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A DESK STUDY-INSTITUTE OF HYDROLOGY

REPORT 33/347

GROUNDWATER SUPPLIES

FOR SUA

PROPOSALS FOR A

DRILLING PROGRAMME

DECMBER 1982

STUDY FRAMEWORK

This report comprises a desk-study to provide a 'wildcat' drilling programme to locate groundwater for a proposed development at Sua in northeast Botswana. Information has been collated from various sources to hand in the UK in order to capitalise upon a drilling capability already present in the area. Clearly it is not a review of all the hydrogeological information, the time scale precluding extensive research. However, the groundwater and geological information available appears to represent the major part necessary to make proposals for an exploration programme.

Qual. difference?
8/5 - 16/5

Groundwater requirements are for a small potable supply of 50 m^3/day and a large industrial brackish water supply initially of 700 m^3/day rising to 1400 m^3/day. Our study suggests that it may be possible to obtained these within about 25 km radius of the development site since two potential aquifers underlie this area. However there are severe constraints to development. The geological strucutre appears to be complex but is largely obscured by surface deposits thus hindering rapid survey. The deeper aquifer of Ecca age is likely to be characterised by extreme variability making the identification of the nature, thickness and extent of significant water bearing horizons difficult and frustrating. Additionally there are few data relating to water quality within the 25 km radius of the development site. Within this area a chemical gradient from potable water to super saturated brine must exist throughout the whole groundwater system, unfortunately its nature and location is unknown.

2. GENERAL SETTING

The surface exposures of the various strata around Sua are given in Figure 1 which also serves to provide a general location and physiographic map for this report. The basis for the map is our interpretation of 1:500,000 scale photographic ERTS data from 20 August 1975 (with additional coverage from 17 January 1973). We have found it necessary to provide an independent interpretation because largely of lack of agreement between other geological sources available to us. A 1:125,000 scale geological map of the Dukwe area

