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SODA ASH BOTSWANA (PTY) LTD

SUA SODA ASH PROJECT

Phase III Investigations

Memorandum No.14

BRINE RESOURCE DEFINITION

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CONTENTS

1. SYNOPSIS

The resource is defined in broad terms as comprising a volume of 15 x 10^9 m^3 of brine held in the saturated pore space of sediments to a depth of 30m over an area of 880 km^2.

This broad definition is developed in the light of the three phase investigation programme undertaken from July 1982 to December 1984.

The findings of the Phase I and Phase II investigations (July to April 1983 and May to October 1983 respectively) are reviewed and the Phase III studies (November 1983 to December 1984) are described in detail.

The results of the investigation programme are utilised to derive resource parameters for use in wellfield design.

The assessment of the recharge process reported upon in Memorandum No.11, dated September 1984, is developed with particular emphasis on the question of long term decline in the quality of the pumped brine as a result of dilution by recharge.

Laboratory simulation work is described leading to the postulation of upper and lower bound cases applicable to the problem.

An analytical approach is also described for use in conjunction with the upper and lower bound concept as a basis for assessment of long term brine concentrations after sustained abstraction.

The brine resource is described as a complex hydraulic system of horizontally laminated aquifer, aquitard and aquiclude layers. Since the design process will necessarily be based on conceptual modelling using estimated regional parameters, it is acknowledged that conditions will vary widely over the wellfield area from those predicted by the model.

These findings call for a flexible approach to wellfield development with progressive adjustment and optimisation based on continuous monitoring of production well performance.

2. OBJECTIVE

The investigations undertaken between July 1982 and October 1983 provided data on the transmissivity of the Sua Pan aquifer which established beyond doubt that a wellfield about 200 km^2 in area would yield a continuous flow of 950 l/s in the short term.

However, it was also concluded that the long term performance of the wellfield would largely depend on a sufficient quantity of brine being drawn from the aquitard layers into the aquifer horizons by vertical leakage. Computer modelling had indicated that an aquitard specific yield of the order of 0.1 would be required to ensure long term viability of the wellfield assuming zero recharge.

No conclusions could be drawn from the data available at the end of the Phase II investigations (October 1983) as to the specific yield of the aquitard and the problem of recharge to the brine resource had not been addressed. Furthermore only tentative conclusions had been reached concerning the process of leakage from the aquitard horizons.

It was acknowledged that further investigations were required to make good these deficiencies in the understanding of long term behaviour.

The Phase III investigations undertaken from November 1983 to date were therefore aimed primarily at improved definition of the parameters governing aquitard storage, leakage and recharge.

These aims have now been met and the objective of this report is to provide a firm definition of the brine resource in terms of parameters which may be carried forward for use in wellfield design.

3. THE BRINE RESOURCE

At the outset (in July 1982) it was agreed in discussion with S.A.B. that detailed investigations would be confined to the northern area of the Sua Pan covered by the Prospecting Licenses 9/81 and 10/81 held by B.P. Botswana as shown on Fig.1.

It was acknowledged that in all probability substantial brine resources occurred outside this area in the Sua Pan to the south of the Sua Spit and also in the Ntwetwe Pan to the west. However, by limiting the areal extent of the investigations maximum use could be made of earlier work carried out by others which had suggested that the northern area of the Sua Pan alone could sustain the anticipated needs of the process plant for production of 300 000 t.p.a. of soda ash over a period of 25 years or more.

The areal extent of the Sua Pan to the north of the Spit is approximately 880 km^2 according to the 1 : 50 000 orthophoto mapping.

The average depth of the unconsolidated sediments over this area as indicated by the Phase II miniwell results is 55m. However, the exploratory holes and test wells put down in Phases I and II indicated that the sediments at depths in excess of 30m were largely cemented by calcium carbonate and hence of low transmissivity.

The total volume of unconsolidated sediments available for brine extraction is therefore estimated as $880 \times 10^6 \times 30 = 26.4 \times 10^9\ m^3$. The brine table occurs at an average depth of approximately 1.5m below the Pan surface, indicating a volume of $25 \times 10^9\ m^3$ of unconsolidated sediments saturated with brine to 30m depth.

The in-situ porosity of the sediments has been estimated from laboratory tests carried out on Shelby samples recovered from sites W1, W2 and W3 and from test pits put down during the Phase I investigations. Since the Shelby tube sampling technique leads to some consolidation of the samples and precludes recovery of loose granular soils in their in-situ condition, the indicated porosity values are low on average relative to those occurring in the undisturbed in-situ soils.

The porosity values derived from the Shelby sampling are shown on Fig.2. They vary from 0.27 to 0.845 with an average value of 0.537 over the full depth of the holes. Over the upper 30m of the sediments an average porosity value of 0.60 is indicated based on 48 samples.

Hence the resource may be considered to comprise a volume of 15×10^9 m^3 of brine held in the saturated pore space of sediments to 30m depth over an area of 880 km^2.

4. BRINE DEMAND

The current estimate of long term brine demand advised by S.A.B. is 660 l/s pumped over 10 months of each year. This represents a total volume of 450 x 10^6 m^3 of brine pumped continuously over a period of 25 years, amounting to 3% of the brine resource as defined under Section 3 above.

It is evident that the brine resource exceeds the total demand over 25 years by a factor of about 30.

It is therefore necessary to establish that more than one-thirtieth of the stored brine is economically recoverable and the remainder of this Report seeks to define wellfield design parameters which will determine whether or not this requirement can be met.

5. EARLIER INVESTIGATIONS

Investigations into the brine resources of Sua Pan have been undertaken by WLPU Botswana in three phases:

Phase I	July 1982 to April 1983
Phase II	May 1983 to October 1983
Phase III	November 1983 to December 1984

The Phase I and Phase II investigations are summarised in Sections 5.1 and 5.2 of this Report. Investigations and results of the work undertaken in Phase III are reported upon in Section 6.

For convenience, a list of reports issued to date on wellfield investigations is given in Appendix A.

5.1 Phase I Investigations: July 1982 to April 1983

The Phase I investigations were limited by budgetary constraints and the fact that the studies were to be undertaken during the wet season.

Continuously cored exploratory holes were put down at each of sites W1, W2 and W3 which were located at the end of Sua Spit, at the north-western edge and at the western edge of the Pan respectively. Each hole was logged and undisturbed Shelby tube samples were obtained, which were used for laboratory testing. Test wells were installed at W1 and W2.

At W1, the well depth was 51m. Johnson 200mm stainless steel wire wound screens were set to maximise yield in the upper laminated clayey/sandy silt sequence from 3 to 30m depth and in the silty sand sequence extending from 30 to 51m depth. A sand filter pack was used around the screen. High transmissivities were recorded at W1,although it was unclear because of the screening arrangement which horizons were supplying brine to the well.

Test well W2 was drilled to 76m with the lower 39m screened. The screens were 200mm Johnson wire wound, of galvanised steel, and with a filter pack similar to that used at W1. A very low transmissivity was recorded here which was attributed to the sediments being cemented at this site, giving a low effective porosity. This was contrary to the findings of earlier investigations which suggested that the most productive aquifer horizons would be encountered below 30m depth.

A comparison was then made of results from W1 and W2 with the logs of holes drilled during earlier investigations. This gave an indication that the heavily cemented deposits were largely confined to the northern part of the Pan.

Also during the Phase I investigations, two 300mm diameter wells, designated SP2 and SP3, were installed close to the pilot ponds to provide a supply of brine for evaporation trials. The wells used stainless steel wire wound Johnson screens with a sand filter pack and were 400m apart. Extended pumping caused no interference between the two wells, which confirmed the interpretation at W1 that the laminated strata overlying the aquifer provided significant recharge by vertical leakage.

5.2 Phase II Investigations: May to October 1983

During the dry season of 1983, the Phase II investigations were undertaken with the following objectives:

To determine the extent of the unconsolidated deposits from which significant yields could be expected.

ii) To establish the parameters governing aquifer behaviour.

With a view to pursuing objective (i), twelve "miniwells", designated M1 to M12, were installed on an approximate 4 km grid in the area lying generally between the Phase I wells W1 and W2. Each miniwell comprised a 125mm O.D. PVC pipe drilled with 20mm dia. holes to give a 10% open area and wrapped in geofabric. Initially a non-woven geofabric (Bidim) was used, but after difficulties were experienced with clogging, this was substituted by mosquito netting. Pump testing was undertaken at each well followed by subsequent monitoring of the brine level recovery, from which estimates were made of transmissivity.

At miniwell sites M3, M5 and M10, twinwells were also installed. These comprised a shallow well drilled to a depth of 25m, and a deep well of 50m depth located at a distance of 10m. Each well used a different commercially available screen, to facilitate comparison of the respective screen efficiencies, surrounded by a sand filter pack similar in grading to that used at well W1.

Analysis of the results of pump testing of the twinwells showed that draw-downs were large at low flow rates. The conclusion reached was that the major source of brine was located at shallower depths than had previously been foreseen. Thus the screens had not intercepted the major inflow horizons and high losses had been experienced as brine had travelled vertically through the filter pack in the annulus. As a result it was difficult to compare the relative efficiencies of the different screens used in the twinwells.

