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Groundwater prospects in south western Nigeria

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ABSTRACT

The conditions favourable for groundwater availability in hard rock regions are adequate weathered depth and fractures. In this paper, the relationship between these conditions and topographic characteristics in south western Nigeria is examined.There is substantial spatial variation in characteristics, but on average the field results indicate good prospects for groundwater in the crystalline rock terrains of south western Nigeria.

INTRODUCTION

Except for the strip of sedimentary formations bordering it in the south, south western Nigeria is underlain dominantly by the crystalline rocks, consisting essentially of undifferentiated gneisses (probably schists), the older granites and a few intrusives (Jones and Hockey, 1964). Crystalline rocks are formed by interlocking mineral crystals. When fresh, crystalline rocks are compact and lack the interstitial voids essential for groundwater accumulation and transmission. However this compact structure can be altered in two ways, viz weathering and tectonic processes. Weathering leads to an increase in porosity but the resulting permeability depends on the lithology and texture of the original rock - for example acid rocks weather to produce a higher permeability compared with basic rocks of the same texture. Also coarse rocks weather to higher permeability than fine-textured rocks though the porosity may be higher in the latter. Tectonism is the process whereby earth movements produce geological structures such as faults, fractures, folds, and intrusions. Faults and fractures act as reservoirs and channels for groundwater storage and transmission. Intrusive rocks such as dykes and diabases are important groundwater features - they act as underground dams and their weakened boundaries with the host rock allow percolating water and its weathering effects to reach deeper. The exploration for groundwater and its eventual exploitation in crystalline rock terrains must therefore aim at locating areas with favourable weathering and tectonic characteristics. At the moment, this is most effectively achieved through geophysical investigations - electrical resisitivity (ER) and EM surveys are the methods most commonly employed. Seismic refraction provides a more reliable estimate of depth to bedrock but it is more expensive to undertake than ER and EM surveys. To undertake geophysical investigations requires specialised equipments and highly skilled manpower. The efforts and the cost involved are probably justifiable only when large groundwater schemes are being considered. For small schemes, perhaps an understanding of the general geology, the topography, the weathering and fracture characteristics could provide guidance in the process of selecting suitable sites for drilling. In this paper, the general prospects for groundwater in the basement of south western Nigeria is assessed. An examination of the spatial characteristics of these prospects is also undertaken in order to identify the factors which affect their optimum development.

RESEARCH METHOD

Seven of the wellfields in the Okene area of Kwara state were chosen for analysis. The drilling and pumping test reports were generously made available for consultation by Messrs Biwater Projects Limited who executed the drilling programme on behalf of Kwara State Utilities Board. The wellfields studied are Kabba, Obangede, Obehira, Esomi, Kuroko, Adogo and Adavi-Egba (see Figure 1). The information extracted from the reports is summarised in Table 1.

DISCUSSION

Although lacking in primary hydrogeologic properties, the results indicate good groundwater prospects for the study area. Widespread fracturing is suggested with an average of between 2 to 3 fractures per borehole. The average yield is 3-4 litres per second over 24 hours. Thus a borehole operating a 12-hr day would on average produce some 130,000 litres per day; enough to supply 2600 persons at 50 l/p/d. Clearly results like these argue against the generally held belief that hard rock terrains are no use as far as groundwater production is concerned. Such attitudes could be excused in the past when the usually abundant surface water available in hard rock areas was generally sufficient to meet the requirements of a small urban population. The situation has however changed with the surface resources shrinking constantly under threats of pollution and a larger and more dispersed population now requiring service. We do realise that some risk of failure is involved with groundwater development in hard rock terrains. However, these risks would be substantially reduced if a judicious definition of the failure criterion is employed which takes into consideration the cost-benefit in alternative sources. A yield of 0.1 litres per second may very well be regarded as successful depending on the circumstances. Also as a safeguard against failure, the factors which govern the spatial distribution of fractures and deep weathering in the area must be studied. In this regard, the pertinent observations for the present study area are presented below.

