoned							
						TOTAL: 1737		

* For the period Jun-Oct, 1974.

b.d. Below datum point.

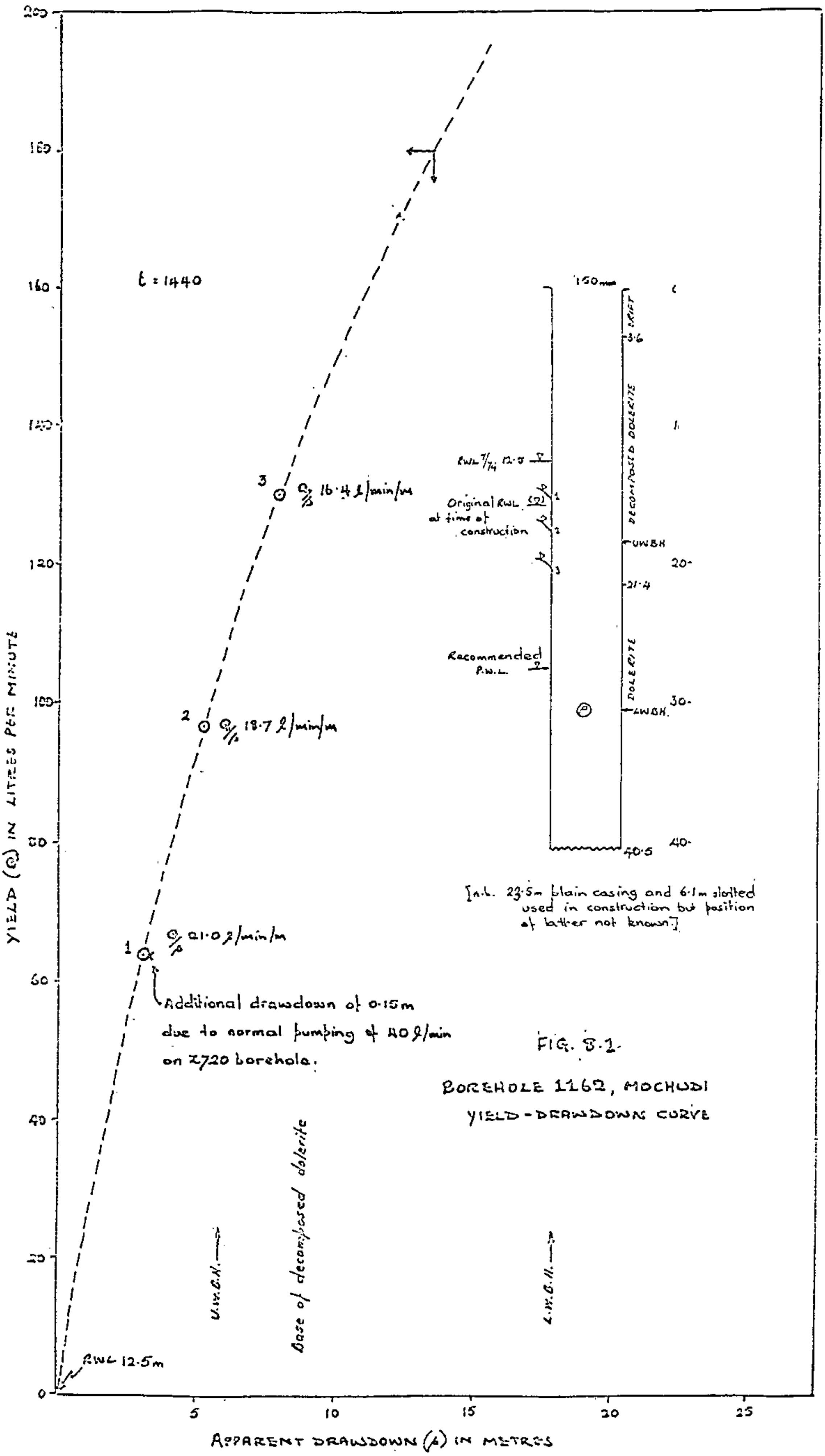


FIG. 8.1.