The miniwells and twinwells had demonstrated that potential well yields were as high as previously anticipated and it was decided to install and pump test larger capacity wells, designated 'maxiwells'. Pairs of maxiwells were installed adjacent to miniwells M5 and M10, which recorded the highest transmissivities: MX5B (drilled with brine), MX5M (drilled with mud), MX10B (brine) and MX10M (mud). The wells were drilled to a depth of approximately 60m and comprised 250mm dia. PVC pipe drilled with 20mm holes and wrapped in mosquito netting in the same manner as the miniwells. Initially, wells were installed without a gravel pack and high yields were recorded. Analysis of maxiwell pump testing further confirmed that the higher yielding aquifers were located at depths shallower than 30m.

Geophysical logging was carried out in miniwells M1 to M4 in order to assess the frequency and thickness of the aquifer horizons. Generally, the logging confirmed that fine grained deposits are predominant, interspersed with occasional sandy layers. Also, the sonic logs confirmed that the upper 25 - 30m of deposits are soft, whilst material below this depth is of higher in-situ density. These findings were entirely consistent with the results of laboratory testing carried out in Phase I.

A preliminary computer model was established as part of the Phase II investigations in order to assess the sensitivity of the yield to variations in aquifer and aquitard characteristics, and to assist prediction of viable long term abstraction rates. Whereas it was shown that behaviour of the aquifer in the short term was reasonably understood, further data on aquitard specific yield and leakiness were required before long term performance could be predicted with confidence.

It was acknowledged that recharge from direct precipitation and river inflows might play an important part in governing the long term behaviour of the resource under sustained abstraction. However, in view of the anticipated difficulty in quantifying this effect, the aim in Phases I and II had been to establish the long term viability of the resource assuming zero recharge.

By the end of Phase II work it became apparent that the problem of quantifying recharge would have to be addressed.

6. PHASE III RESOURCE STUDIES (1984)

The objectives of the Phase III investigations were defined in the Report on Phase II Investigations issued in November 1983 and are summarised as follows:

To establish design values for leakiness and specific yield.

ii) To extend data on transmissivities to the south and east of the area explored by the Phase II miniwell programme.

iii) To establish whether or not recharge will have a significant effect on the long term performance of the aquifer, and, if so, to assess the order of magnitude of this effect.

iv) To investigate further the 'maxiwell' concept as a basis for the design of low cost production wells.

Items (i), (ii) and (iii) are discussed within this Memorandum. Item (iv) is reported upon separately in Memorandum No.15 which covers Wellfield Design.

6.1 Test Well Programme

To meet the objectives summarised above, a programme for installation of 12 maxiwells, 12 monitoring wells and 2 miniwells was compiled. This programme represented an expansion of earlier proposals, essentially to take advantage of the establishment on site of the ASTE Rotamec rig, although it was appreciated that the programme was ambitious if the work was to be completed by the end of August 1984, as scheduled.

The proposed drilling programme was described in Memorandum No.5 dated May 1984 and specific objectives for drilling and pump testing of the wells were defined as follows:

a) Areal Transmissivity Exploration: Wells MX17, 20, 21, 22 and 23.

b) Well Design Trials: Wells MX12, 14, 18 and 19.

Leakiness Investigation: Well MX15 with 4 monitoring wells, each of 30m depth.

d) Specific Yield Investigations: Wells MX13 and MX 16, each with 4 monitoring wells of about 15m depth. At each specific yield site, a 30m deep miniwell was proposed, to obtain an initial uphole velocity profile.

From the previous investigations it was recognised that the long term viability of the project was dependent on aquifer and aquitard specific yield, and on vertical permeability of the aquitard necessary to give replenishment of the aquifer during abstraction. Thus, in the knowledge that practical difficulties might prevent the full test well programme from being completed, priority was given to wells allocated for specific yield and leakiness investigations.

In the event, wells MX17 to MX23 inclusive were not drilled. Thus, whereas the specific yield and leakiness investigation wells were completed, transmissivity investigations were not extended to the southern area of the Pan nor to the Nata delta,and well design trials were not completed. Results and analyses of pump testing on wells MX12 to MX16 are discussed in succeeding sections of this Report and well locations are shown on Fig.3.

Investigations into recharge of the brine aquifer were carried out separately and recharge potential was examined in Memorandum No.11 dated September 1984. The question of recharge is discussed further in Section 9 of this Report.

6.1.1 Well Drilling and Pump Testing

The Phase III drilling and testing programme was curtailed, as a result of delays arising from drilling rig, test pump and engine breakdowns.

All wells were drilled by SAB using the ASTE Rotamec 1302 rig and pump testing was undertaken with diesel powered Mono pumps. Maxiwells were drilled to a diameter of 375mm, and 250mm diameter perforated PVC screen used with an open area of 10%, generally wrapped with polypropylene fabric mosquito netting. Gradings of the sand packs used were as recommended in Memorandum No.5. A review of the work completed is given below in the chronological order in which it was carried out over the period June to November 1984. The details of all Phase III pump testing are presented in Appendix B and the results are summarised on Fig.4.

Maxiwell MX14 (Drilled 24 May 1984)
The well was drilled to 31m and initially comprised a 250mm PVC screen wrapped in mosquito netting. The annulus was not sand packed. Test pumping here was hampered by siltation and blocking of the pump, necessitating repeated removal, cleaning and re-installation. Eventually the annulus caved to 10m and the inside of the screen silted up to an open depth of 19.2m. A section of 200mm Johnson screen was later inserted inside the existing PVC screen enabling a successful step drawdown test at 3.3/8.0/10 l/s followed by recovery monitoring to be undertaken during October.

Miniwell M14 had originally been installed to test the performance of a simple fabricated mild steel drill bit. However,during pumping of MX14 the response of this well was also monitored to give data on aquifer storage characteristics. The well was located 18m from MX14 and comprised 75mm slotted PVC screen with 1% open area, wrapped in mosquito netting and set to 30m. No sand packing was used. A constant rate test of some 600 minutes duration was carried out at 3.6 l/s as well as a step drawdown test at 5.6/1.0 l/s followed by recovery.

The difficulties experienced at MX14 were attributed to the lack of sand packing and it was concluded that filter packing would be required for the brine production wells, notwithstanding the fact that maxiwells had been successfully pumped in Phase II for long periods with a free-standing open annulus at MX5 and MX10.

Maxiwell MX13 (Drilled 23 June 1984)
At this site four monitoring wells were set to 30m, each with 75mm PVC screens. The inner monitoring well was put down by driving Shelby tubes to obtain continuous undisturbed samples which were later sent for laboratory testing. The well was then screened to 15m and packed with Type A sand.

During drilling of the maxiwell an aquifer horizon was identified from the cuttings logs at 7 to 12m depth. The well was drilled to 18m ending in aquitard, but partial caving occurred. However, a 250mm PVC screen wrapped in mosquito netting was satisfactorily set to 14.5m and the annulus was packed with Type A sand. A pump test of short duration was carried out at 10 l/s followed by recovery. Operations were then temporarily suspended due to mechanical problems and flooding of the Pan caused by unseasonal rainfall.

Upon resumption of testing a step drawdown test was undertaken at 9/17 l/s followed by monitoring of recovery. A constant rate test of some 4 000 minutes duration was then carried out at a flow of 13 l/s. On commencing the long term constant rate test it was discovered that failure of the well screens had occurred. However,this was remedied by setting a section of 200mm Johnson screen inside the existing screen to a depth of 11.1m. A further step drawdown test to determine head losses through this new screening arrangement was then carried out at 7.0/8.8/12.0 l/s. A long term constant rate test was then started at 10 l/s and was continued for 26 days.

Throughout the duration of this long term test continuous monitoring of the response of the brine table was made by Ott autographic float recorders set on the two inner monitoring wells.

Maxiwell MX12 (Drilled 29 July 1984)
This well was drilled to 30m, and a PVC screen installed triple wrapped with mosquito netting and sand packed with Type A sand. (Triple wrapping was used following the problems experienced with ingress of silt in MX14 and MX13).

Various mechanical problems with pumps and engines were experienced during pumping. However, a satisfactory testing programme was achieved. A step drawdown test at 8.5/9.3/11.7 l/s was followed by two constant rate tests at 4.5 l/s with subsequent monitoring of recovery and then a further test at 11.6 l/s.

Maxiwell MX15 (Drillled 5 August 1984)
A major aquifer horizon was identified from 25 to 36m by reference to the monitoring well cuttings logs and several hard formations of cemented sands and silcrete/chalcedony bands were encountered.

After drilling the maxiwell to 36m and on examination of the ground conditions it was considered likely that the hole would stay open without sand packing. A second maxiwell was therefore put down to facilitate a possible comparison of behaviour with and without a sand pack. The two maxiwells, MX15A and MX15B, were 5m apart. Both were equipped with 250mm diameter bored PVC screens. The screen on MX15B was wrapped in mosquito netting only and that on MX15A was wrapped firstly with a PVC 'Netlon' wrap having some 80% open area followed by mosquito netting on the outside.

The installation of two maxiwells obviated the requirement to drill a miniwell for monitoring purposes.

A step drawdown test was made at 10/12.5/21.7 l/s and followed by recovery. This high rate of pumping induced the annulus to cave to an open depth of 12m. Nevertheless a satisfactory constant rate test of 13 days duration was carried out at 23.5 l/s before being abandoned due to pump bearing failure.