Photogeological map Sua Pan — Dukwe Area

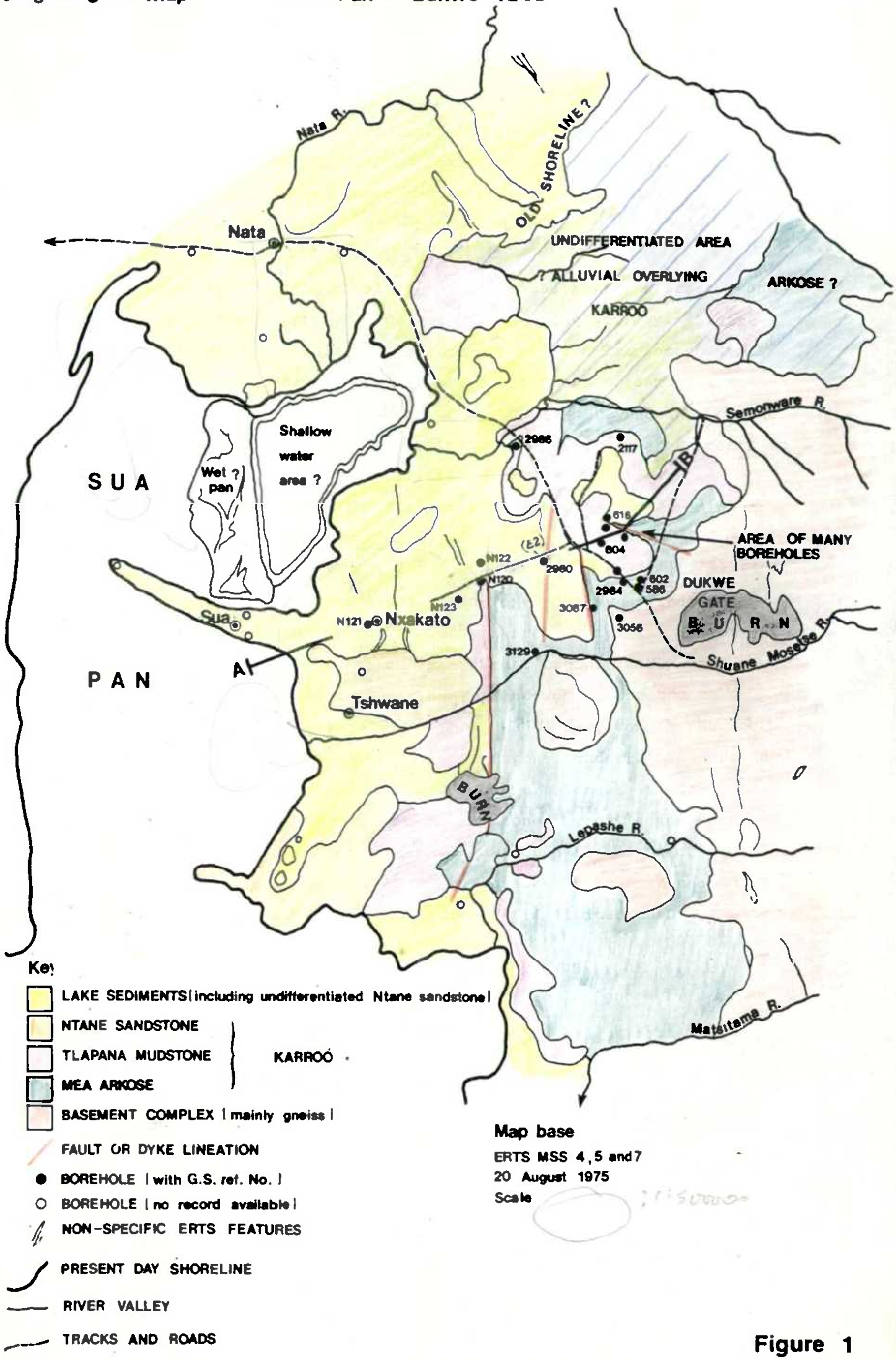


Figure 1

forms the basis for our interpretation (Stansfield 1973). There does not appear to be a similar map for the Nata area to the north and we have therefore used the Photogeological Map of Botswana at a scale of 1:1,000,000 (Mallick et al 1978). Small but nevertheless significant differences appear between these two sources. Essentially they relate to the geology around the margin of Sua Pan.

Various superficial deposits comprising calcretes, silcretes and alluvium overlie and partly obscure the underlying geology. Strong physiographic features relating to a more extensive lake occupy this area and the present-day pan is but a small remnant of a much larger system. The old shoreline extends for up to 20 km beyond that of the present day and the approximate margin of the original lake appears to be marked not only by these superficial deposits but also by southwestern deflection of the various ephemeral streams draining to the pan. These are shown in Figure 1.

Beneath the superficial deposits and extending westwards for about 30 km are sedimentary rocks of the Karroo, which in turn overlie basement gneisses. The Karroo sediments rest unconformably upon the basement which is exposed in occasional "windows" before the main outcrop to the west of Dukwe Gate. Three major units of the Karroo are present. The youngest, the Ntane Sandstone, underlies Sua Pan and extends perhaps 15 km westwards towards Dukwe. Beneath these sandstones occurs a thick sequence of mudstones, the Tlapana Mudstone, clearly affected by faulting, and exposed around the limit of the old shoreline. Between these rocks and the basement complex a second sandstone occurs, the Mea Arkose. Exposure is limited at Dukwe Gate but becomes much more extensive to the south.

Stanfield (1973) Quarter Sheet 2026C, Dukwe Area, Geological Survey of Botswana.

Mallick, Hapgood and Skinner (1978), Photogeological Map of Botswana, Directorate Overseas Surveys, London.

Recognition of these various formations is not easy and has led to differences of interpretation between Stanfield (presumably from conventional aerial photography) and Mallick (from ERTS imagery). Our own study provides a third interpretation which we present not necessarily as an improvement on this other work but rather as a model upon which we can base exploration proposals. The difficulty arises partly due to lithological similarities between the sandstones and the difficulty of separating these from the superficial deposits, but also because of the strong physiographic element of the ancient lake.

3. GEOLOGY AND GROUNDWATER OCCURRENCE

The strata sequence in the Dukwe area is given by Sweco (1976):

Alluvium			
Calcretes and Silcretes			Recent
	EROSION FAULTING?		
Dolerite Intrusions			Post-Karroo Intrusions
Ntane sandstone (Cave ?)		Stormberg series	
	EROSION FAULTING		
Non-carbonaceous		Beaufort	
Tlapana Mudstone		Upper Ecca	Karroo Supergroup
~~Non-~~Carbonaceous		Middle Ecca	
Mea Arkose	EROSION UPLIFT		
Dukwe Mudstone		Upper Dwyka?	
Dukwe Formation		Lower Dwyka	
	MAJOR HIATUS		
Mosetse River Gneiss			Precambrian Complex

This interpretation expands upon the earlier work of Stanfield recognising the occurrence of the lowest Karroo unit, Dwyka, in drill cores and cuttings from water boreholes at Dukwe. Generally hydrogeological interest must focus upon Karroo strata from the Dwyka to the Ntane sandstone with little potential for large groundwater supplies from either the Precambrian basement complex or the recent

Sweco (1976), Sua Project, Dukwe New Town, Ground Water Study, Inception Report.

deposits.

An evaluation of the underground water resources of Botswana, in particular of the Karroo, has recently been completed (Farr et al 1981) and it is essential to set interpretation of the sparse hydrogeological data from the Sua-Dukwe area against this wide ranging and extensive review. Our desk study therefore first attempts to provide a setting from the broad perspecture of the GS10 research, then interprets the existing data to provide a conceptual model of the groundwater conditions in the area of interest in order to provide drill targets for an immediate programme of drilling.

The geological sequence in the Sua-Dukwe area closely resembles the general model for Karroo sedimentation described by Farr. The area lies toward the northern margin of a central Botswanian basin of deposition but close to an axis of upwarp separating the central basin from a more northerly one toward the Zambia and Zimbabwe borders. The full Karroo sequence is not present presumably due to the near influence of the upwarp.

Karroo sedimentation begins with glacial deposits of the Dwyka. These, the earliest in Southern Africa, are described by Sweco as sandstones, siltstones and shales resting directly upon basement gneiss and overlain by shales and mudstones deposited in the immediate post-glacial period. Typically Dwyka rocks are preserved in hollows in the pre-Karroo landsurface and this certainly appears to be the case at Dukwe. The more easterly boreholes do not seem to have encountered such strata although they appear more regularly and in greater thickness toward Sua. Borehole 3129 (15 km southeast of Dukwe Gate) records 28 m "clay" overlying 51 m "sandstone" which appear to be attributable to the Dwyka. This is the only borehole to record a water strike in the Dwyka (at 152 m depth in the sandstone) elsewhere at Dukwe sandstones are subordinate to the shales and perhaps behave more as an aquiclude than aquifer.