BOREHOLE 1162, MOCHUDI
YIELD-DRAWDOWN CURVE

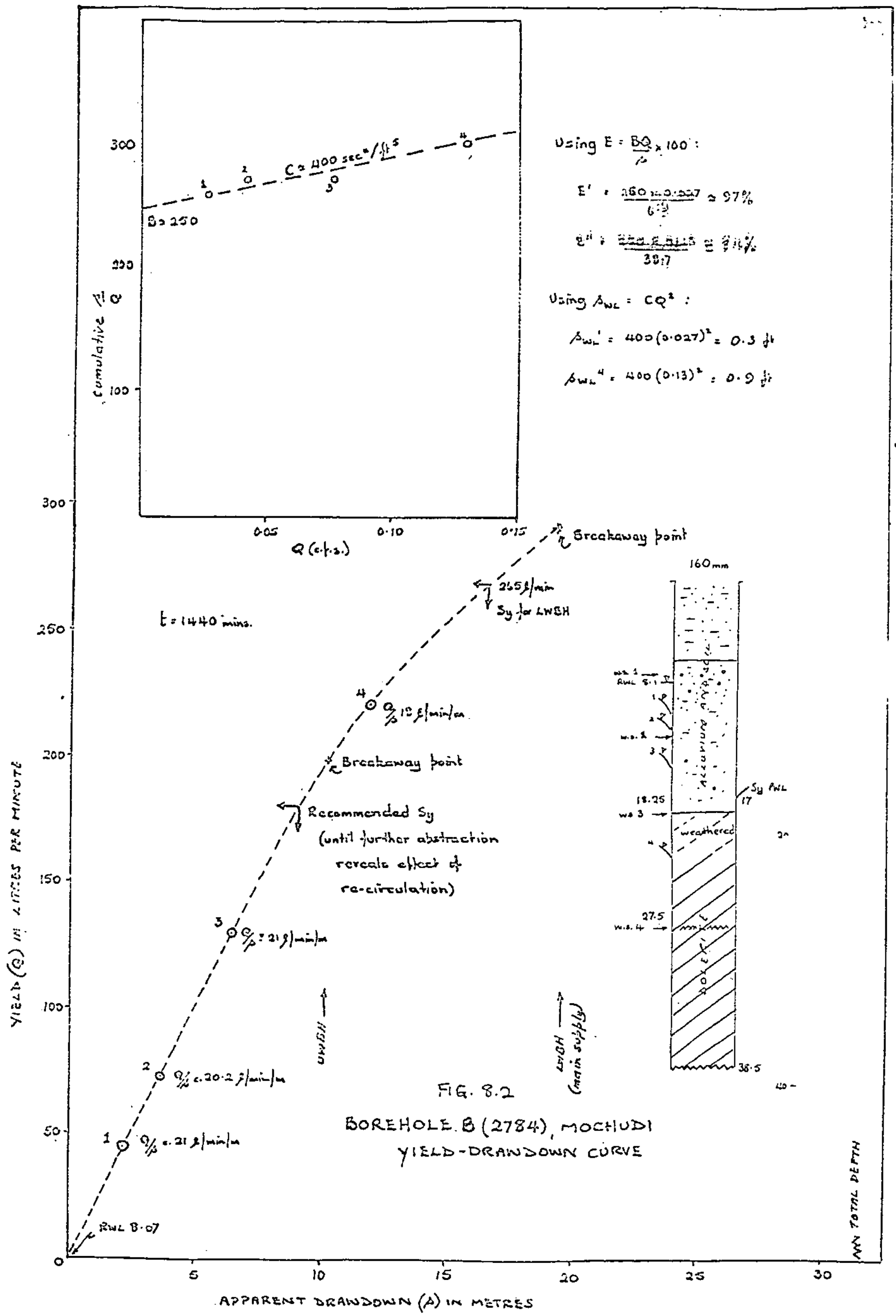


FIG. 8.2

BOREHOLE B (2784), MOCHUDI
YIELD-DRAWDOWN CURVE

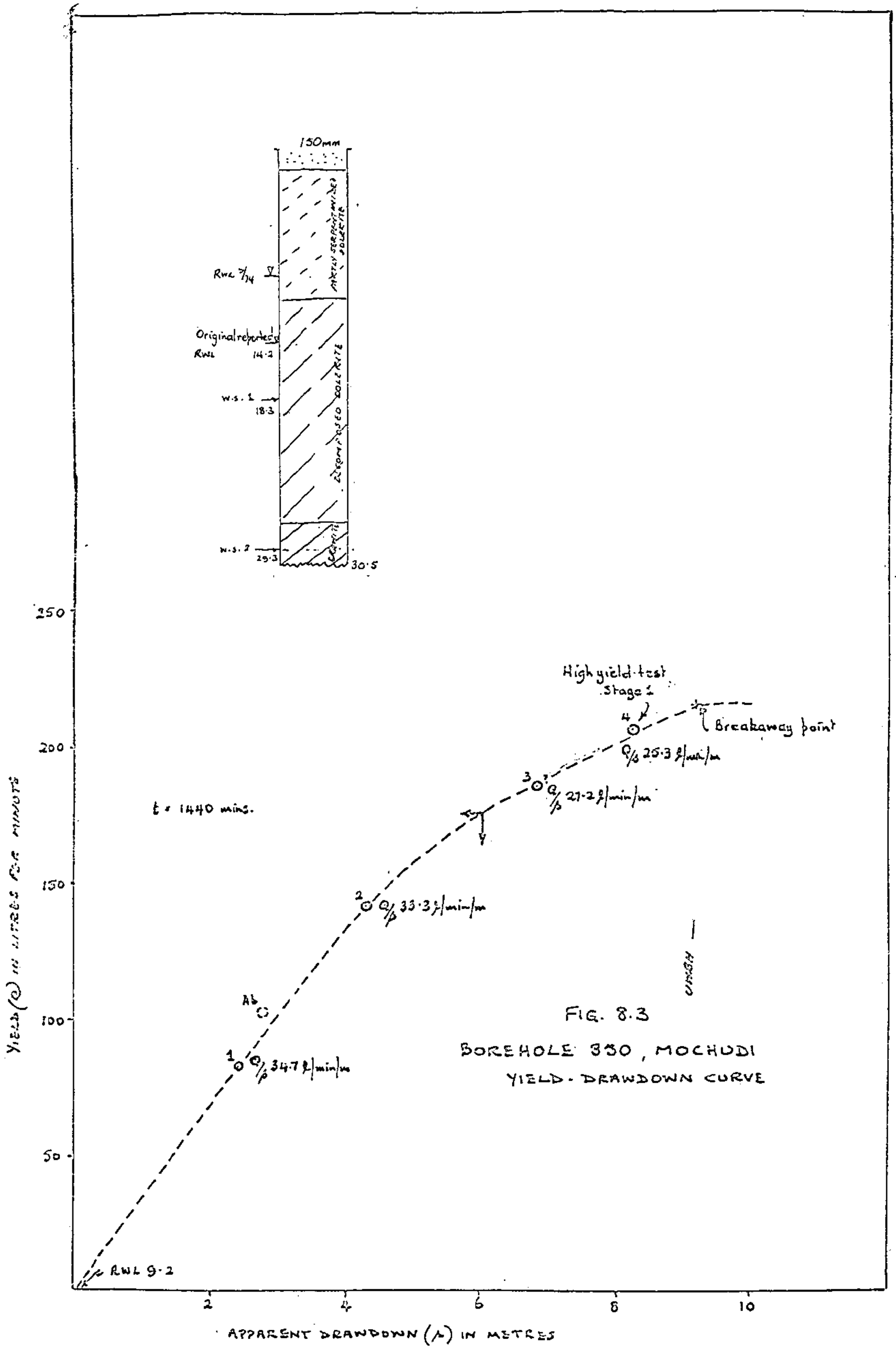


FIG. 8.3

BOREHOLE 330, MOCHUDI