Although no pumping trials could be made with gravel packs at the MX15A site, comparisons of head loss were possible for the two screening arrangements used. A step drawdown test was therefore made at MX15A at 10/15/21.7 l/s for comparison with that undertaken at MX15B.

Ott autographic recorders were set up on the two outer monitoring wells to augment manual dip readings. Dip measurements were also made in auger holes set 2m away from each monitoring well in order to compare response of the groundwater level in the aquitard with the phreatic surface in the aquifer, as recorded in the adjacent monitoring wells.

Maxiwell MX16 (Drilled 30 August 1984)

Four monitoring wells were set to 30m depth. Only the inner monitoring well was screened with 125mm perforated PVC screen. The remainder were free standing. None of the monitoring wells was sand packed. Examination of the cuttings logs from the monitoring wells, indicated a major aquifer horizon occurring from 12 to 24.5m depth.

The maxiwell was drilled to pass through this aquifer and ended in aquitard at 26m. 250mm PVC screen wrapped with both polypropylene and aluminium netting was inserted and the annulus was packed with Type B sand.

All four Ott recorders were set up over the monitoring wells and auger holes were put down adjacent to each monitoring well. Manual dip measurements were made at each monitoring well and auger hole throughout the pump testing programme.

A step drawdown test was carried out on MX16 at 7.0/13.3/17.4 l/s This was followed by monitoring of recovery. Two constant rate tests were then carried out; the first of 8 days duration at 17.1 l/s and the second of 30 hours duration at 20.0 l/s.

6.1.2 Velocity Profiles on Miniwells

Velocity profiling was undertaken in selected miniwells in order to identify the major inflow horizons (aquifers). A Braystoke vertical flow meter was progressively raised from the bottom of each hole during pumping at rates of 3.7 to 9.0 l/s using a "Homelite" suction lift pump.

Velocity readings were taken at 1.0m vertical intervals.

The results are presented in Figs.5 and 6. A profile was attempted at miniwell M1 but the drawdown after prolonged pumping of adjacent well W1 was too large to permit operation of the small suction pump required for velocity profiling. A profile was also attempted at M13 but the miniwell was found to have collapsed below 13m depth.

It is evident from the results of the velocity profiling that there is considerable variation over the Pan in aquifer depth and thickness. At miniwells M4, M9 and M11 a number of distinct aquifer horizons are indicated. Significant inflows were recorded at less than 20m below ground level at M2, M4, M7, M8, M9, M11 and M16.

In considering the location of inflow horizons on the plotted velocity profiles, it is necessary to take account of the depth to which the hole is cased above the well screen. A major inflow recorded close to the top of the screen is likely to reflect inflows at shallow depths which have passed vertically down the open annulus around the blank casing before entering the screen. This is illustrated by the profile obtained in M10 which was cased to 24m depth. During the Phase II investigations this maxiwell indicated a specific capacity of 3.6 l/s per metre of drawdown prior to packing. A pack was inserted but 'hung up' at about 35m depth. The top of the packed section was at about 16m depth. Subsequent pump testing indicated that the specific capacity had been reduced by a factor of 3,as a result of head losses arising from vertical flow through the pack from aquifer horizons above the top of the screen.

Inaccuracies also arise from the insensitivity of the propellor meter at low flows. The propellor can be slowed or even stopped by ingress of silt. Thus it is possible that inflows may be missed or that an apparent inflow can be registered as the meter frees itself of silt. Also, variations in velocity may be attributable to changes in hole diameter as a result of overbreak or caving.

Notwithstanding these sources of error, valuable results have been obtained using the velocity profiling technique, and reasonable correlation has been obtained with the geophysical logs where they are available.

6.1.3 Investigations Outside Main Exploration Area

At the request of S.A.B. a superficial appraisal has been carried out of areas lying beyond the boundaries of the main exploration area as defined in Section 3.

In October 1984 nine auger holes were put down on a 10 km grid to the south of the Sua Spit and in November five auger holes were sunk into the Ntwetwe Pan to the west. The approximate locations of these holes,together with brine table depths and specific gravity readings taken on samples recovered from them, are shown on Fig.7.

The auger holes generally indicate conditions similar to those prevailing at shallow depths in the main exploration area.

The specific gravities recorded on brine samples taken close to the mouth of the Mosetse (holes S3, S5 and S6) are low, reflecting recent recharge from river inflows.

On the basis of the limited investigations outlined above, there is no reason to suppose that the Ntwetwe Pan and the area to the south of the Sua Spit would prove any less productive, in the light of detailed investigations, than the principal exploration area.

6.2 Specific Yield Tests

By August 1984 it became apparent that the Phase III maxiwell pumping tests were unlikely to yield a design value for aquitard specific yield.

Despite prolonged pumping at high rates from relatively shallow wells (especially MX13, which had an effective depth of only 12.6m and was pumped for 24 days at 10.2 l/s) the pumping tests indicated confined aquifer storage coefficients throughout with no indication of aquifer dewatering.

It was therefore decided to attempt simulation of aquifer dewatering in the laboratory. Triaxial cell samples were cut from Shelby tube cores recovered from 3.4 to 4.0m and 7.5 to 8.1m depth in maxiwell MX13. According to the cuttings log, these samples were from an aquitard layer and an underlying aquifer layer supplying brine to the pumped well.

The samples were confined in triaxial cells at the Civilab laboratories in Johannesburg, under axial and radial confining pressures corresponding to the in-situ conditions at the depths from which the samples were recovered. The drain taps on the triaxial cells were then opened allowing brine to drain from the pore space of the samples under gravity. This process simulates the conditions arising from lowering of the piezometric surface during pumping.

The results of the tests are tabulated below:

	Aquitard	Aquifer
Sample No.:	E926	E930
Shelby Sample depth (m):	3.4 - 4.0	7.5 - 8.1
Axial Pressure (kPa):	69.6	146.6
Radial Pressure (kPa):	34.8	73.3
Drainage Time (hrs):	24	24
Sample Volume SV (ml):	65.3	61.0
Volume of Brine Released BV (ml):	3.8	3.5
Specific Yield $\frac{(BV)}{(SV)}$:	0.058	0.057

Hence, in each case, a specific yield value in excess of 5% is indicated.

This value is considered conservative for the following reasons:

a) The Shelby sampling technique causes consolidation of the recovered soil, tending to reduce the drainable pore space.

b) The Shelby tube will only satisfactorily recover the more cohesive soils with a relatively high fines content.

The aquifer horizons are known to include coarser soils, having a higher drainable pore space, of which the samples tested are not representative.

There are large inaccuracies implicit in extrapolation of small scale laboratory tests to the regional wellfield model. However, in the absence of regional data obtained from aquifer dewatering in the field, the laboratory results provide an indicative value of specific yield for use in the computer modelling.

7. AQUIFER PARAMETERS

The results of all investigations undertaken to date are utilised below in defining aquifer parameters for use in wellfield design.

7.1 Boundary Conditions

In Memorandum No.1, dated February 1984, the boundaries of the potential wellfield area were discussed, in the light of investigations carried out in Phase I and Phase II.

During the Phase III studies, further field investigations have been undertaken towards the west, north-east and south of the area previously defined, and consideration is given to this work in the review of the boundary locations which follows.

a) Western Boundary:
The auger holes put down on the Ntwetwe Pan, as described in Section 6.1.3 above, generally indicate similar conditions to those prevailing at shallow depth in the Sua Pan and there is no reason to suppose that the Ntwetwe Pan would not constitute a viable source of brine.

However, for the current studies we have conservatively assumed the western boundary of the brine resource as lying along the western shoreline of Sua Pan. This is consistent with our earlier assumptions,derived from a consideration of a boundary fault suggested by Bailleul (1979).

b) Eastern Boundary:
The best assessment of the eastern boundary of the resource remains the eastern shoreline of the Sua Pan. This boundary was suggested from consideration of low yielding freshwater test wells drilled to the east of the Pan during the Phase I and Phase II investigations.

c) Northern Boundary:
Borehole records for the area to the north of the Nata-Maun road indicate low yields and so the road remains the assumed northern boundary of the brine resource. The transmissivity data derived from wells MX12 to MX14 suggest that favourable conditions for brine abstraction are likely to exist towards the Nata delta.

d) Southern Boundary:

Nine auger holes were put down on a 10 km grid to the south of the Sua Spit in October 1984 as described in Section 6.1.3.

Further information was anticipated from the 3 wells programmed to the south of the Spit, but it has not proved possible to drill these for the reasons outlined earlier in this Report.

Although the auger holes indicate that the area to the south of the Spit is similar to the exploration area to the north it has been assumed conservatively that the southern boundary of the resource lies approximately 5 km south of the Spit.

The computer modelling has demonstrated that drawdowns will be localised around the wellfield area and so the choice of boundary locations will have little effect in the context of the initial wellfield.

However, the Ntwetwe Pan and the area to the south of Sua Spit may be regarded as potential resource areas for exploration in the long term.

7.2 Depth and Areal Extent

The velocity profiles have confirmed that the high yielding strata generally occur at less than 30m depth. The aquifer layers are typically interspersed with less permeable horizons such that yields may be obtained from a number of different strata at varying depths within a single well.