Farr, Cheney and Baron (1981) Evaluation of Underground Water Resources, GS10 Final Report, Dept. of Geological Survey.

Lower Ecca strata (siltstones) have not been recognised at Dukwe. The Dwyka, or the basement gneiss, are regularly overlain by up to 110 m of white, feldspathic sandstones - the Mea Arkose described by Sweco as the only suitable formation for groundwater abstraction (at Dukwe). Generally we believe this statement requires qualification and will return to this point later. Certainly the arkose is an aquifer and pebbly and conglomeratic beds reported between 25-58 m and 94-109 m from the top of this formation could be hydrogeologically significant. Sweco's borehole appendix and Stanfield's geological description are not available to us for more detailed comment but the groundwater potential of the arkose is extremely variable indeed.

The Tlapana Mudstone formation overlies the Mea Arkose to a reported thickness of 119 m. We can find little detailed description of these deposits. They are reported as a lower dark grey to black and carbonaceous part, and an upper light grey to yellowish red part. These are attributed to the Upper Ecca and Beaufort units of the Karroo by Sweco although the basis for this correlation is not explained. They are reported to have a very low permeability and to confine groundwater in the underlying arkose. In our view there is some doubt regarding this conclusion also and we shall return to this point again.

Next in sequence is the Ntane Sandstone, a brownish-red medium to fine grained rock, variably consolidated and in places white in colour. Composed mainly of well rounded quartz grains, we assume this formation to be the Cave Sandstone and as such to be a potential aquifer, although few borehole records available to us confirm this point. Generally this sandstone occurs to the west of the Dukwe area toward Sua Pan and is beleived to underlie that area.

Kalahari beds appear to be absent from the area but an extensive cover of superficial deposits (calcrete, silcrete and alluvium) surround Sua Pan and underlie the river valleys draining to the pan. These can be thick, in excess of 20 m, and are probably quite permeable deposits. However their groundwater significance is unlikely to be great since they lack spatial continuity and probably will act only as local conduits transmitting groundwater either leaking from deeper aquifers or recharging from occasional floods.

We have attempted to verify the broad conclusions regarding aquifer potential of the various formations in Table 1. Here we have grouped the borehole data according to aquifer configuration dealing first with water table conditions where the standing water level is either in calcrete, Ntane Sandstone or Mea Arkose without the intervening Tlapana Mudstone. Under artesian conditions we list boreholes through the Tlapana Mudstone indicating either the height of the standing water level above the base of the mudstones or the height of the water level above the mudstones.

The main point to emerge is that boreholes through Tlapana mudstones seem to have encountered groundwater with much greater regularity than under water table conditions. Only one borehole (3099) is reported dry in this group compared with three dry water table sites. Surprisingly one borehole (604) entirely within the mudstones has the third highest yield. Also only two of the artesian records fail to record a yield, as opposed to a reported dry hole, compared with five under water table conditions. Generally we assume these indicate some groundwater but probably not in an abstractable quantity. We must conclude from this evidence that the Tlapana Mudstone contains water bearing horizons and probably contributes to the reported supplies rather than acting solely as an impermeable confining formation.

The second point which emerges is that yields are very variable, occasionally large, but generally quite small perhaps averaging 2 l/sec. There appears to be no relationship between thickness of any of the formations and the yield. The best, 20 l/sec, is from 27 m of mudstones and 13 m of arkose, with the next highest apparently from 44 m of Ntane Sandstone.

The third point which should be made concerns water quality. This is signficantly poorer whenever Ntane Sandstone or calcrete is present below the standing water level. The best quality groundwater (3129) is from a borehole in the valley bottom of the Mosetse river and we must assume this indicates modern or at least recent recharge at the site. All other sites for which we have records are away from major water courses.

TABLE 1

Borehole No.	Yield l/sec	TD	Calcrete	Ntane Sst	Tlapana Mdst	Mea Arkose	Dukwe	Basement	Water Quality TDS (ppm)
			(Thickness	(m)	below water	level)			
WATER TABLE CONDITIONS									
2979	?		5	47	-?	4+			1900
2980	?		3	33	-	21			
2981	17.4		8	44	-	4			1724
2008	0.1					37		28	
2017	2.5					28	-	3	1000
2037	Nil					(46)	-	(18)	
3071	Nil	Sun Pan	located.			(12)	(24)	(29)	
3074	?					(9)	(27)	(3)	
3087	Nil	— Sua Pan				(63)	(2)	(22)	
2982	?					(43)	(32)	-	
2984	?					(58)	?	?	
3129	0.8				TD 180? wl 34.4	58 93	79	9	324
ARTESIAN CONDITIONS									
604	8				32	-			868
3099	Nil				(48)	-			
E2	?			48	118	17			4000
3098	0.2			18	(31)	(51			
3106	2			46	40+	?			2136
616	20				27	13			1016
1239	8				22	16			900
2016	1.1				36	25			1330
2028	?				(58)	(18)			
2117	1.9				119	19			
2146	2.5				75	28			920
2157	2.5				75	21			950
2165	1.0				78	33	-		840
3067	0.8				15	103	-		688
3107	1				17	113	79		
3112	?				(49)				
COAL EXPLORATION BOREHOLES (Total sequence)									
N47			4	-	62	110	-	2	
N120			25	-	22	15	25	28	
N121			-	34	120	-	-	-	
N121			-	46	8	25	17	-	
N123			14	32	45	-	24	11	
N 124?									

say Q ≤ 1 l/s (unknown, ...)