YIELD - DRAWDOWN CURVE

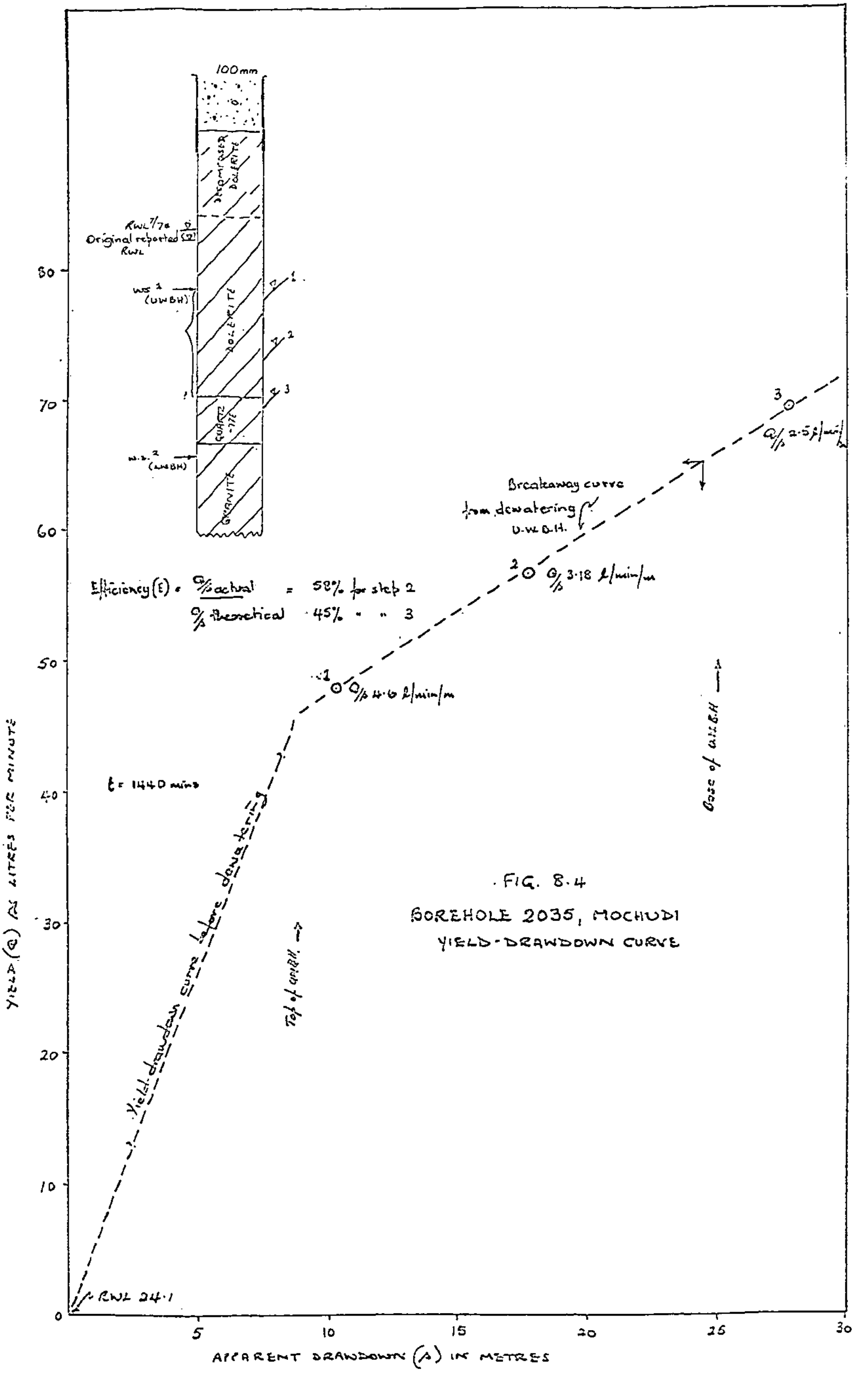


FIG. 8.4

BOREHOLE 2035, MOCHUDI

YIELD-DRAWDOWN CURVE

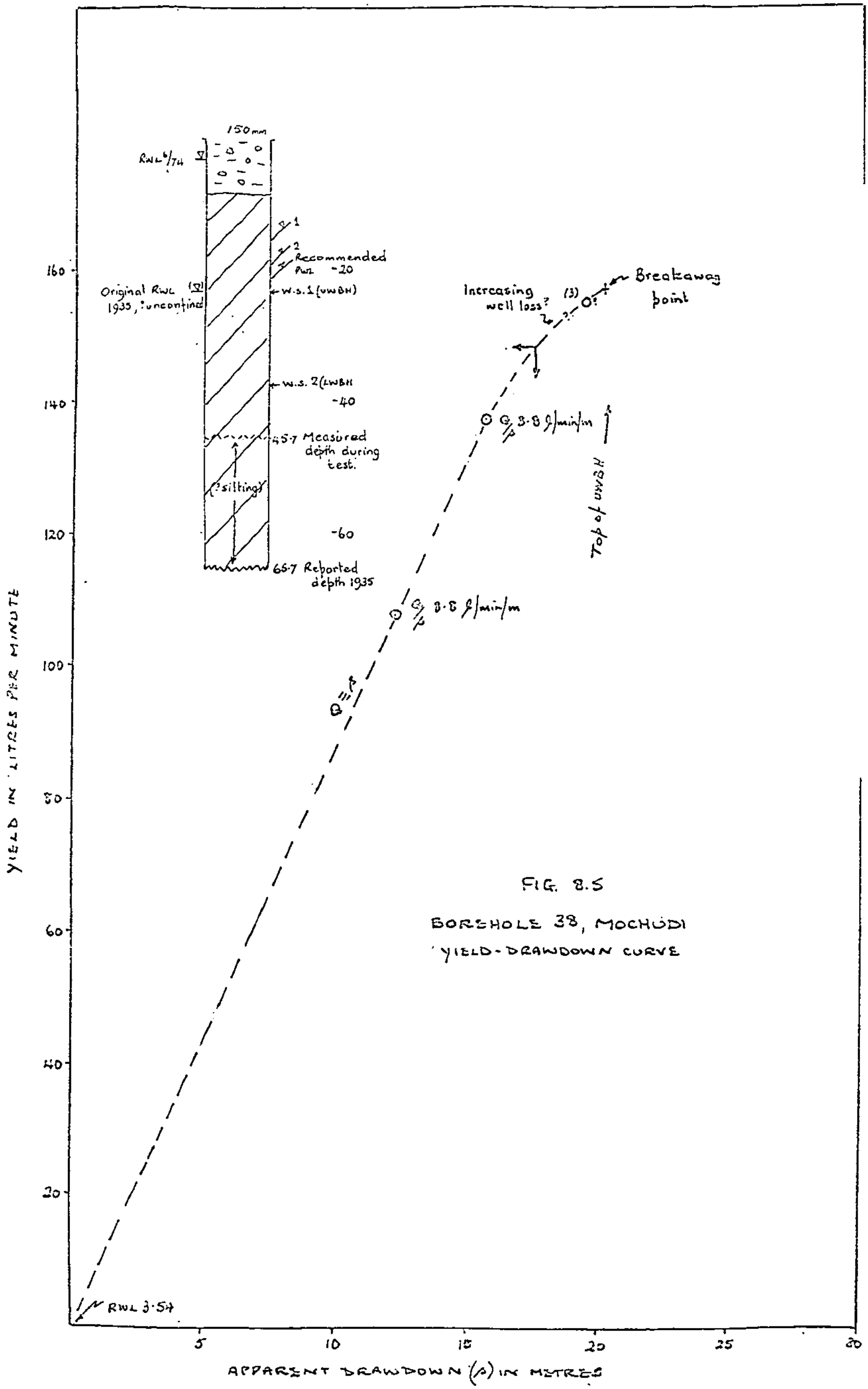


FIG. 8.5

BOREHOLE 38, MOCHUDI

YIELD-DRAWDOWN CURVE