The major inflow horizons occur at between 7 and 30m depth. These findings are consistent with the geophysical logs. The average total aquifer thickness indicated by the velocity profiles is 8m, but the configuration varies significantly from site to site. A maximum aquifer thickness of 17m is indicated at M5. The average aquifer thickness taking account of the earlier work undertaken in Phases I and II is approximately 10m.

The resource is conservatively assumed to be bounded by the Pan shorelines to the west and east, by the Nata/Maun road to the north and by a line close to the Sua Spit to the south. The area within these boundaries is approximately 1 000 km^2 which is some 14% greater than the area used for the outline appraisal of the brine resource described in Section 3.

7.3 Transmissivity

Transmissivity is the product of the average horizontal permeability and the thickness of the aquifer. Drawdown at the well itself is primarily dependent upon transmissivity, particularly in the short term.

Data gathered on transmissivities during Phases I and II of the investigations cover the western part of the exploration area only. It was intended that the Phase III investigations would extend data on transmissivities to the south and east. Curtailment of the drilling programme precluded planned exploration in the vicinity of the Nata delta, and to the south of the Sua Spit. However, maxiwells MX12 to MX16, provided a valuable extension of the transmissivity data assembled from Phases I and II.

On Fig.3, the best estimates obtained by reviewing miniwell, twinwell and maxiwell results for each site have been plotted in order to aid an appreciation of the areal variation of transmissivity over the exploration area. Transmissivity values typically vary from 150 to 400m^2/day.

The value of transmissivity at test well W2 has been revised since the Phase I report was issued, as a result of retesting carried out after the screens had been raised to less than 30m depth. The screens were originally installed between 39 and 76m depth and pump testing had yielded very small flows. However, when it became clear that the aquifer was located above 30m the screens were raised, and the subsequent pump test yielded 10.5 l/s indicating a transmissivity of about 300m^2/day.

7.4 Storage Parameters

The brine resource generally comprises a sequence of aquifer and aquitard layers. Locally layers of exceptionally low vertical permeability constitute aquicludes giving rise to perched brine tables.

The aquitard layers are of low, though measurable permeability. They contain large quantities of brine but cannot release it by horizontal flow to wells. However,when a well is pumped, the piezometric head in the aquifer horizons is lowered, generating vertical flow from the adjacent aquitard layers. This behaviour is characteristic of semi-confined aquifers and leakage from the aquitard layers may equal pumping from the aquifer horizons in the long term.

Generally at Sua Pan, the near surface strata comprise aquitard horizons. The underlying aquifer layers are confined initially, although they may become unconfined with long term abstraction.

The volume of brine released from storage within the confined parts of the aquifer is governed by the storage coefficient or storativity, whereas that released from the unconfined regions is represented by specific yield. The storage coefficient depends on the elasticity of the aquifer material and the fluid. The specific yield may be considered as the drainable pore space; the effects of the elasticity and the fluid being negligible.

The value of the aquifer storage coefficient as calculated from pump testing during the Phase II investigations was found to vary in the range 0.0004 - 0.0015. Analysis of the Phase III pump testing has yielded storage co-efficients between 0.0001 and 0.0015 with a typical value of 0.0005.

Specific yield may be measured directly during pump testing once the aquifer has assumed an unconfined state. This was attempted at MX13, 15 and 16 by means of prolonged pumping at high rates from shallow wells. However,the required watertable conditions were not attained and the aquifer horizons at these sites indicated confined behaviour throughout.

As a result, specific yield values were not obtained directly during the pump testing, and the best available estimate of specific yield is 0.05, obtained from laboratory testing as described in Section 6.2.

It was,however,possible to check the laboratory value of specific yield from an interpretation of the computer modelling of aquifer and aquitard drawdowns recorded during pump testing of wells MX13 and MX15. Using drawdowns recorded at 50m and 200m radii in the computer model, together with estimated vertical permeability, values of aquitard specific yield were derived which gave reasonable agreement with that obtained from laboratory testing.

In the context of the Sua Pan brine resource, in which aquitard horizons predominate, the specific yield of the aquitard under vertical leakage is of great significance as it will control drawdown of the brine table.The aquifer horizons, being more coarsely graded, will tend to be of higher porosity and hence will tend to exhibit higher specific yield values if and when they reach an unconfined condition under long term pumping.

7.5 Leakage

The aquitard layers typically have permeabilities in the range 10^{-8} to 10^{-6} m/s according to Phase I laboratory testing. The average vertical permeability will tend towards the lowest value, compared with an aquifer permeability of 10^{-5} to 10^{-4} m/s.

Vertical leakage from aquitard horizons into the aquifer layers has the effect of reducing aquifer drawdowns. This effect is more pronounced with increasing radius from the well giving higher apparent transmissivities with increasing radius.

Walton* has developed a method of interpretation of pump test data for semi-confined aquifers, based on the Theis method of analysis using type curves, to give a measurement of the leakage factor, L. Using a curve fitting technique, a value for L can be derived directly from the appropriate $^r/L$ curve.

In the Phase I investigations, piezometer monitoring during the pump testing of well W1 suggested that the influence of leakage was small, with an L value of the order of 1 000m.

From the results of pumping tests undertaken on twinwells and maxiwells during Phase II investigations, there was evidence of vertical leakage from the aquitard reducing drawdowns remote from the well, but leakage could not be quantified with confidence. However,laboratory testing of cored samples from boreholes BH1/82, BH2/83 and BH3/83 suggested that the vertical aquitard permeability varied from 0.002 to 0.2 m/d, with a value of 0.02 m/d being typical.

The programme for the Phase III investigations provided for leakage data to be gathered during pump testing of MX13, MX15 and MX16, especially from long term testing undertaken at MX15. As a result of the re-programming necessitated by mechanical breakdowns, it was only possible to undertake a test of one week duration at MX15, although a longer term test was made at MX13 of 24 days duration.

* Walton, W.C. (1962). Selected Analytical Methods for Well and Aquifer Evaluation.

Taking account of the storage depletion in the aquitard, analysis of the Phase III testing indicated a leakage value of about 1 500m which corresponds to an aquitard vertical permeability of approximately 0.002 m/day or 2.3×10^{-8} m/s.

The computer modelling curves derived to estimate specific yield from pump test data were also used to give an approximate vertical permeability value. The value indicated was between 0.002 and 0.005 m/day, which gives good agreement with results obtained directly from the Phase III test data and earlier laboratory work.

Thus a vertical aquitard permeability of 0.002 m/day has been carried forward to the updated computer modelling of the wellfield.

8. BRINE QUALITY

It has been assumed for the purposes of brine resource exploration that the specific gravity of the in-situ brine provides an adequate index of quality in terms of the marketable dissolved salts, sodium chloride and sodium carbonate (common salt and soda ash respectively). It is understood from discussions with S.E.L. that a feed brine specific gravity of more than 1.100 is desirable for concentration by evaporation in the solar ponds to saturation in the marketable salts.

Specific gravity readings have been taken at the pump discharge from all test wells. In general the SG recorded after prolonged pumping differs little from that recorded on the initial discharge, suggesting relatively small variations in brine quality over the area of influence of the well.

The specific gravities recorded at all 15 test sites are shown on Fig.3, varying from 1.086 to 1.153 with an average value of 1.12.

9. RECHARGE

The process of recharge to the brine aquifer was reported upon in Memorandum No.11, dated September 1984.

The subsequent Phase III fieldwork and laboratory specific yield tests have confirmed that the high aquitard specific yields required to maintain long term vertical leakage in the absence of recharge cannot be relied upon in practice.

The Phase II computer modelling showed that an aquitard specific yield of at least 0.1 would be required whereas the best available estimate of specific yield based on laboratory tests and computer simulation is only about half of this figure. Hence, the recharge process assumes vital importance to the viability of the resource in the long term, not in terms of the volume of brine stored in the resource, but in order to maintain the hydraulic conditions necessary to sustain viable recovery rates.

The work described in Memorandum No.11 established that, in volumetric terms, recharge by direct precipitation on a wellfield area of 200 km^2 would more than compensate in average rainfall years for the volume of brine pumped from the wellfield.

It was acknowledged that,because the recharge enters the system at a specific gravity close to unity, there would be a progressive decrease in specific gravity by dilution of the brine entering the aquifer by vertical leakage.

The time scale of this process was examined and it was tentatively concluded that the system would sustain pumping at 25×10^6 m^3 per annum for 25 years without a significant decline in brine quality expressed in terms of specific gravity.

Further work on the question of brine quality in the long term has now been undertaken as described below.

9.1 Laboratory Testing

In order to gain an improved understanding of the leakage process, tests have been undertaken in the Ashford Laboratories of WLPU. The permeability of the Shelby tube samples recovered from the Pan is low, so that drainage under gravity is too slow to enable meaningful results to be obtained within the time available. In the Civilab tests, described in Memorandum No.11, this problem was addressed by passing distilled water through Shelby samples under pressure.

In the subsequent tests undertaken in Ashford more coarsely graded soils (locally available sands and mill tailings) were used to obtain a qualitative illustration of the process.

A set of four glass tanks, square in plan and with facilities for vertical drainage, were filled with soil deposited under brine to a depth of 240mm. The brine solution used was made up by dissolving sodium chloride and sodium carbonate in distilled water to give ionic concentrations comparable with the Sua brine at a specific gravity of approximately 1.11. The samples were initially saturated with this solution.