= 86 m³/d

expect 50 - 100 m³/d   2-4 O for supply

Perhaps the final point we should make concerns the extreme variability of the reported thicknesses of the various formations. The Tlapana Mudstone varies from 8 m to 120 m in apparently completely penetrating boreholes and similarly the Mea Arkose from 15 m to 110 m. Dukwa (Dwyka) beds can be absent or up to 79 m thick and only the Ntane sandstone shows any regularity.

Here we must return to the work of Farr to seek an explanation of this confusing if not contradictory set of results. He concludes from all the Ecca groundwater records that the inherent hydrogeological characteristic is one of extreme variability such as to make delineation of aquifer units in terms of thickness, extent and nature difficult both locally and regionally. Aquitards and aquicludes are similarly discontinuous and variable and hydrogeologically the whole Ecca sequence below its general piezometric surface is saturated but not necessarily a significant aquifer. This is exactly the point being made by the Dukwe borehole records. We can find no correlation between the high yielding boreholes and their structural setting or lithology, any more than there is an explanation of the dry holes.

It is clear therefore that the best approach to the Ecca is to consider the whole sequence from Tlapana Mudstone to the Basement gneisses as of equal potential. For exploration purposes, wildcat drilling should attempt therefore to penetrate as full a sequence as possible. In this context we should point out that in our opinion there is doubt regarding some of the borehole strata correlations. It is undoubtedly extremely difficult to separate Tlapana Mudstone from Dwyka mudstone and since many boreholes only penetrate partial sequences there are likely to be some errors contained in Table 1.

The Ntane Sandstone (? Cave Sandstone) must be separately evaluated despite having little local development. Generally it is a more uniform and reliable aquifer than the Ecca although elsewhere exploitation is generally from thicker sequences than are proven as yet in the Sua-Dukwe area. In the Sua area thicknesses in excess of about 40 m are not evident although formation may thicken toward the pan. Water quality can certainly be shown to be poorer than in the Ecca even at Dukwe. To the west toward the pan this must be assumed to deteriorate and we therefore regard the Ntane Sandstone as a possible source mainly for the industrial supply.