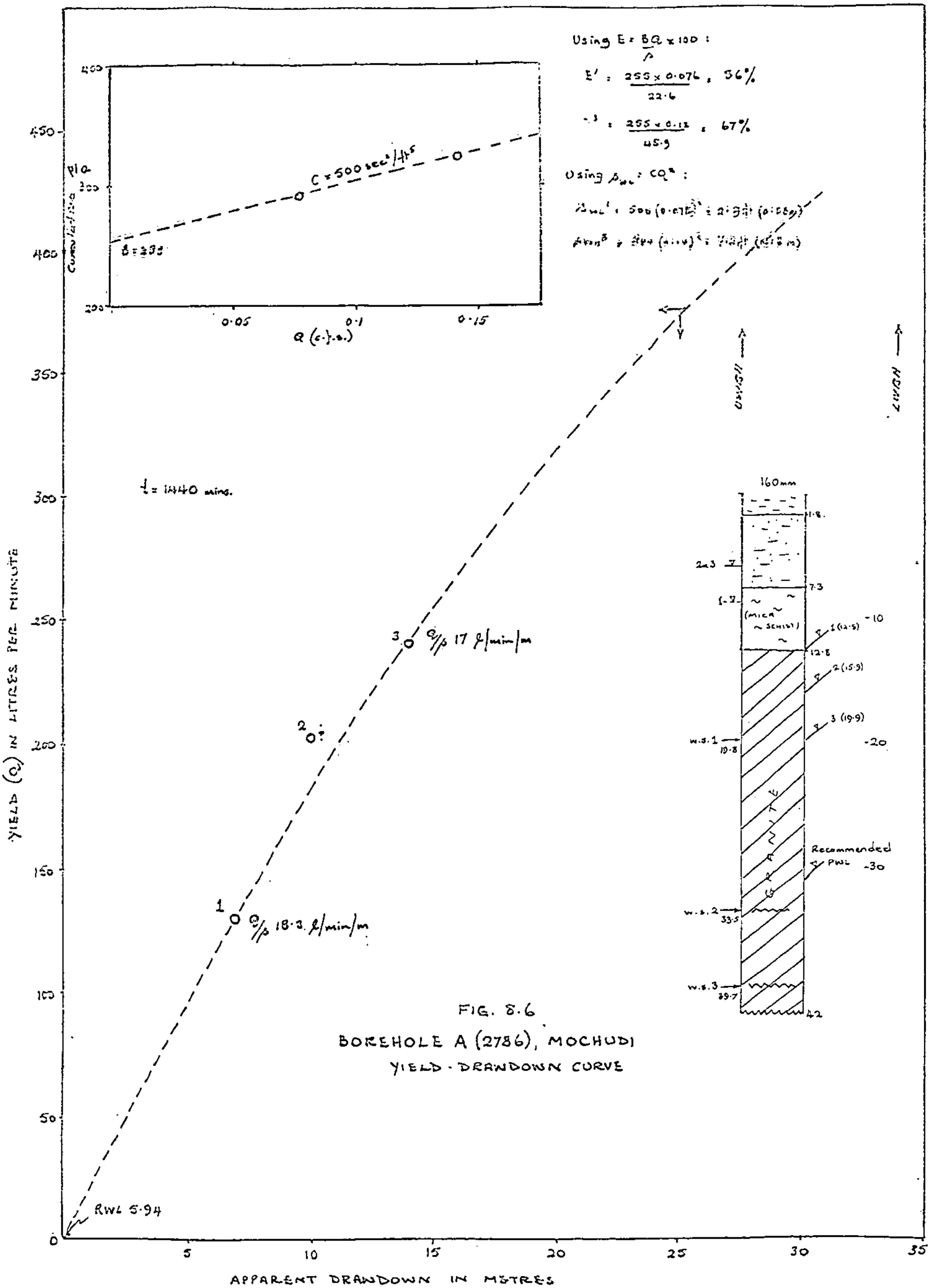


FIG. 8.6

BOREHOLE A (2786), MOCHUDI

YIELD - DRAWDOWN CURVE

FIG. 8.7

BOREHOLE 1668, MOCHUDI
YIELD-DRAWDOWN CURVE

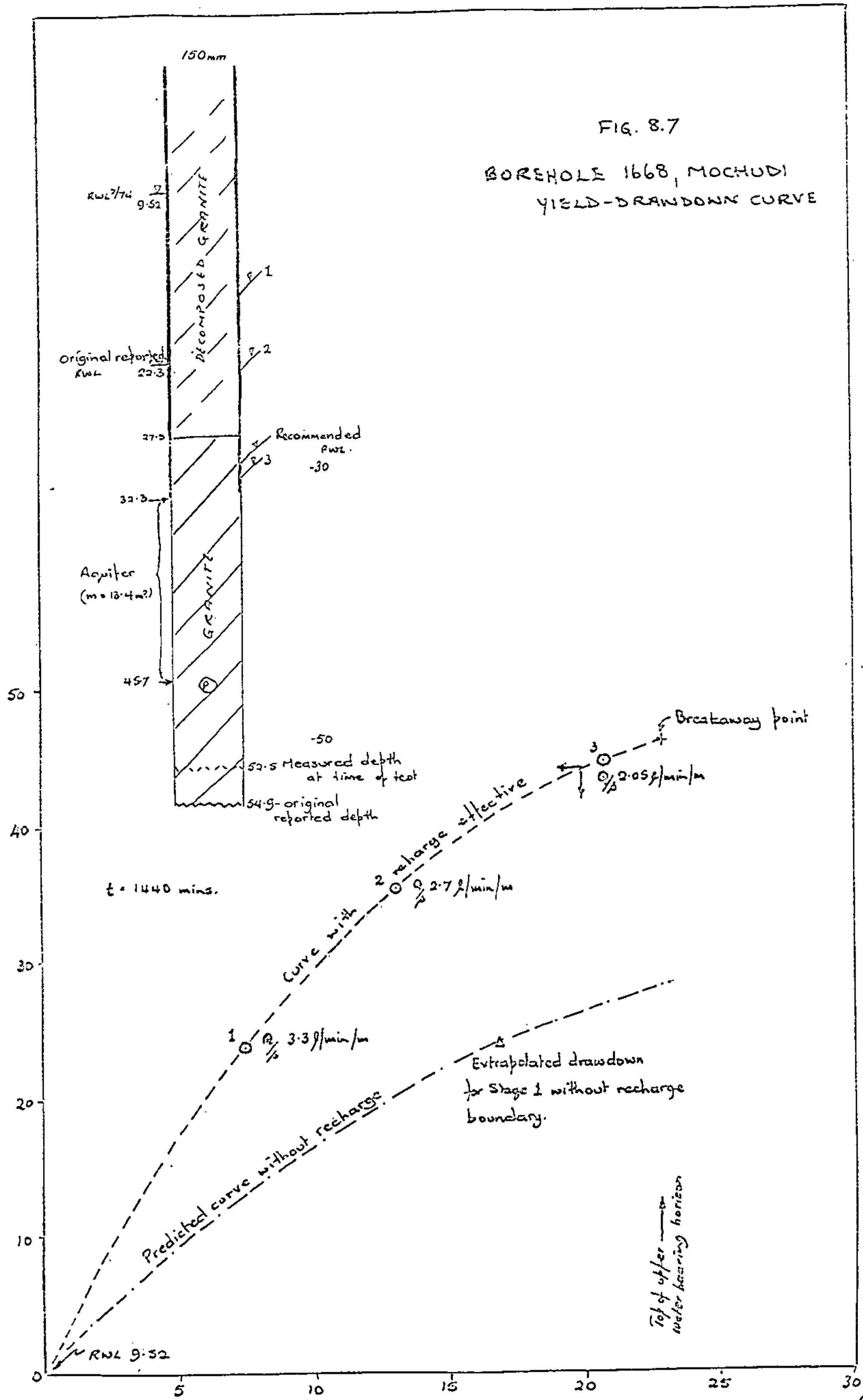
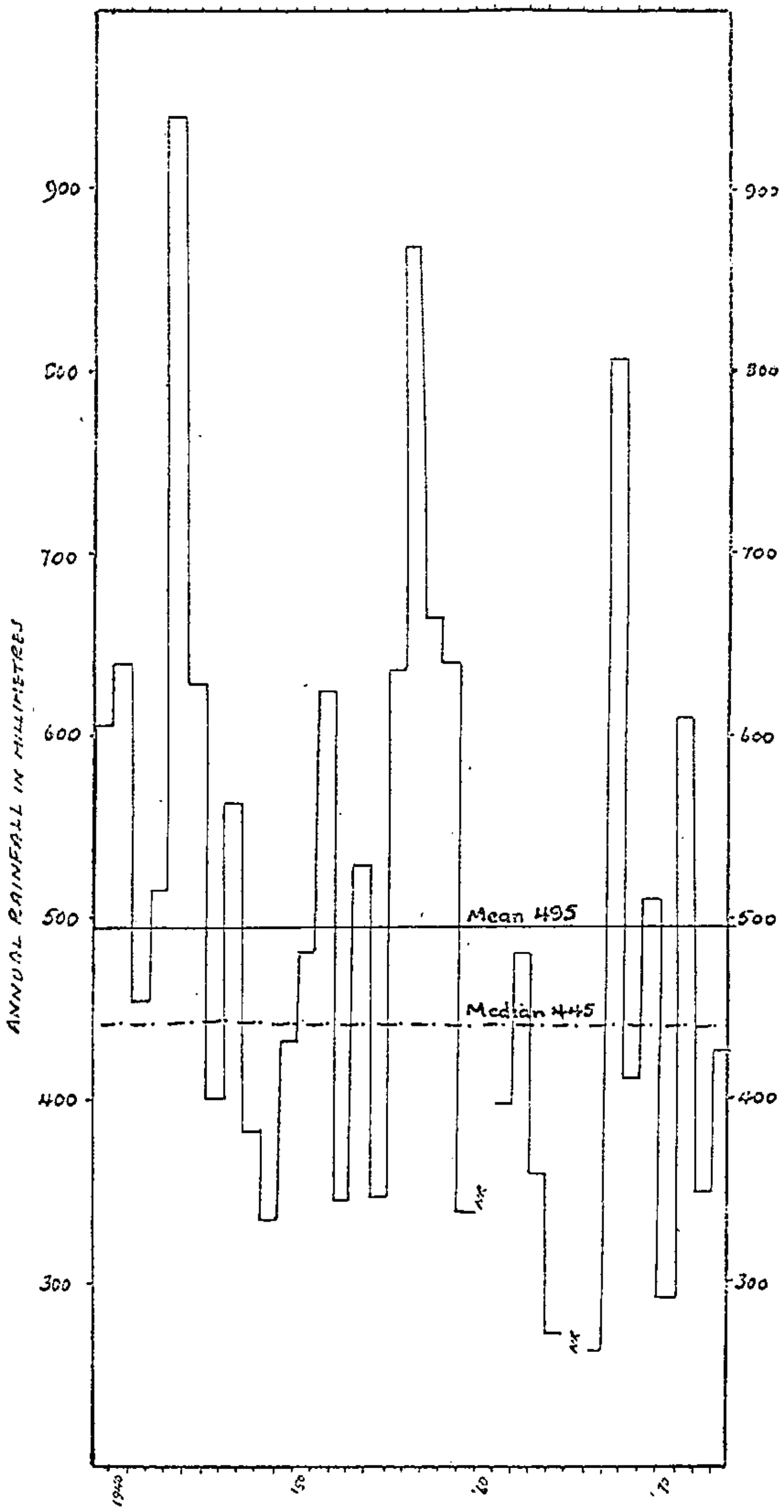