Spatial variation in groundwater characteristics

Spatial variation in groundwater characteristics could be due to variations in topographic, geologic, vegetation, climatic or land use characteristics. Vegetation and

Table 1 Mean drilling and pumping test results

Wellfield	No of wells	Elevation masl	Water level (mbg)	Water* strikes per well	Weathering depth (mbg)	Dev airlift (l/s)	Safe Yield (l/s)	Trans. (sq m/d)	Specific capacity (l/s/m)
Adavi	4	120	6.6	3.3	39	6.8	3.6	8.4	0.19
Adogo	6	94	3.5	3.2	24	3.3	4.7	13.3	0.26
Esomi	10	87	4.6	1.5	8	3.7	3.7	27.7	0.55
Kabba	14	109	3.4	2.6	28	7.7	4.9	18.6	0.23
Obangede	20	79	3.3	1.7	12	1.0	1.8	6.3	0.09
Kuroko	11	n.a	3.2	2.7	15	4.0	2.7	13.5	0.29
Obehira	8	92	4.5	2.3	15	15.1	3.5	17.8	0.34

*In the analysis, a water strike recorded during drilling has been interpreted as corresponding to a fracture location.

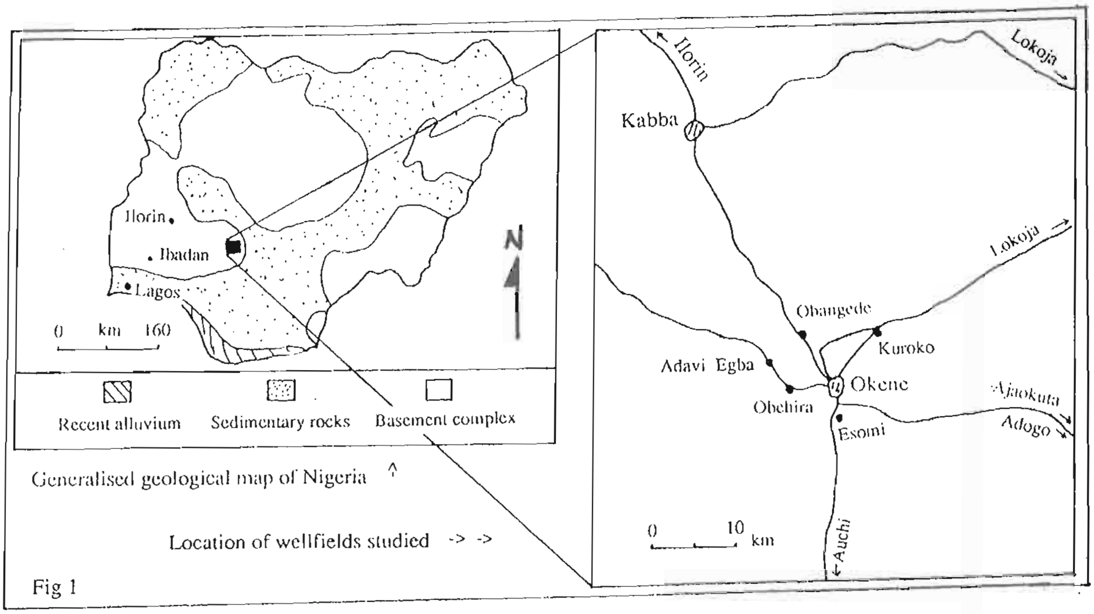


Fig 1

climate are generally uniform for all the wellfields studied. The spatial variations observed may then be traced to the other factors listed. Unfortunately, geology and land use are difficult to quantify, hence their effects cannot be staistically analysed. However there is qualitative evidence that they do influence the groundwater prospects in the study area. On the other hand, topography is quantifiable through the use of a number of indices. An indirect way of assessing geologic/land use effects is to first determine the variance accounted for by topography and then assign the unaccounted variance to geology/land use as a lumped parameter.

The topographic indices used in the regression analysis were the site elevation and mean overland slope (as characterised by the coefficient of variation in site elevation since contour maps are not available at the right scale for slope determination). The regression coefficients are presented in Table 2. For each groundwater characteristic examined, the second-order polynomial better describes the relationship with the topographic indices used - in each case, there was a substantial improvemnt in both the correlation coefficient (R%) and the coefficient of determination (R^2%). In the study area, weathering depth and elevation are strongly positively correlated (R=91%). One should therefore expect the groundwater characteristics and weathering depth to have similar regression coefficients as those of Table 2. The plots of the second-order polynomial relationships are presented in Figure 2. These relationships (and the coefficients in Table 2) were based on regional mean values of the parameters. The effects of local factors have thus been statiscally averaged out. In individual wellfields, the regional trends are quite often masked by these local factors especially lithologic/textural variations in rocks and the effects of urbanisation on recharge characteristics.