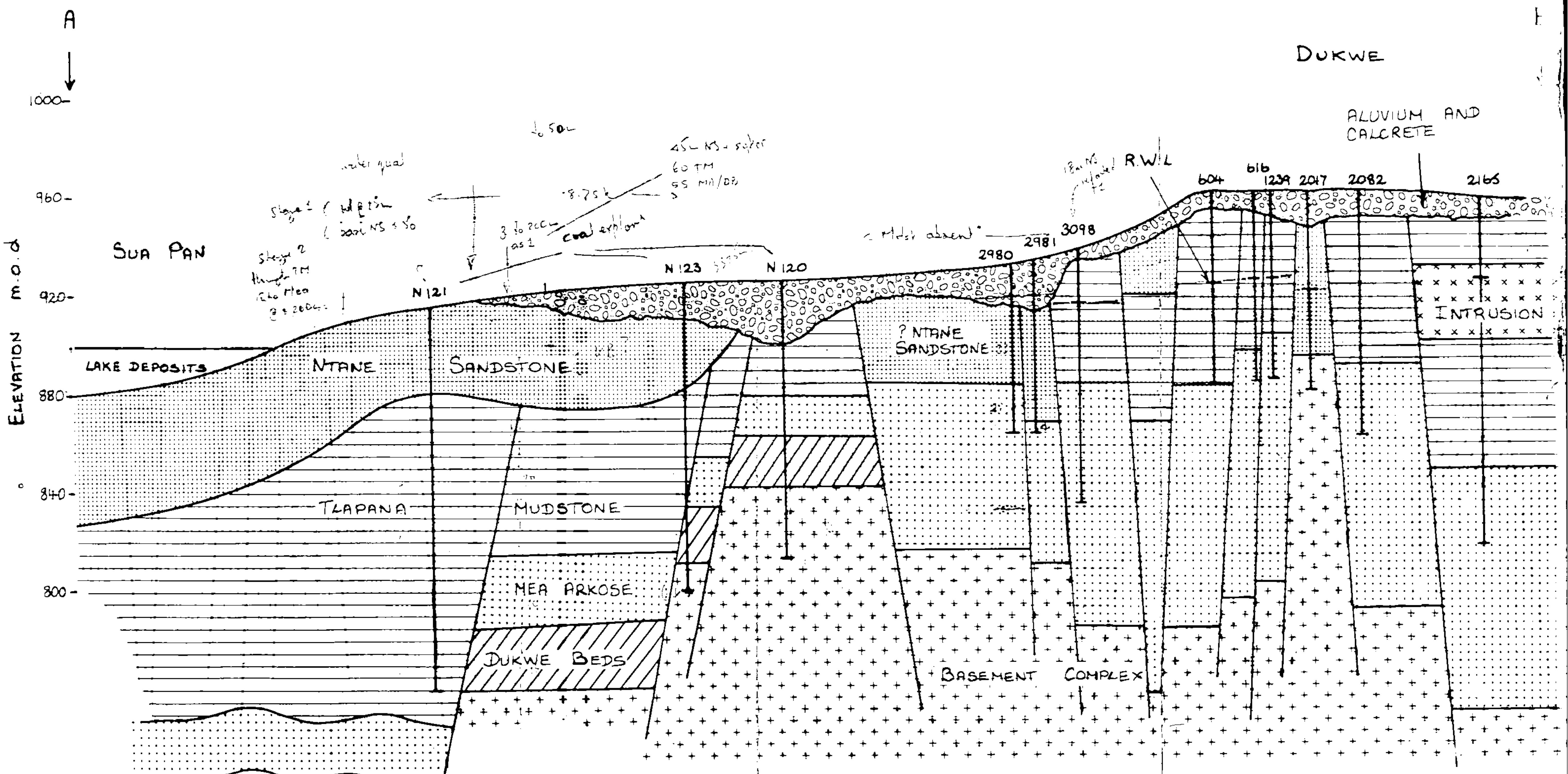
GEOLOGICAL STRUCTURE AND HYDROGEOLOGY

Our main concern with regard to interpretation of ERTS imagery has been to provide evidence for the geological structure close to the pan at Sua. This will influence drilling strategy and it is clearly advantageous to locate suitable groundwater soures as close as possible to the proposed development. We sought two targets from ERTS, firstly location of possible faults and secondly a clearer understanding of the identity of any bedrock exposures.

With regard to faulting, those shown in Figure 1 were known from other sources, our own work merely serving to confirm them. Several other parallel lineations (approximately north-south) are evident particularly near Nxakato and correspond to linear photogeological features recorded by Stanfield. We have to assume that these probably indicate additional faulting but are generally unable to confirm this by means of identification of specific formations. Whilst we believe we have been able to identify exposures of Tlapana mudstones not previously located these are generally away from the area of main interest. Between Sua and Nxakato various superficial deposits appear to hide any underlying geology and in consequence we have had to develop a structural model almost entirely from coal exploration boreholes. This is shown in Figure 2, a geological cross section along the line of the Sua to Dukwe road.

The section demonstrates the complexity of faulting at Dukwe as proven by drilling. The Tlapana mudstones are absent to the west between boreholes 3098 and N120 through an upfaulted block. Toward Sua we interpret the geology as a series of step faults downthrowing to the west and continuing the mudstone beneath the Ntane Sandstone which serves to hide the actual frequency and magnitude of such faults. Upfaulted blocks might equally well occur in this zone.

The section also serves to illustrate an apparent thinning of the Mea Arkose and the complimentary appearance of the Dukwe (Dwyka) beds toward Sua.



GEOLOGICAL CROSS SECTION FIG. 2

Water level elevations are also shown on the cross section. They appear rather discontinuous, suggesting poor interconnection between fault blocks, but perhaps overall a very shallow gradient toward Sua Pan. However we have no record of water levels within about 20 km of Sua and can only postulate a gradual decline to about an elevation of 900 m at Sua. If this is the case the Ntane Sandstone should contain groundwater to a depth of 25 m, perched, or in poor hydraulic connection with Ecca groundwater leaking upward from below.

Broadly the cross section must represent our interpretation from the Mosetse to the Semonwane river valley. This should not imply any uniformity of structure or of groundwater potential but rather the severe lack of information close to the pan.

5. AQUIFER CHARACTERISTICS

Comments here must necessarily be brief, there are few data. Aquifer properties are known for 4 pumping tests from the sites of maximum yield at Dukwe. Not surprisingly very high transmissivities are indicated (Table 2) but these are exceptional boreholes and there are no grounds to suppose that similar sites can be actually located from present hydrogeological knowledge. High transmissivities elsewhere (50 to 2500 m^2/day) in the Ecca are imparted by fracturing, particularly lithological controlled fissuring, enlarged bedding plane joints or dissolution of feldspathic matrix from arkose sandstones. Any combination of these may account for the situation at Dukwe, where occasional fairly thin horizons of exceptionally high permeability exist.

The main mass of the Ecca has undoubtedly a very low permeability with small groundwater supplies again arising mainly from thin horizons. If the model of a fully saturated Ecca sequence is correct then an exploration strategy based upon complete penetration is the most likely to determine any locally more extensive zones of greater potential. Dry holes may occur and these are as likely as the discovery of a high yield site. A wildcat drilling yielding 2 l/sec would be an acceptable result in our opinion.

With regard to the Ntane Sandstone (as opposed to the Ecca) the test results from borehole 2981 are unexplainable. The Cave Sandstone rarely has a permeability much greater than 0.5 m/day giving a transmissivity of about 22 m^2/day for the 44 m saturated thickness at borehole 2981. Generally the Ntane Sandstone has still to be explored in the Sua area but potentially it must be almost as attractive as the Ecca providing that it contains groundwater and this still has to be proven. Elsewhere 2 l/sec or perhaps 3 l/sec can normally be expected from a saturated thickness of 80 m for a drawdown of perhaps 30 m.

more like 1.5-1d

The storage coefficients require little comment, they are typical low values regularly found under artesian conditions in the Ecca or the Cave. Steep but narrow cones of depression develop around abstraction wells in low transmissivity aquifers with drawdowns stabilizing as confined conditions revert to a water table state, performance thereafter depending upon the nature and thickness of the producing horizon.