FIG. 9.1



MOCHUDI - TOTAL ANNUAL RAINFALL IN MM.,
1939-73

FIGURE 10.1

GROUNDWATER QUALITY,

MOCHUDI

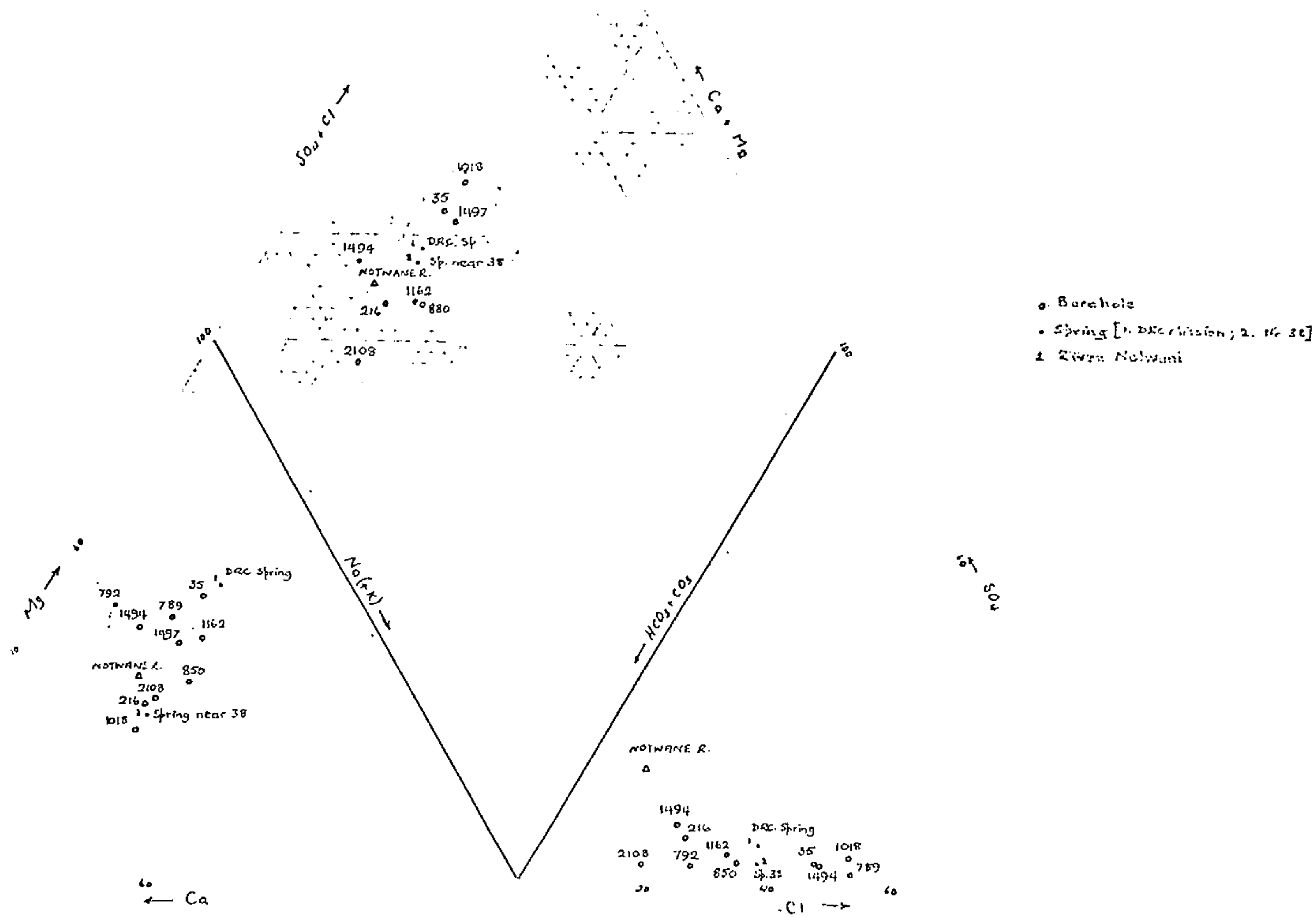


TABLE 10.1

GROUNDWATER SAMPLES FROM MOCHUDI SUPPLY :OREHOLES

Analyses carried out by Geological Survey Department

Borehole Number	1162				850		1668		2035				B	
Date of collection	5.74		P.T.St.2	16.7.74	5.74		P.T.St.3	12.7.74	6.67		P.T.St.2	5.7.74	P.T.St.4	20.9.74
	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Calcium	86	4.29	65	3.24	51	2.55	102	5.09	48	2.40	45	2.25	40	2.00
Magnesium	79	6.49	93	7.65	32	2.63	124	10.19	33	2.72	47	3.87	26	2.14
Sodium	88	3.83	78	3.37	46	2.00	73	3.15	45	1.96	38	1.63	22	0.96
Potassium	2	0.05	2.25	0.06	13	0.03	4	0.10	3	0.08	2.5	0.06	[illegible]	0.05
Total Cations		14.66		14.32		7.21		18.53		7.16		7.81		5.15
Bicarbonate	552	9.05	550	9.01	404	6.62	733	12.01	331	5.43	409	6.70	308	5.05
Sulphate	31	0.65	20	0.42	13	0.27	71	1.49	22	0.46	26	0.55		
Chloride	158	4.46	144	4.06	37	1.04	223	6.29	36	1.02	36	1.02	25	0.71
Fluoride	0.10	0.005	0.25	0.013	0.65	0.03	0.40	0.021	1	0.05	0.25	0.01	0.5	0.03
Total Anions*		14.16		13.50		7.97		19.81		6.96		8.28		6.31
Conductivity (in micromhos @ 20°C)	1200		1320		600		1530		525		630		490	
Total dissolved solids @ 120°C	880		1252		296		1172		384		320		256	
Theoretical dissolved solids	715		732		380		1042		351		396		300	
pH	7.0		7.2		6.5		6.9		7.3		7.3			
Iron			0.15				0.15						0.2	
Nitrate			65	1.04			75	1.2			(< 10)		33	0.53

792(?)		2052		2058		2108				2098		Spring near Dutch Reform Mission		Spring near Borehole 38		Notwane near borehole 1668	
5.74		6.67		6.67		1.68		5.74		1.68		5.74		5.74		5.74	
mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
82	4.09	67	3.34	61	3.04	63	3.14	63	3.14	65	3.24	13	0.65	84	4.19	19	0.95
62	5.10	47	3.87	43	3.54	43	3.54	31	2.55	60	4.94	20	1.65	33	2.71	10	0.87
23	1.00	40	1.74	30	1.31	63	2.74	45	1.96	120	5.22	13.5	0.59	47	2.05	8	0.35
1	0.03	3	0.08	3	0.08	4	0.10	2	0.05	4	0.10	7	0.18	13	0.33	5	0.12
	10.21		9.03		7.97		9.52		7.70		13.50		3.06		9.28		2.21
310	5.08	478	7.84	420	6.89	433 (carbonate 38/1.27)	7.10	404	6.62	407 (Carbonate 75/2.5)	6.67	108	1.77	350	5.74	94	1.54
9	0.19	14	0.29	8	0.17	10	0.21	13	0.27	89	1.85	10	0.21	15	0.31	22	0.46
66	1.86	29	0.82	22	0.62	28	0.79	52	1.47	92	2.59	37	1.04	125	3.53	7	0.20
0.25	0.01	1	0.05	5	0.26	1	0.05	0.65	0.03	1	0.05	0.4	0.02	0.4	0.02	0.25	0.01
	7.15		9.00		7.94		9.42		8.39		13.66		3.04		9.60		2.24
875		680		610		780		760		910		210		1150		150	
632		488		412		560		480		880		176		816		140	
		388		385		470		406		710		154		419		117	
6.9		7.6		7.7		7.8		7.1		8.15		7.8					