Distilled water was added to the first tank with the bottom drain tap open and the liquor emerging from the first sample was introduced to the top of the second. The liquor emerging from the second tank was then passed through the third and so on. This process was repeated with specific gravity monitoring on the effluent liquors from each tank until the specific gravity of the effluent from the fourth tank had declined essentially to 1.0.

The aim was to simulate vertical flow through the aquitard with the four tanks representing successive depth increments in the field.

The results are presented on Fig.8 for both the sand and mill tailings samples.

In terms of grading the sand is coarser and more uniform than the tailings and both materials are substantially more permeable than the typical Sua Pan soils.

The following important conclusions may be drawn from a comparison of the two sets of curves on Fig.8:

a) In the sand, a sharply defined "front" is evident between the distilled water and the underlying brine which it displaces. The curves suggest a simple volumetric displacement process with the specific gravity dropping sharply from 1.11 to 1.0 as the last of the brine is driven from the pore space in the sand.

b) In the tailings, the front is attenuated and the effluent brine specific gravity declines more slowly.The attenuation arises from physical mixing as a result of flow through capillaries of differing sizes at differing rates in the less uniform and finer soil and also from molecular diffusion at the interface between the distilled water and the brine. The diffusion process is time dependent and has more effect in the less permeable soil where the downward progress of the interface is slower.

Although the results of these tests are of little significance in quantitative terms, they enable the following upper and lower bound cases to be postulated for the downward progress of the recharge/in-situ brine interface at Sua Pan:

Upper Bound - Complete Mixing

The recharge process will have maximum effect on the specific gravity of brine entering an aquifer at depth if the recharge entering an overlying aquitard at SG 1.0 is immediately and intimately mixed with all of the brine stored in the aquitard pore space, causing a slow but continuous decline in specific gravity at any abstraction well fed by the aquifer.

Lower Bound - No Mixing

The recharge process will have minimum effect on the specific gravity of brine entering an aquifer at depth if the recharge simply displaces the underlying brine stored in the aquitard with no mixing at the interface. Under these conditions the brine pumped from an abstraction well will maintain full strength for a period dependent upon the aquitard thickness, before declining instantaneously to 1.0.

The situation at Sua Pan will lie somewhere between these upper and lower bounds. As the Pan soils are known to be of low permeability and variable grading it is certain that mixing will occur by the processes outlined above. However,the soils are known to be horizontally stratified and there will be a buoyancy effect arising from the lower specific gravity of the overlying fluid. Each of these factors will tend to limit the degree of mixing.

9.2 Theoretical Approach

The process of dilution of the brine resource at Sua Pan by the recharge process is analogous to a classical, one-dimensional solute disperion problem.

A uniform groundwater flow field in the x direction is considered, in which $\bar{V}_x$ is the average linear velocity. For time t less than or equal to zero, the solute concentration throughout the flow field is zero. For times greater than zero the concentration at $x = 0$ becomes a constant Co. These conditions would be applicable to the sudden dumping of a soluble polutant into an aquifer in which a steady state uniform flow is established in the x direction.

At Sua Pan similar conditions are applicable to vertical flow in the aquitard. The uniform flow takes place vertically (in the y direction), the "solute" is conceived as the recharge at Concentration zero (S.G. 1.0) and the "solvent" as the in-situ brine at concentration C_1. At the brine table elevation, y = 0 and the problem centres on the determination of the brine concentration C(y,t) at depth y in the aquitard after time t.

In mathematical terms the initial and boundary conditions of the problem are as follows:

Initially: $C(y,0) = C_1$ for all y

Boundary Conditions: $C(0,t) = 0$ for $t > 0$

$C(\infty,t) = C_1$ for $t > 0$

The analytical solution has been derived by Ogata and Banks (1961) and may be written, in the context of dilution under vertical flow in the aquitard, as follows:

$$C(y,t) = \frac{C_1}{2}\left\{\exp\left(\frac{\bar{V}_y y}{D_y}\right)\operatorname{erfc}\left(\frac{y+\bar{V}_y t}{2\sqrt{D_y t}}\right) + \operatorname{erfc}\left(\frac{y-\bar{V}_y t}{2\sqrt{D_y t}}\right)\right\}$$

Where Vy is the average flow velocity, Dy is the longitudinal component of the dispersion coefficient in the vertical direction and erfc(z) is the complementary error function.

In common with all standard analytical solutions of dispersion problems, the above equation assumes homogeneous isotropic conditions.

The dispersion coefficient is the product of dispersivity and velocity and its value is influenced by aquitard tortuosity (or mixing as a result of preferential flow paths and "dead end" pores) and by molecular diffusion.

In small scale tests the value of dispersivity tends to be lower than in the field where the regional situation may be governed by large scale discontinuities giving rise to preferential flow (for example vertical fissures).

A survey of the available literature (see Appendix C) suggests that for soils similar to those occurring at Sua Pan and for an aquiclude thickness of 10 to 20m it would be appropriate to adopt Dy values of 0.005 to 0.01 for isotropic homogeneous conditions.

A solution based on these values would tend to be conservative because conditions at Sua Pan differ from the idealised case in the following important respects:

a) The strata are horizontally laminated which will tend to inhibit vertical mixing except at local discontinuities.

b) The "solute" is of lower density than the "solvent". Hence mixing will be further inhibited by the buoyancy effect.

The brine concentrations C(y,t) derived from the analytical solution outlined above are expected to lie between the upper and lower bound cases postulated on the basis of the laboratory tests as described under Section 9.1.

10. CONCLUSIONS

On the basis of the three Phase programme of investigations undertaken on the Sua Pan brine resource from July 1982 to December 1984, aquifer design parameters have been derived and a conceptual understanding has been achieved of the process of recharge through the infiltration of direct precipitation.

It is concluded that definition of the brine resource has reached a stage at which outline wellfield design can proceed, using the parameters defined in Sections 7 and 8 of this Report, applied in conjunction with an appraisal of the recharge process based on the approach outlined in Section 9.

For ease of reference the principal parameters of the resource carried forward for use in wellfield design are summarised below:

Depth of laminated aquifer/aquitard sequence: 30m
Defined area of the exploitable resource: 1 000 km^2
Average total thickness of aquifer horizons: 10m
Average total thickness of aquitard horizons: 20m
Transmissivity: Typically in the range 150 to 400 m^2/d
Aquifer storage coefficient: 0.0005
Aquitard specific yield: 0.05
Aquitard Vertical Permeability: 0.002 m/d
Brine quality: Specific gravity in the range 1.09 to 1.15
(Average value 1.12)

The resource is known to comprise a complex hydraulic system of interbedded aquifer,aquitard and aquiclude layers and the design process will necessarily be based on conceptual modelling using estimated regional parameters. In practice it is acknowledged that conditions will vary widely over the wellfield area and that in some locations well performance may fall short of that predicted by the conceptual model whilst in others the model is likely to give a very conservative picture of well performance.

These conditions call for a flexible approach to wellfield development, with progressive adjustment and optimisation of the operation on the basis of monitoring of production well performance.

The findings of this Report are carried forward to Memorandum No.15 where they are used in the development of an outline wellfield design.

APPENDIX A

Schedule of WLPU Reports on Resource Investigations

APPENDIX A

SCHEDULE OF WLPU REPORTS ON RESOURCE INVESTIGATIONS

Report on Phase I Investigations (Vols 1 and 2), September 1983.

Report on Phase II Investigations, November 1983.

Memorandum on Phase III Investigations, January 1984.

Numbered Memoranda on Phase III Investigations:

No.1 Computer Modelling, February 1984

No.2 Aquifer Terminology and Interpretation of Pumping Tests, March 1984

No.5 Proposals for Wellfield Site Investigations, May 1984

No.6 Mineralogy of Pan Sediments, May 1984

No.10 Interim Report on Recharge, June 1984

No.11 Report on Recharge of the Brine Aquifer, September 1984

APPENDIX B

Results of Phase III Pump Testing

RESULTS OF PHASE III PUMP TESTING

Well No.	Date Tested	Test Type & Duration (mins)	Pumping Rate (l/s)	Drawdown (m)	Specific Capacity (l/s/m)	Transmissivity (m^2/d) Jacob	Transmissivity (m^2/d) Theis	Remarks
MX12	1-9-84	S 100	8.5	3.920	2.17			
	1-9-84	S 115	9.3	3.880	2.40			
	3-9-84	S 120	11.7	3.990	2.93			
	3-9-84	R 100	-				662.2	
	26-8-84	C 125	4.5	3.770				
	26-8-84	R 104	-				296.5	
	4-9-84	C 1 925	11.6	3.550	3.27			
MX13	7-7-84	C 120	10.0					MW13a, 13b, 13c and 13d monitored
	7-7-84	R 135	-				261.0	
	21-7-84	S 2 x 120	9.0	5.925	1.52			
		S	17.0	5.965	2.85			
	21-7-84	R 135	-				410.0	
	22-7-84	C 4 000	13.0	5.750	2.26	583 - 599	136 - 704	
	24-8-84	C 34 717	10.2	7.730	1.32	403 - 478	312 - 477	Storativity: 3×10^{-4}
	28-9-84	S	7.0	4.225	1.66	180.9		
		S 3 x 100	8.8	6.105	1.44			
		S	12.0	7.705	1.56			
	28-9-84	R 135	-				372.1	
MX14	4-10-84	S 100	3.3	1.497	2.20	326		M14 monitored throughout
		S 165	8.0	5.240	1.53	141 - 251	195.0	
		S	10.0	4.819	2.08			
	4-10-84	R 135	-			358		
M14	26-6-84	S 90	1.0	0.445	2.20			MX14 monitored throughout
		S 60	5.6	3.610	1.55		191.2-318.6	Storativity: 2×10^{-4}
	26-6-84	R 135	-				234.5	
	24-6-84	C 613	3.6	2.935	1.23	287.5-384.7	281.3	Storativity: 3×10^{-3}
MX15A	20-10-84	S	10.0	2.740	3.65			
		S 3 x 100	15.0	4.020	3.73			
		S	21.1	6.730	3.14			
MX15B	30-9-84	S 100	10.0	2.460	4.07	378.6		Storativity: 2.9×10^{-3}
		S 107	12.5	3.360	3.72			MX15A, MW15a and MW15b monitored
		S 1 100	21.7	8.080	2.69			
	30-9-84	R 100	-				457.3	
	4-10-84	C 18 697	23.5	9.590	2.45	129.8		MX15A, MW15a and MW15b monitored
MX16	21-10-84	S	7.0	4.163	1.68	186.7		MW16a, 16b, 16c and 16d monitored
		S 3 x 100	13.3	10.775	1.23			
		S	17.4	12.370	1.41			
	21-10-84	R 135	-				254	
	24-10-84	C 11 482	17.1	15.355	1.11	263 - 272	272 - 360	Storativity: 1.5×10^{-3}
	16-11-84	C 1 779	20.0	19.108	1.05	414 - 498		

Notes:
S: step (production)test with intervening recovery
C: constant rate test
R: recovery
Drawdown measured at elapsed time of about 100 mins.

APPENDIX C

References Relating to Solute Dispersion

APPENDIX C

REFERENCES RELATING TO SOLUTE DISPERSION

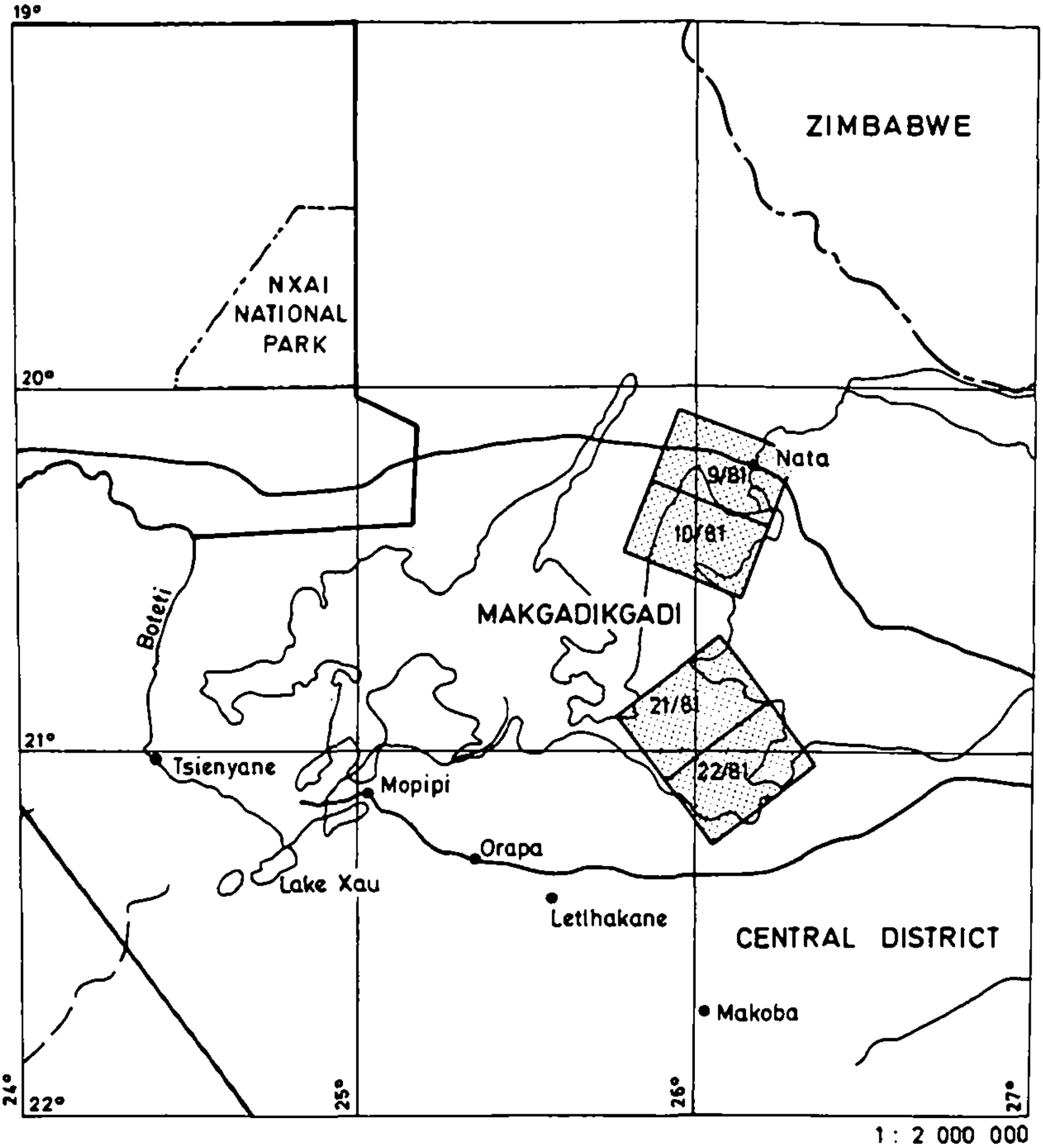
Herbert F. Wang and Mary P. Anderson. 1982. "Introduction to Groundwater Modelling - Finite Difference and Finite Element Methods".

Miguel A. Marino. January 1974. "Longitudinal Dispersion in Saturated Porous Media" - Journal of Hydraulics Division, Proceedings of A.S.C.E.

Hung Tao Shen. June 1976. "Transient Dispersion in Uniform Porous Media Flow" - Journal of Hydraulics Division, Proceedigs of A.S.C.E.

Uri Y. Shamir and Donald R.F. Harleman. "Numerical Solutions for Dispersion in Porous Mediums" - Water Resources Research, Vol.3, No.2, 2nd Quarter 1967

FIG. 1

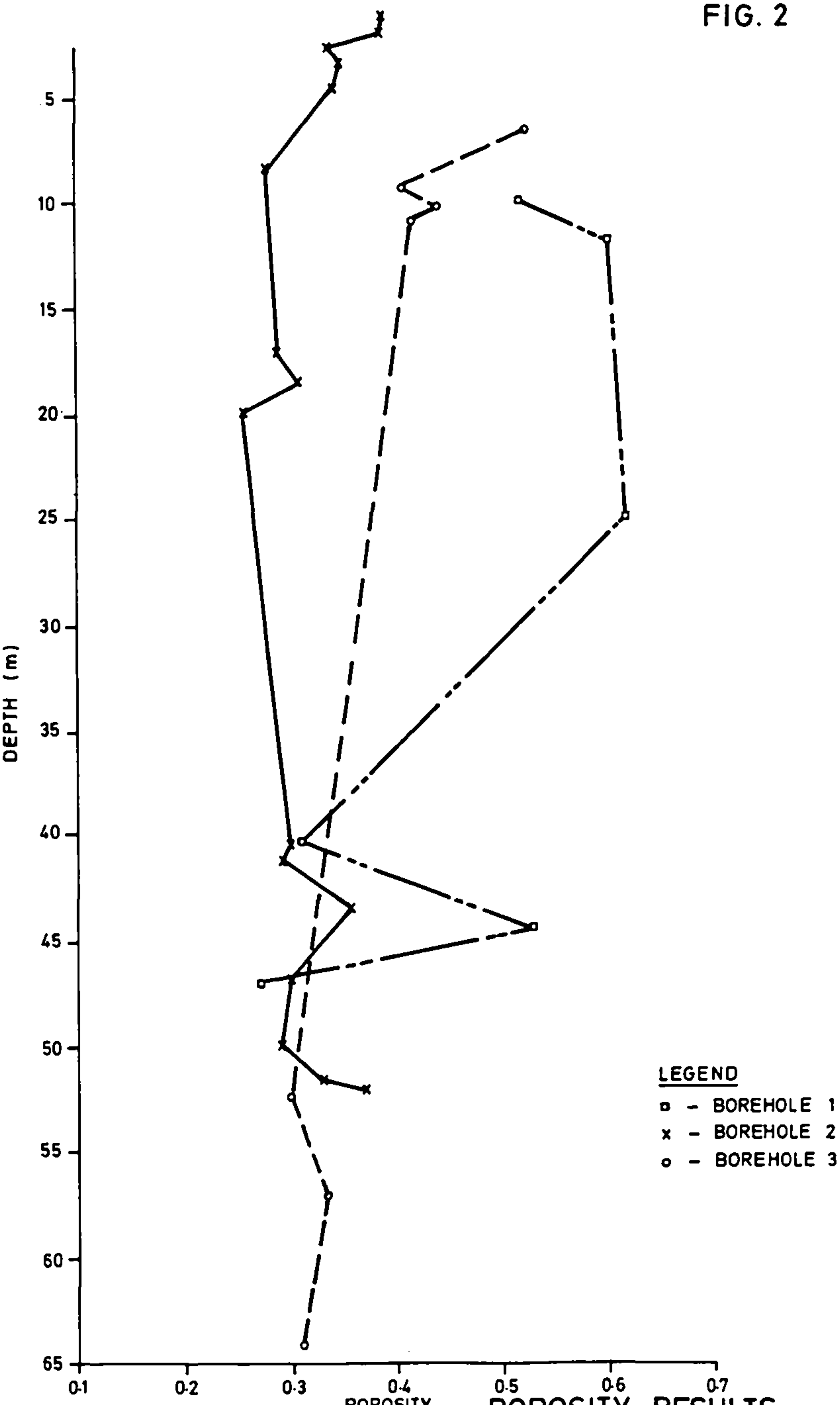


LEGEND

PROSPECTING LICENCE AREAS - B.P. BOTSWANA (PTY.) LTD.