TABLE 2 Aquifer Characteristics (After Farr)

Borehole		Transmissivity m^2/day	Coefficient of storage
2981	Ntane/Mea Arkose	400-4000	1.3×10^{-3} to 1.4×10^{-4}
604	Tlapana Mdst.	570	-
616	Tlapana/Mea Arkose	372	-
1239	Tlapana/Mea Arkose	276-458	2.7×10^{-4}

6. RECHARGE

The possibility of recharge in the area has to be briefly considered since it does have a bearing upon drilling strategy. Most investigations which have examined recharge potential have dealt with Ecca and Cave mainly beneath a cover of Kalahari deposits and as such these results are not strictly applicable to the Sua area. Several different approaches have reached rather different conclusions and it is inappropriate to examine these in detail. There are however two broad recharge conditions to examine.

Firstly the potential for direct recharge from rainfall over the various rock exposures can be considered. Average annual rainfall is about 440 mm in the area which generally should be sufficient to generate some replenishment from major storms at least in areas where blocky calcrete or jointed rocks are exposed. In areas of fine grained sands, or homogeneous sandstones and mudstone, there might be some doubt as to whether widespread recharge will contribute to groundwater. There are no water level records for the Dukwe area upon which to develop a possible rainfall/recharge model but indirect evidence from isotope results seem to indicate little recent replenishment. Hutton and Loehnert (1977) reviewing chemical and stable isotope results point out that at Dukwe deuterium and oxygen-18 depletion is the highest for the Kalahari aquifer system, and follow other workers in suggesting that these groundwaters recharged during cooler climatic periods of the Pleistocene. If correct this implies the bulk of the groundwater originated from recharge up to 30,000 years ago.

Recharge from occasional floods in the main drainage network is a much more attractive possibility and the water quality at borehole 3129 seems to provide direct evidence for such a process. Relationships between rainfall and run-off are considered by Gibb (1976) who estimated a mean annual runoff from the Basement Complex of the Mosetse at 34 mm, some $37 \times 10^6 m^3$ from an area of about 1000 km^2. We assume such flows discharge directly to Sua Pan or recharge Ecca, Ntane and superficial deposits along the watercourse. Hand-dug wells and a strong vegetation provide evidence for some persistence at least of groundwater baseflow along these valleys and these must be target areas for shallow potable water supplies close to the pan.

Hutton and Loehnert, (1977), Hydrochemical surveys of selected Karroo areas in Botswana, Proc. IAH symposium, Birmingham F63-72.

Gibb, Sir Alexander and Partners (1976) A reconnaissance study for major surface water schemes in Eastern Botswana.

The Mosetse, closest to Sua, is clearly of prime interest. The Nata with a considerable larger catchment is less attractive partly due to distance but also because the solid geology appears totally hidden by superficial deposits.

EXPLORATION AND DEVELOPMENT STRATEGY

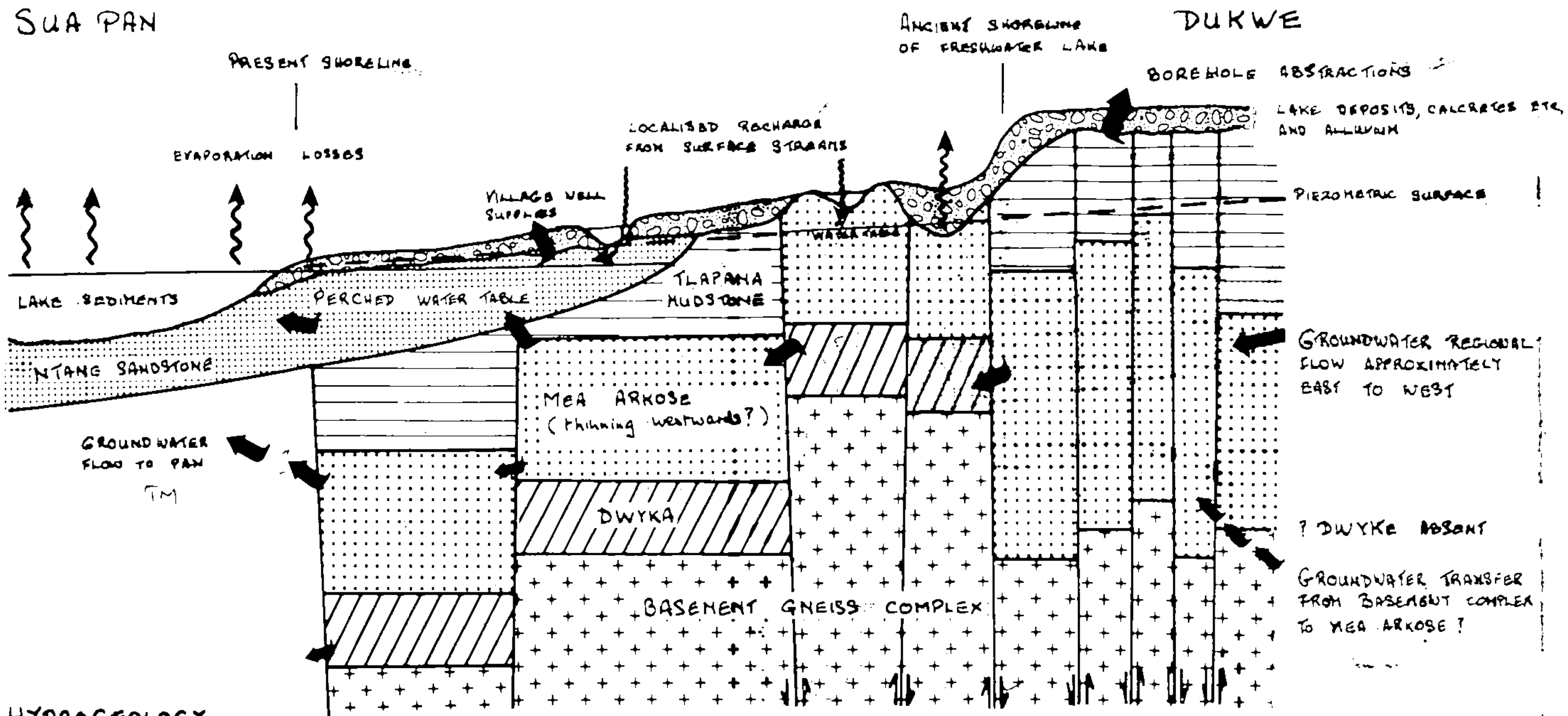
The question of resource estimation does not enter at this time, there is no way of assessing these other than in qualitative terms. The more limited and thinner occurrence of the Ntane Sandstone as compared with a thicker and apparently more extensive Ecca clearly suggests the Ecca as the main exploration target despite its greater aquifer variability. Clearly in view of the relatively small groundwater supplies needed the Ntane Sandstone cannot be discounted completely but water quality, and indeed the presence of a groundwater body in these beds near to Sua, has to be confirmed.