TABLE 10.2

BACTERIOLOGICAL ANALYSES OF WATER SAMPLES
FROM MOCHUDI AREA
Analyses by Veterinary Diagnostic Laboratory, Gaberone

Borehole Number	Sample Point Description	Date	Presumptive Coliform Count/100 ml	Faecal Coliform Count
35	1. Standpipe, heated 2. Reservoir inlet 3. Standpipe, unheated	4/74 8/74 8/74	2 Nil 10	2 Nil Nil
789	Reservoir inlet	4/74	Nil	Nil
1162	1. Standpipe 2. End of discharge pipe during pumping test	4/74 7/74	Nil Nil	Nil Nil
850	1. Lorry filler pipe, unheated 2.	4/74		
1668	End of discharge pipe during pumping test	7/74	2	Nil
2108	1. Garden standpipe at school 2. Air trap	4/74 8/74	40 Nil	35 Nil
1018	1. Air trap	4/74	11	5
1497	Air trap	4/74	Nil	[illegible]
1494	Air trap	4/74	Nil	Nil
792	1. Open Reservoir 2. Air trap	4/74 9/74	8 Nil	8 Nil
216	1. Reservoir outlet 2. Reservoir inlet 3. Reservoir	4/74 9/74 9/74	20 Nil 8	20 Nil 1

TABLE 10.2 (Contd)

(A)		9/74		
(B)		9/74		
(C)				
(E)				
	Notwani River near BH 1668	4/74	180 +	180 +
	Spring near BH 38	4/74	180 +	180 +
	Spring near DRC Mission	4/74	4	4

TABLE (11.2)

COMPARISON OF RAINFALL AND WATER LEVEL

FLUCTUATIONS AT MOCHUDI

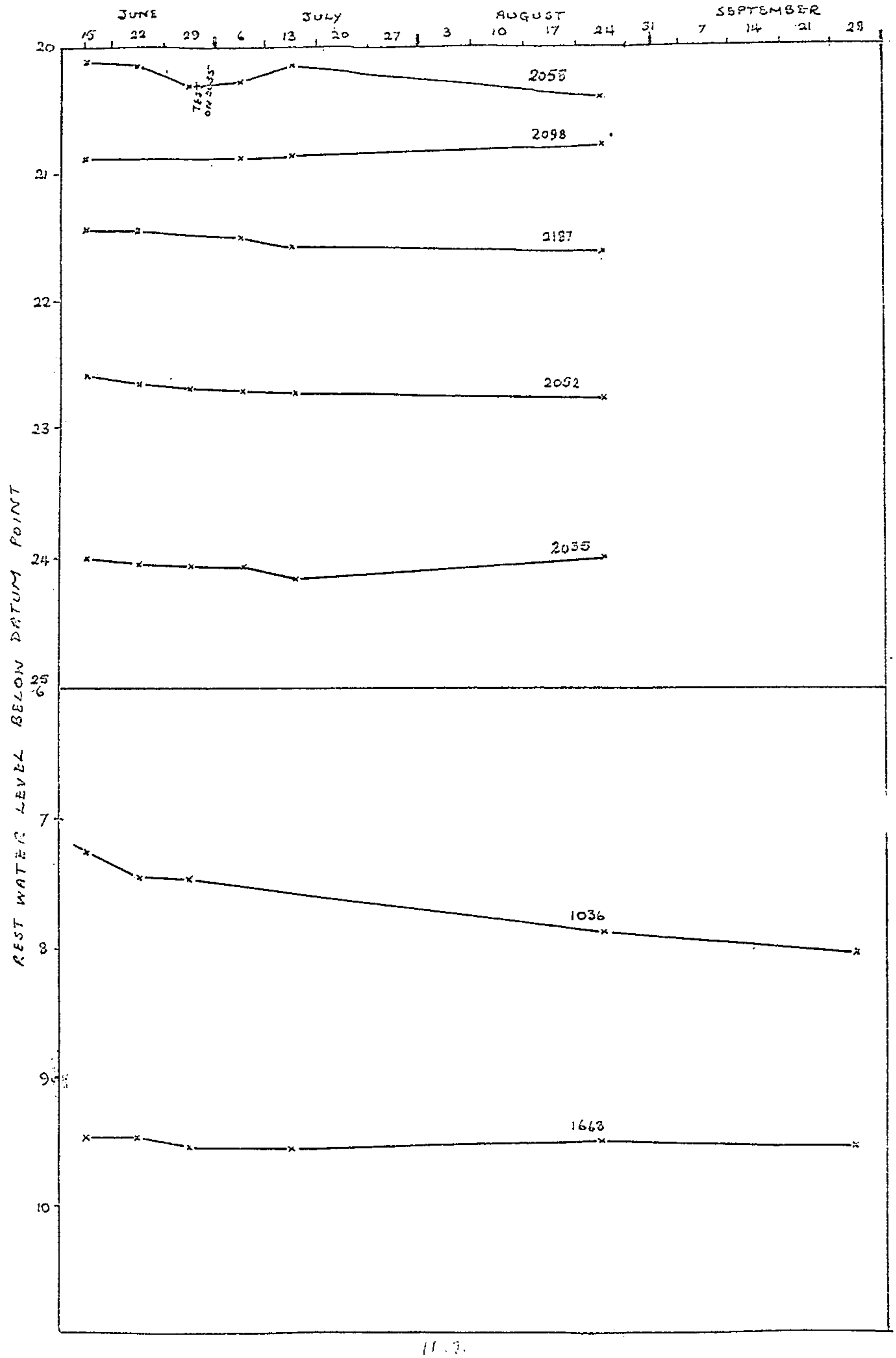
BOREHOLE	REST WATER LEVEL AT DATE OF CONSTRUCTION		REST WATER LEVEL IN 1974		DIFFERENCE	*RAINFALL FOR YEAR PRECEEDING READING	
	m	date	m	date	m	mm	
1668	22.25	8/64	9.5	7-8/74	+ 12.75	301	24
2098	21.03	11/67	20.7	8/74	+ 0.33	852	
2052	22.25	6/67	22.7	8/74	0.45	852	
2035	25.6	6/67	24.0	8/74	+ 1.6	852	
2058	18.59	7/67	20.4	8/74	+ 1.81	852	
Z720	20.42	10/63	12.3	7/74	+ 8.12	301	[illegible]
1632	18.29	7/64	6.5	7/74	+ 11.8	339	32
850	14.33	6/57	9.1	6/74	+ 5.23	546	36
2187	25.3	9/68	21.6	6/74	+ 3.7	322	109

*Rainfall 1973-74,
724 mm

n.b. Dry spell 1961-1966 preceded by very wet year.

1967 had 810 mm rainfall

FIG. 11.2



11.2

GROUNDWATER FLUCTUATIONS ON SELECTED OBSERVATION BOREHOLES AT MOCHUDI, JUNE - SEPTEMBER 1974

APPENDIX A

PUMPING TEST DATA

Pumping test teports, including data summaries and relevant figures, are given for the pumping tests carried out on the selected existing boreholes. These are numbered as follows:

Molepolole:	1,	Camp
	2,	Ntloedibe
	3,	2126/2127
	(4)	(2)
	(5)	(3)
Mochudi:	6	1162
	(7)	(B)
	8	850
	9	2035
	10	38
	11	1668
	(12)	(A)
	(13)	(E)

Only data summaries and time-drawdown graphs are presented for those sites shown in parentheses.