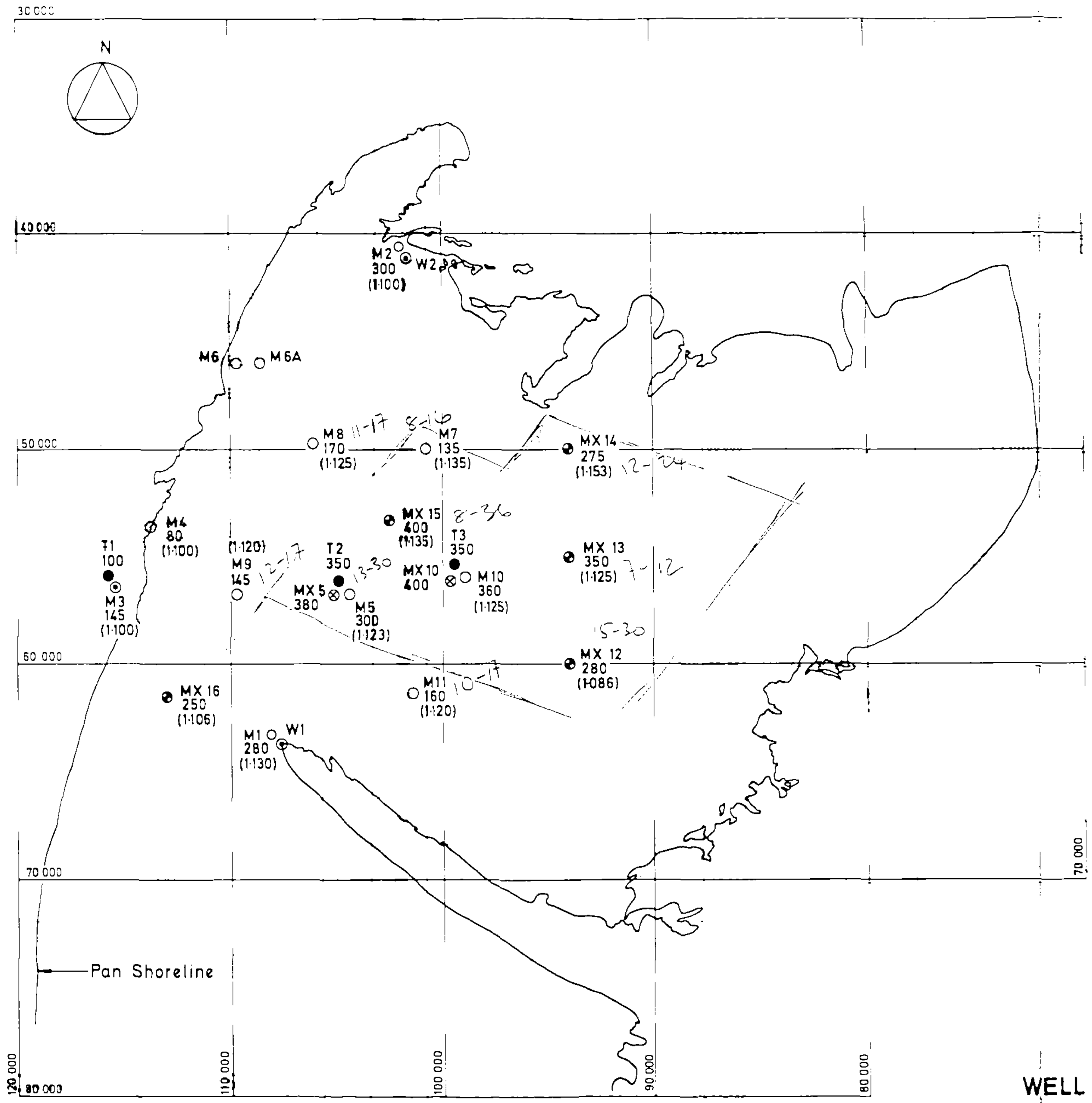
PROSPECTING LICENCES

FIG. 2



POROSITY RESULTS FROM BOREHOLE SAMPLES

FIG. 3

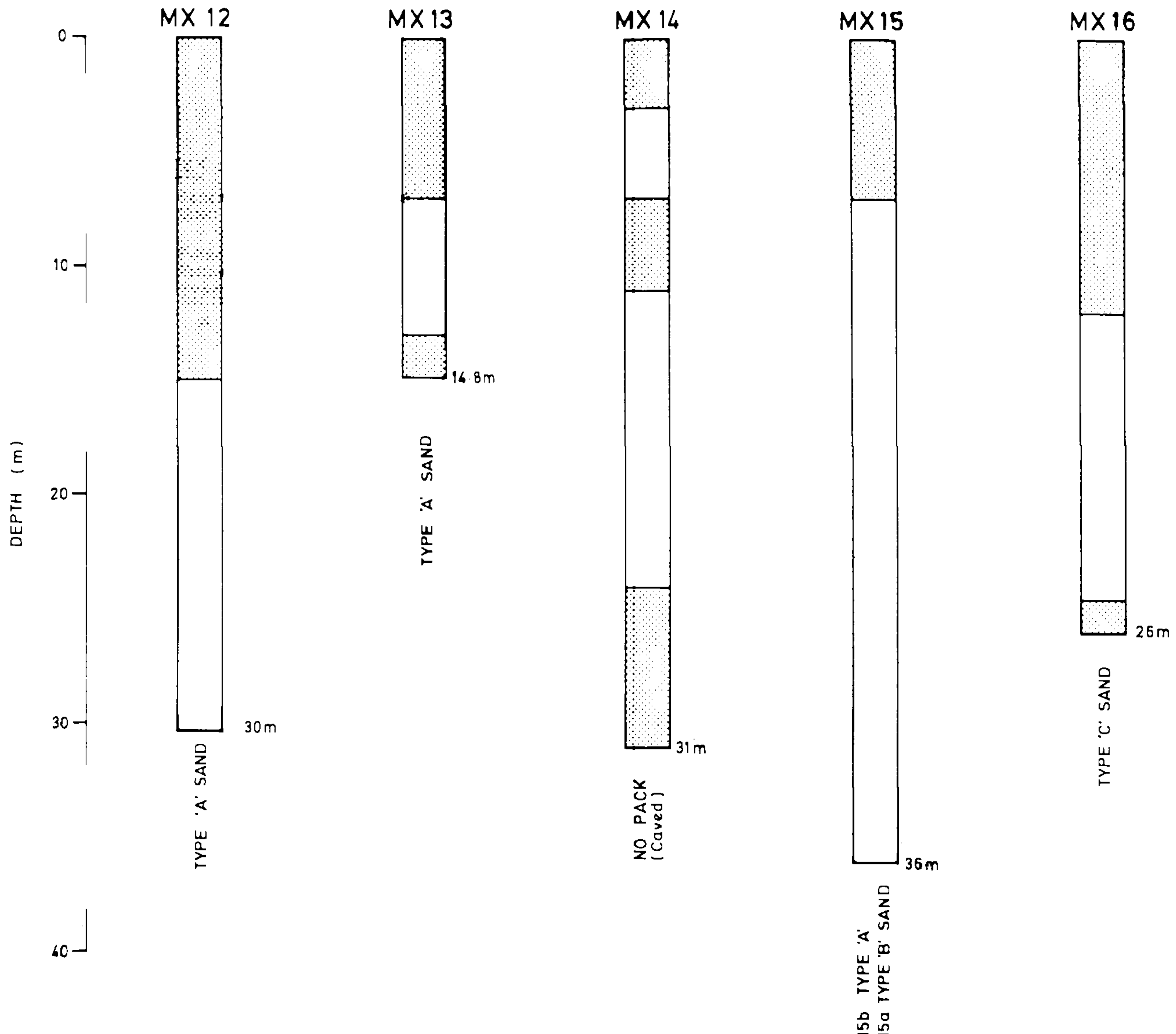


NOTES:

1. ⊙ PHASE I WELLS
   ○ PHASE II MINIWELLS
   ● PHASE II TWINWELLS
   ⊗ PHASE II MAXIWELLS
   ◐ PHASE III MAXIWELLS
2. TRANSMISSIVITY VALUES GIVEN IN m^2 / DAY
3. FIGURES IN BRACKETS ARE AVERAGE SPECIFIC GRAVITIES

WELL LOCATIONS, TRANSMISSIVITIES AND BRINE SPECIFIC GRAVITIES

FIG. 4



NOTES

1. Schematic Logs Are Based Upon Cuttings Samples
2. Filter Pack Gradings As Follows (Particle Sizes In mm)

TYPE	GRADING
A	D_{10} 1.0
	D_{80} 2.0
	D_{100} 5.0
B	D_{10} 0.6
	D_{80} 1.2
	D_{100} 3.0
	D_{10} 2.0
	D_{80} 4.0
	D_{100} 10.0

LEGEND

- AQUIFER (blank)
- AQUITARD (stippled)

	MX 12	MX 13	MX 14	MX 15	MX 16
TRANSMISSIVITY (m^2/day)	280	350	275	400	250
MAX FLOW (l/s)	11.7	17.0	10.0	23.5	20
SPECIFIC CAPACITY (l/s/m)	3.27 @ 11.6 l/s	2.85 @ 17 l/s	1.53 @ 8 l/s	2.45 @ 23.5 l/s	1.05 @ 20 l/s
STORATIVITY	—	0.0003	0.0004	0.0001	0.001
SPECIFIC GRAVITY	1.086	1.125	1.153	1.135	1.106

SUMMARY OF MAXIWELL TEST RESULTS

FIG. 5

MAJOR INFLOW HORIZONS AS INDICATED BY VELOCITY PROFILES.