To proivide a drilling strategy we have produced a conceptual hydrogeological model of the area (Figure 3) which brings together the geological, hydrogeological and water quality aspects. Our drill target locations are largely self explanatory and are based upon drilling first close to the pan and then extending east ~~west~~wards if acceptable results are not obtained.

The main choice to be made is whether to drill close to the development site, and indeed how close to the pan there, or to move away toward the main drainage channels of the Mosetse or Semonware rivers. These valleys are at least 16 km from Sua spit. On balance we would recommend first drilling close to Sua regarding confirmation of the geology and of the presence or absence of groundwater of whatever quality as more useful than precise knowledge of say the existence of shallow good quality water further distant.

The general drilling strategy we would propose is to drill first within about 5 km of the spit, if unsuccessful then to more some 5 km westwards and to move a further 5 km if water of suitable quality or quantity has not been proven. If no satisfactory results are indicated then we suggest drilling should move back to the pan but in

CONCEPTUAL HYDROGEOLOGICAL MODEL SUA PAN — DUKWE AREA



HYDROGEOLOGY

LAKE SEDIMENTS UNDERLAIN BY NTANE SANDSTONE. DEEPER GEOLOGY UNKNOWN PERHAPS TLAPANA MUDSTONE BUT GROUNDWATER LEAKAGE TO PAN IMPLICIT IN REGIONAL HYDROGEOLOGY	SOME FAULTING INDICATED BY COAL EXPLORATION BOREHOLES AND PHOTOGEOLOGY. DETAILED STRUCTURE OBSCURED BY SURFACE DEPOSITS AND NTANE SANDSTONE. TLAPANA MUDSTONES PRESENT ASSUMED TO BE UNDERLAIN BY MEA ARKOSE AQUIFER	MEA ARKOSE AQUIFER AT OUTCROP IN UPTHROWN BLOCK	AREA OF EXTENSIVE FAULTING PROVED BY NUMEROUS BOREHOLES TO CONFINED MEA ARKOSE AQUIFER

GROUNDWATER QUALITY

T.D.S. 160,000 ppm. ? BRINES ? Saline groundwater	TDS 5000 ppm ← TDS 2000 ppm ? TDS 5000 ppm ← ? TDS 1000–2000 ppm	TDS 500 ppm in vicinity Mekoop	TDS 2000 ppm ? evaporation or localised solution

GROUNDWATER TOTAL DISSOLVED SOLIDS 800 — 1000 ppm IN MEA ARKOSE

GROUNDWATER SALINITY GRADIENT UNPROVEN

DRILL TARGETS

NTANE SANDSTONE	*	POSSIBLE INDUSTRIAL AND/OR POTABLE SUPPLY SOURCE
MEA ARKOSE	*	PRIMARY INDUSTRIAL SUPPLY SOURCE
MEA ARKOSE AND DWYKA		* PRIMARY POTABLE SUPPLY SOURCE

FIGURE 3

the near vicinity of the Mosetse valley and again move westwards away from the pan according to results. This spacing carries the exploration sites across the main fault blocks we show in our geological cross-section.

Clearly locating water of a suitable quality for either the potable or the industrial supply will focus further attention in that area. A single borehole in either the Ecca or the Ntane Sandstone should be capable of providing the potable water supply even given the small yields generally anticipated. The industrial supply on the other hand will require a small wellfield on present evidence and generally we expect this to be in the Ecca. Our reasoning here is based upon the general nature of the two possible aquifers. 10 boreholes in the Ntane Sandstone, if it exhibits similar characteristics to the Cave Sandstone, will produce 10 small yielding sites. Given that the formation does not appear to be more than 50 m thick, exploration will be needed to locate a region to sustain a long-term abstraction without dewatering problems. At this stage the wildcat drilling is mainly to prove such groundwater and its quality rather than a wellfield location.

The Ecca on the other hand is a much larger exploration target. Once suitable quality groundwater can be located then the geological structure and the yield potential for wellfield design purposes would advance considerably from several boreholes.