PUMPING TEST REPORT 1

CAMP BOREHOLE, MOLEPOLOLE

A borehole situated just west of the main road west of the District Commissioner's office has no known official number and is usually referred to as the Camp borehole. Some 33 m downslope and to the west is a disused borehole which was used as an observation site during the pumping test. No construction or drilling details are available for either borehole, except that both are of 150 mm diameter and the Camp borehole is 73 m deep.

The Camp borehole is one of five boreholes which provide the main Molepolole water supply. It is reported to pump for 8 hrs per day, and, from the pump size and water levels taken on shutdown on the 6 June at the observation borehole, the present pumping rate is about 50 litres per minute. The aquifer is probably Upper Waterberg sandstones and mudstones.

From verbal reports (District Officer) the anticipated yield was 150 litres/ minute and the test was planned on this basis. A variable rate test commenced on the 24 July with three stages: the first two for 150 minutes each, at 45.8 and 90.6 litres per minute respectively, and the third for a further 996 mins at 142 litres per minute. Ingress of dirt or overheating caused the pump to stop after a total of 1296 minutes pumping. Water levels were measured at both the pumping and observation boreholes throughout the test. The rest water levels were 14.96 m and 13.98 m below datum point respectively.

Uncorrected water levels below each measuring point are plotted against time as shown in Figure A.1.1. These data were extrapolated to determine the drawdown after 24 hrs pumping at each rate: 5.75 m, 13.09 m and 23.94 m respectively for the pumping borehole. These levels were plotted against the respective yield to construct a yield-drawdown curve. Although de-watering was not apparent, specific capacities dropped from 7.97 to 6.92 to 5.93 litres per minute per metre, which may suggest increasing well losses in proportion to the increase in yield. From this curve a yield of 140 litres per minute could be sustained. However, as the existing pump was set at 45 m below the surface (and possibly against the main supply) the available drawdown may be 30 m and, allowing for a margin of 3 m, the potential yield could then be 150 litres per minute. This pre-supposes a definite water bearing horizon below which yields may sharply decrease.

Lateral and normal subsurface resistivity logs were carried out by a simple sonde. These suggest that a change in lithology occurs at 37 m below the rest water level, but no definite water bearing horizon is indicated. However, from 37 m a more arenaceous lithology may be suggested and which would probably be the main water bearing horizon. This being the case, a breakaway curve could be postulated at a yield of about 190 litres per minute and a pumping water level of 52 m below casing top. The decrease in specific capacity from the test results could therefore imply dewatering, and thus increased aquifer losses, of the upper part of the mudstone and sandstone sequence at less than 52 m below casing top.

Drawdown data was used to calculate the borehole efficiency and drawdown losses. Jacobs method gave a well-loss constant (C) that increased from 4295 to 4642 sec^2/ft^5 and that well losses accounted for 41% of the total drawdown for step 3. A graphical solution, Fig A.1.3 (after Bruin and Hudson) gave C as 5400 sec^2/ft^5 and efficiencies that dropped from 70% to 52% by step 3; and well losses that increased from 21% to 48%. Aquifer losses from 13.2 ft to 41 ft and other losses, such as partial penetration, accounted for about 1.73 ft for steps 1 and 2 but only 0.33 ft for stage 3. A distance drawdown plot (Fig A.1.2) gave similar efficiency values to those above: 80% (step 1) to 50% (step 3).

Aquifer parameters were calculated from the time drawdown plot, transmissivity (T) was calculated as 19 m^2/d and storage co-efficient (S) as 4×10^{-6}.

The extent of the cone of depression (the distance at which s = o) is shown at t = 600 and t = 1440 mins in Fig A.1.2. At the third rate this had extended to 2800 metres.

Although residual drawdown data was plotted this was found to be inaccurately recorded. The original rest water level was attained after about 24 hrs after cessation of pumping.

TIME-DRAWDOWN DATA SUMMARY FOR WELL PRODUCTION TEST ON CAMP BOREHOLE

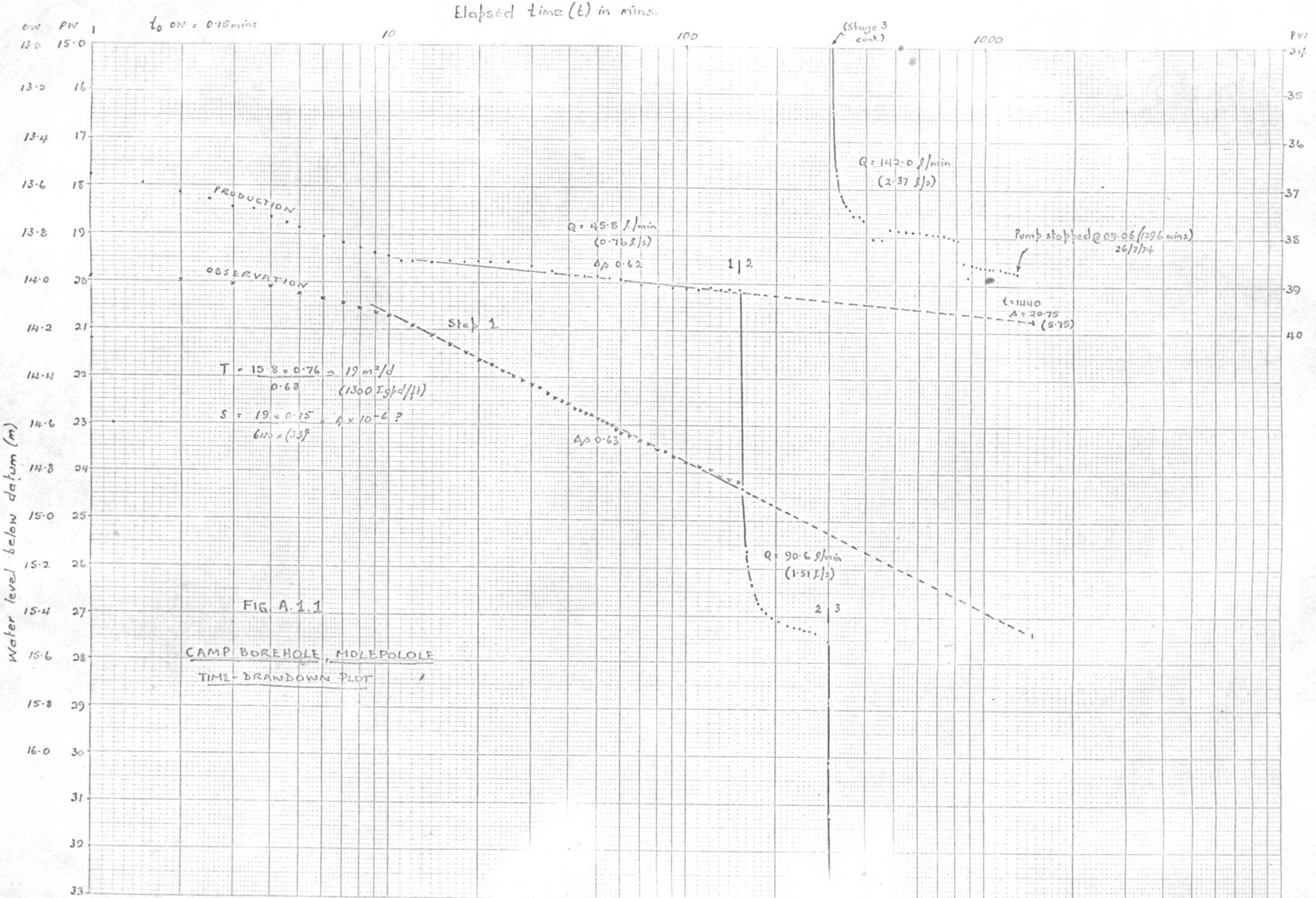
Date of Test: 25th & 26th July, 1974. Datum Point: Casing top, 0.23 m above ground level

Rest water level immediately prior to test: 14.97 m below casing top.