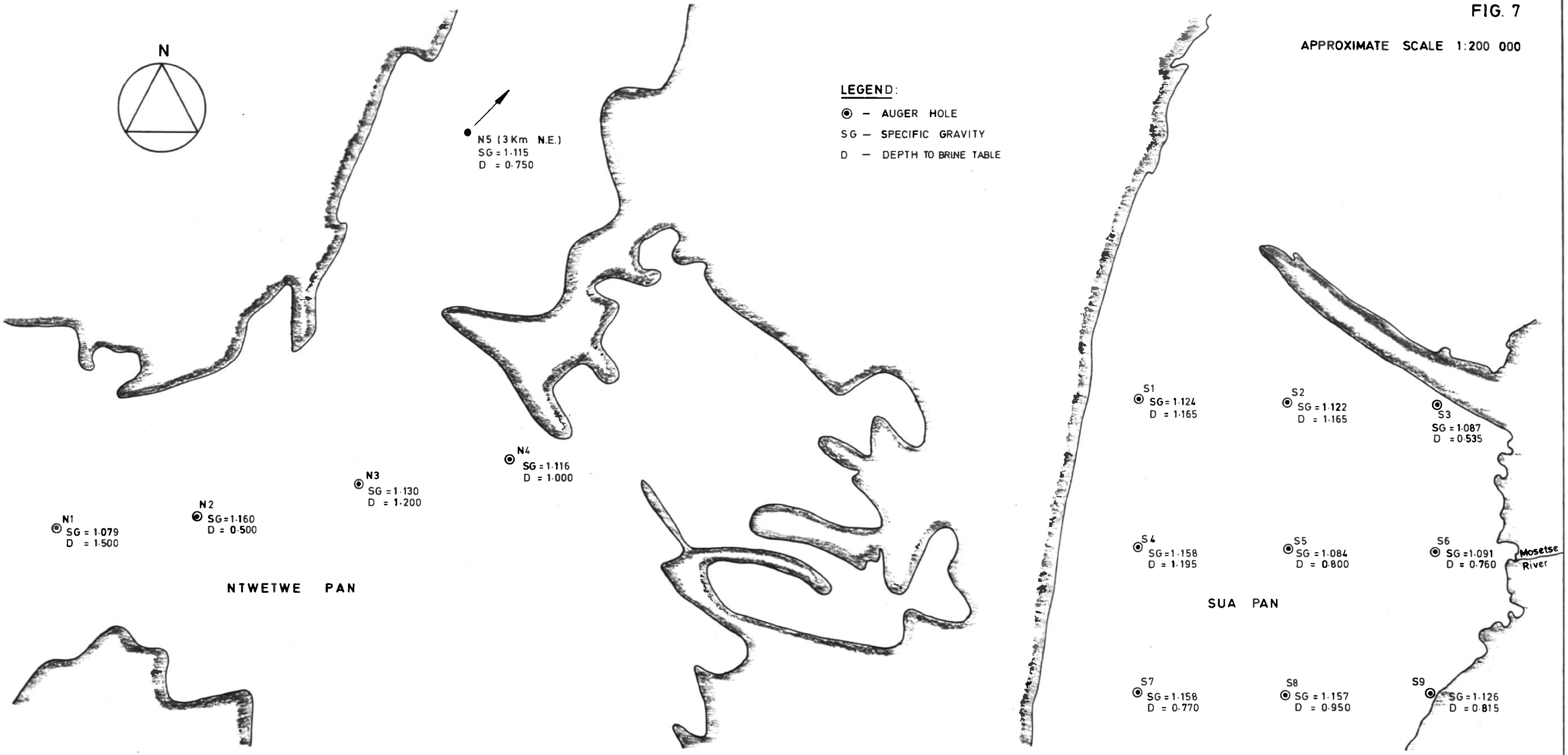
MINIWELLS M2 TO M7

FIG. 6

MAJOR INFLOW HORIZONS AS INDICATED BY VELOCITY PROFILES.

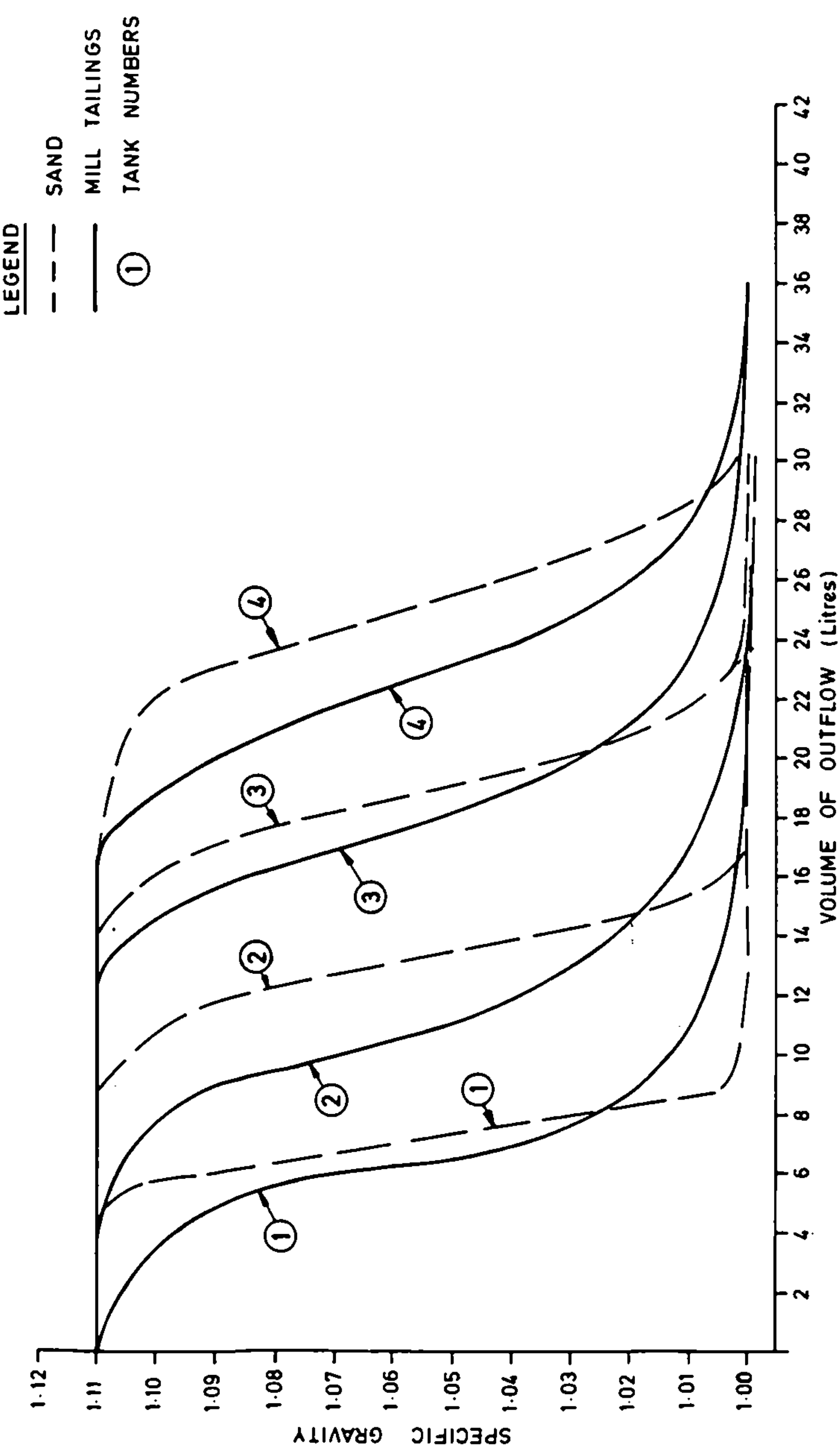
MINIWELLS M8 TO M16

FIG. 7



EXPLORATORY AUGER HOLE RESULTS

FIG. 8



RESULTS OF LABORATORY TESTS ON BRINE DILUTION