With regard to drilling techniques then there is no purpose in exploring with rotary mudflush or polymer mud systems. The supression of groundwater which would be inherent rules this out. Air flush ideally with a rock hammer system is the most attractive.

rotary mudflush to be used though?

A comment is also necessary concerning yield evaluation and borehole diameter. The production of water solely by air flush drilling is not reliable enough to gain yield information. This requires a separate exercise involving air lift pumping or a mechanical/electrical pump. Air lift pumping requires a two pipe assembly, an inner air line and an outer water delivery pipe. To air logging?

lift pump at 50 m depth will require a 150 psi compressor whilst at 200 m a 400 psi air supply is needed. Even within the framework of this proposed exercise we strongly recommend air lift pumping to test wildcat borehole yields.

Drilling with a 4½ inch bit will provide a suitable hole for air lift testing but at this diameter the borehole could not be put into supply. A 6½ inch bit would allow a 4 inch pump to be installed but we believe that such pumps are difficult to obtain in southern Africa. An 8½ inch diameter bit to provide a borehole to accommodate a 6 inch pump is perhaps the most likely production well design.

In our opinion drilling should just be treated as a prospecting exercise for strata identification, groundwater occurrence and water quality. Once a suitable quality or quantity is proven, then further drilling could follow at the production diameter. Strata samples must however be regularly retained throughout all drilling.

DRILL SITES

Site 1

The only clue to groundwater in the near vicinity of the spit is a small settlement immediately to the south of the Sua-Nxakata road 4 km west of Nxakata. We assume there may be wells here. Close examination of the ERTS photographs, the 1:50,000 scale photographic map, and the Dukwe geolgoical map, suggests either an old stream or shoreline feature from the NNE. We suggest drilling in this vicinity as the closest point to the pan which may contain an acceptable water quality. A site is proposed 2 km north of the road at a constriction within the feature at UTM Zone 35 grid reference: 772800N, 410600E. A two stage drilling operatrion is required.

Initially a borehole to a depth of 50 m should completely penetrate the Ntane Sandstone. Given the ground elevation at the site relative to the pan, a water table at about 15 m would be expected if groundwater is present. It will be essential to monitor water quality most carefully here from any water strike. Measurements every 1 m will be needed.

If groundwater is NOT encountered in the sandstone then the borehole should be continued through the Tlapana Mudstone which is expected to underlie the sandstone to a depth of about 200 m, and into the Mea Arkose. Clearly a water of unacceptable quality would justify termination of drilling. We have not been given precise salinity tolerances for the supplies but suggest the following broad relationships as a guide:

Conductivity (umhos)	Total Dissolved Solids (mg/1)	
2500	1500	WHO highest desirable level potable supplies
5000	7000	"Brackish"
7500	10500)	"Saline"
10000	14000)	

7500 TDS

If groundwater is encountered in the Ntane Sandstone we suggest either that a separate borehole should be constructed to explore the Ecca, or that the sandstone should be cased off after air lift testing, and then drilling continued at reduced diameter. Clearly this decision will depend upon the equipment available. Very saline groundwater might make further drilling unecessary. This would be a difficult site decision to take since as we show in the conceptual model better quality Ecca groundwater could underlie the sandstone.

SITE TWO

Our second site is concerned with exploration of the strong ridge feature running approximately east-west from Sua spit. Examination of the ERTS photographs suggests that this may represent a remnant river deposit of an old course of the Mosetse joining the present valley at the point of the strong SW deflection noted previously. Unfortunately we do not have 1:50,000 scale map coverage (Sheet 2026C2) for precise site location. This ridge appears to broaden considerably in the area 3 km south east of Nxakato and we believe a fairly shallow borehole within the ridge may be useful.

3km SW actual site

To some extent the suitability of this high ground for exploration depends upon its geology. Our photographic interpretation suggests a blocky calcrete or even a gravel. Local recharge or perhaps subsurface flow from the Mosetse may be possible here. We envisage drilling the superficial deposits and the undrlying Ntane Sandstone to a depth of 50 m.

SITE THREE

east?

Immediately to the west of this site a strong photogeological linear feature running approximately N-S for 10 km intersects the ridge. This we interpret as a fault within the Ecca and is shown in Figure 2 between boreholes N121 and N123. The grid reference of the approximate site (from Geological Map 2026C) is $26^{0}14'30"$E and $20^{0}35'30"$N. The general strategy for drilling here would follow that propsoed for site 1. Field location needs to be accurate; the site should be close to the fault but just to the west of it. The expected geology is: 45 m Ntane Sandstone/Superficial Deposits

likely to be fault.

60 m Tlapana Mudstone

55 m Mea ARkose/Dukwe Beds

\- Basement Gneiss

The evidence at our disposal suggests this area as the most attractive for the main source of supply in the area immediately to the west of Sua.

DRILL SITE IN THE MOSETSE VALLEY

Failure to locate groundwater of suitable quality at these first 3 sites would indicate that a supply should be sought in the Mosetse valley to exploit local recharge. Several sites are suggested from photogeological evidence but the results of the initial drilling should clearly influence precise location of any drilling. In outline our proposed locations would be:

1. 1 km south of Tshwane
2. 5 km ESE of Tshwane in the main valley
3. 4 km upstream of site 2
4. 6 km downstream of borehole 3129 *