PRODUCTION				OBSERVATION			
Elapsed time since pumping commenced mins	Pumping water level below casing top, m	Elapsed time	Pumping water level	Elapsed time	Water level casing top, m	Elapsed time	Water level
1	17.79	230	27.22	1	13.97	260	15.75
2	18.125	240	27.245	2	13.99	270	15.78
3	18.42	250	27.29	3	14.015	280	15.825
4	18.66	270	27.323	4	14.02	290	15.845
5	18.865	290	27.595	5	14.045	300	-
9	19.365	300	-	8	14.105	301	15.86
10	19.43	301	28.75	10	14.14	302	15.865
12	19.515	302	30.11	12	14.185	303	15.865
16	19.545	303	31.295	16	14.26	304	15.878
20	19.56	304	32.395	20	14.325	305	15.88
25	19.585	305	33.25	26	14.396	308	15.925
30	19.645	309	35.110	30	14.435	310	15.972
40	19.83	310	35.365	40	14.51	312	16.015
50	19.86	312	35.83	50	14.575	320	16.195
60	19.915	316	36.385	60	14.634	330	16.37
70	20.035	320	36.70	70	14.667	340	16.505
80	20.09	325	36.945	80	14.704	350	16.605
90	20.09	330	37.15	100	14.755	360	16.705
100	20.08	340	37.35	120	14.787	390	16.86
120	20.09	350	37.465	150	-	460	17.135
140	20.115	360	37.59	151	14.84	580	17.365
150	-	390	37.63	152	14.845	700	17.51
151	20.87	420	38.045	153	14.85	820	17.725
152	21.95	480	37.85	154	14.852	940	17.785
153	22.975	540	37.87	155	14.859	1060	17.875
154	23.745	600	37.90	158	14.894	1180	17.98
155	24.315	660	37.945	160	14.94		
159	25.49	720	37.956	162	14.985		
160	25.67	780	38.045	170	15.135		
162	25.935	840	38.57	176	15.224		
166	26.345	900	38.59	180	15.285		
170	26.565	960	38.615	190	15.405		
175	26.755	1020	38.635	200	15.49		
180	26.87	1110	38.64	210	15.55		
190	27.025	1200	38.70	220	15.60		
200	27.07	1296	Pump stopped	230	15.64		
210	27.135			240	15.68		
220	27.19			250	15.725		

Graph Data Ref. 5541

Log 4 Cycles x mm, ½ and 1 cm



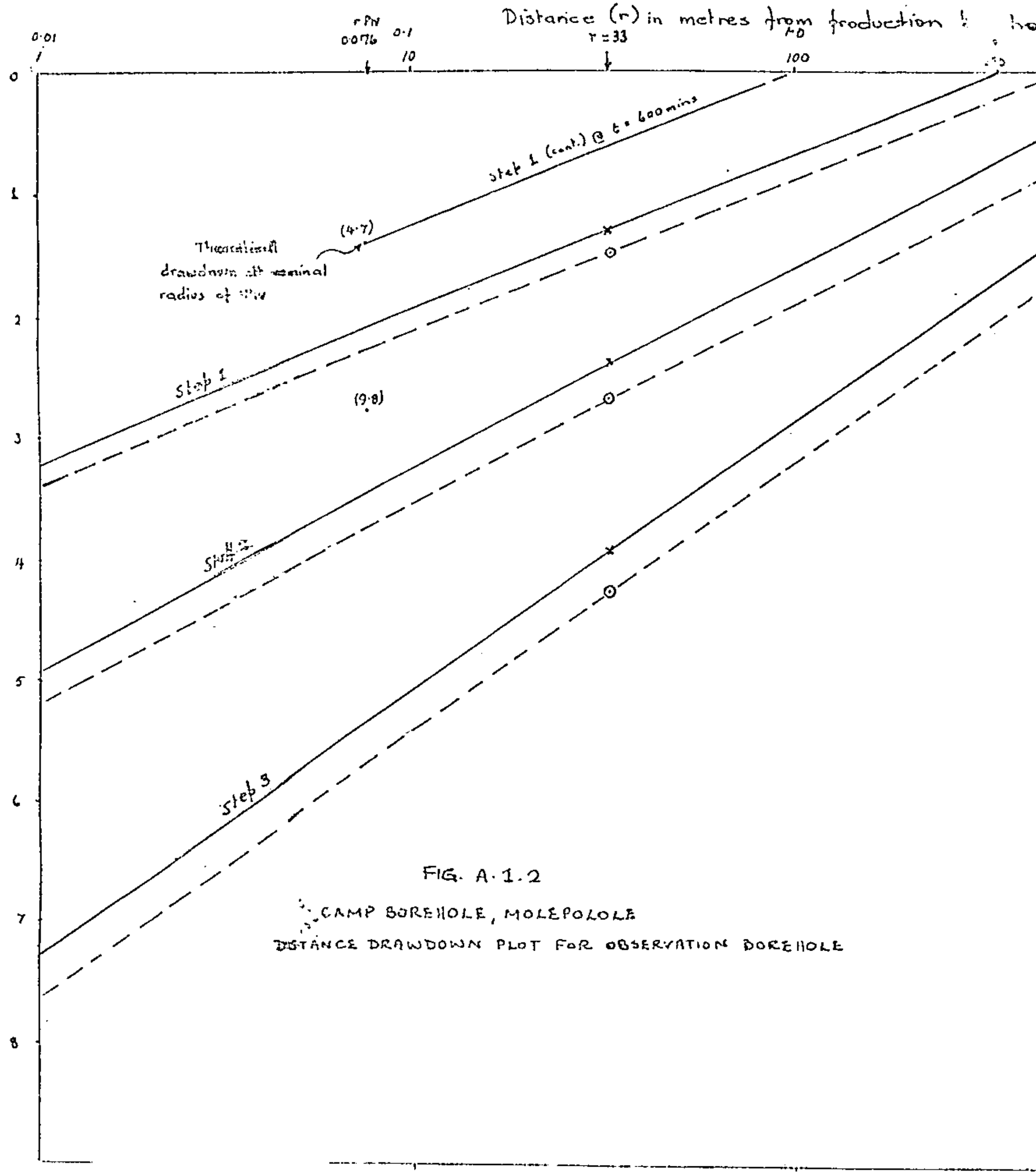


FIG. A.1.2

CAMP BOREHOLE, MOLEPOLOLE

DISTANCE DRAWDOWN PLOT FOR OBSERVATION BOREHOLE

Step	Q l/min.	Δs @ t=600	Δs @ t=1440	Δs t-d plot	Δs d-d plot
1	45.8	1.20	1.49	0.63	1.26
2	90.57	2.39	2.70	0.84	1.68
3	142	3.92	4.26	1.11	2.22

For Step 1: Theoretical drawdown at PW = 4.7m

Actual " " " = 5.75m

$$\text{Efficiency} = \frac{\Delta \text{theor.}}{\Delta \text{actual}} \times 100 = \frac{4.7}{5.75} \times 100 \simeq 80\%$$

For Step 3: Theoretical drawdown at PW 9.8m

Actual 23.94m

$$E = \frac{9.8}{23.94} \times 100 \simeq 50\%$$

$$S = \frac{Tt}{640 r^2} \quad \text{for Step 1} \quad S = \frac{19 \times 600}{640 \times (330)^2} = 1.6 \times 10^{-4}$$