It must be pointed out that the original field results excluded hilltops and slopes down to the break of slope, sites which for geomorphological reasons are obviously not suitable for groundwater accumulation. The correlations must therefore be seen as referring to a groundwater catchment extending from the river channel up to the break of slope (Figure 3).

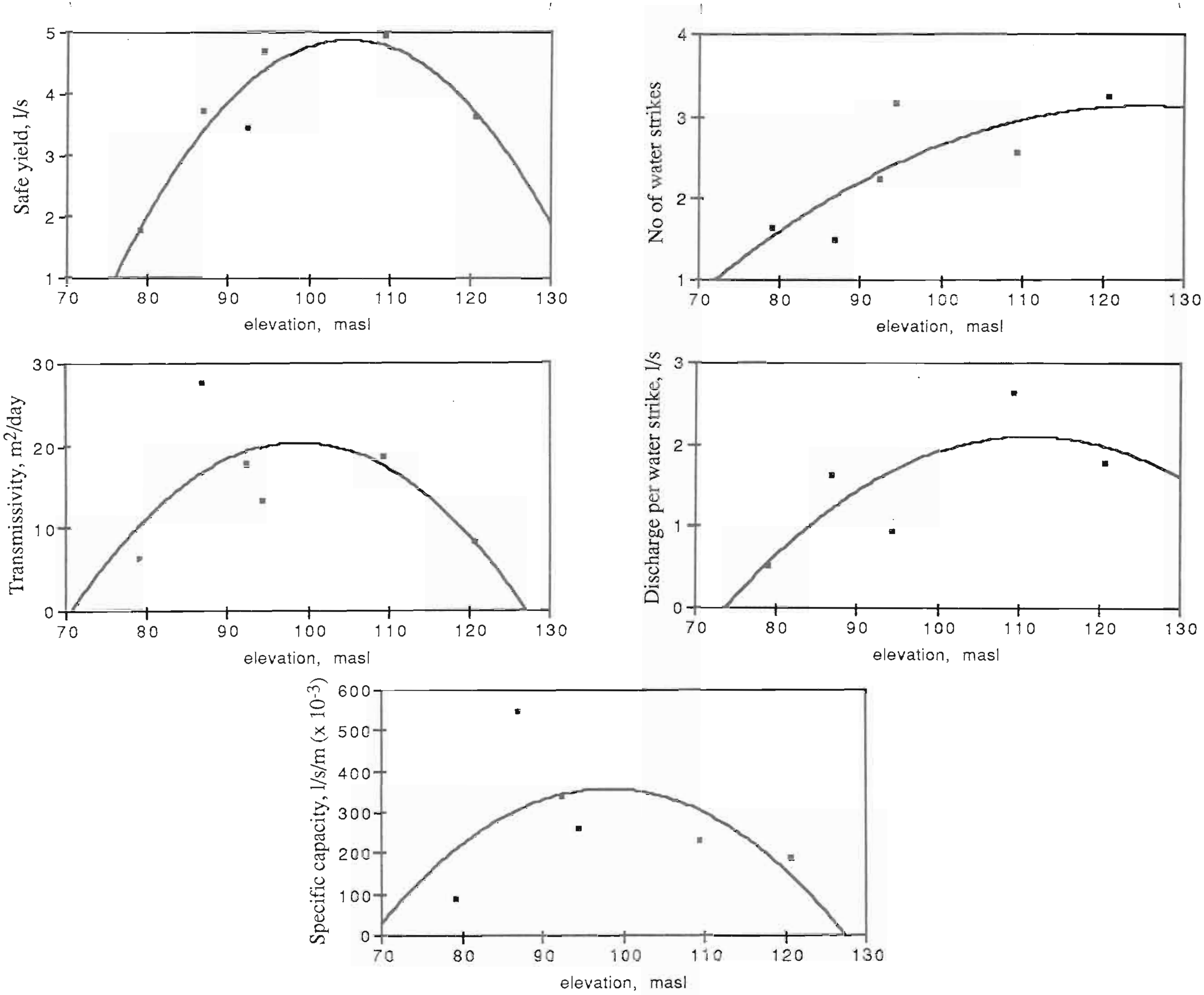


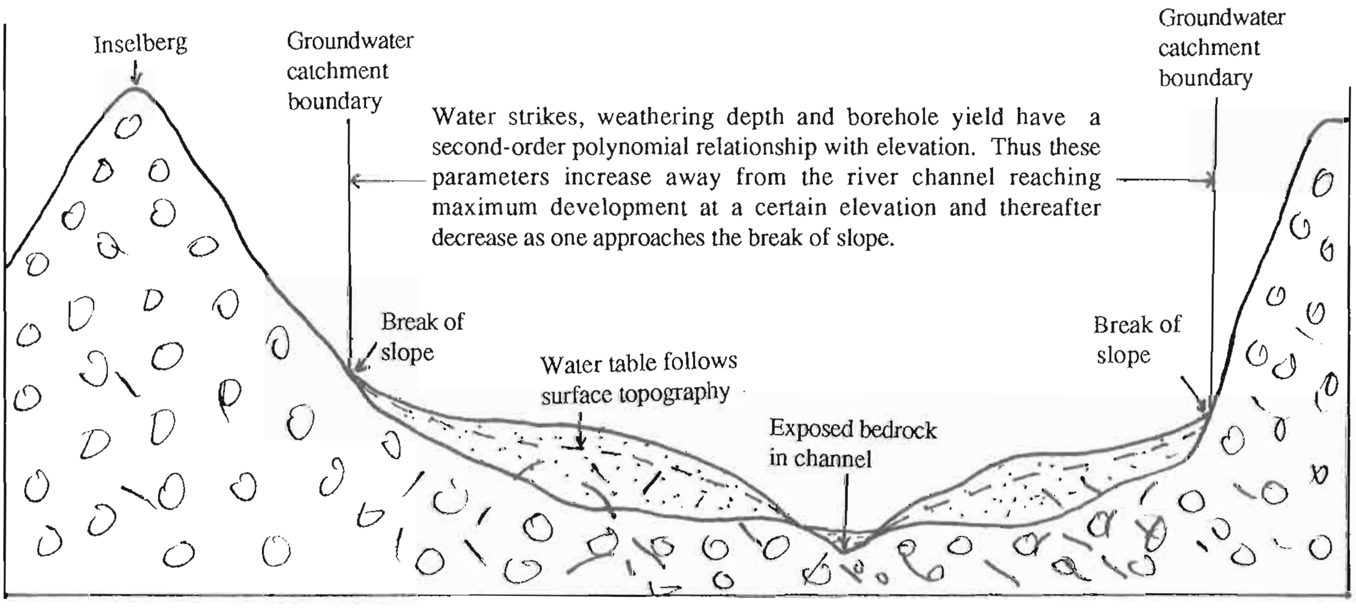
Fig 2 The influence of topography on the spatial variation in groundwater characteristics

Table 2 Regression coefficients between topography and groundwater characteristics in southwestern Nigeria

Groundwater characteristic	Site elevation				Overland slope			
	simple regression		2nd-order polynomial		simple regression		2nd-order polynomial	
	R %	R^2 %	R %	R^2 %	R %	R^2 %	R %	R^2 %
Water strikes	77	59	79	63	62	38	62	38
Discharge per water strike	70	49	78	61	50	25	61	38
Weathering depth	91	83	n.d	n.d	65	42	71	50
Development airlift	31	9	55	30	16	3	41	17
Safe yield	55	30	94	89	56	31	87	79
Transmissivity	16	2	63	39	19	4	79	62
Specific capacity	19	4	52	27	33	11	70	49

Even though the correlation is generally good, topographic characteristics do not adequately predict the parameters analysed - the coefficients of determination (i.e the percentage variance accounted, R^2) are generally low except in the case of yield where the fit was 89%. The low R^2 is indicative of the importance of local variations in rock composition and/or texture, vegetation and land use. These factors are however difficult to quantify. All the wellfields studied are within the same vegetation and climatic zone and the unaccounted variance can be reasonably attributed to rock lithologic/textural and land use variations between wellfields. An examination of the borehole lithologs did indicate an association between the occurence of pegmatites and quartzitic veins and good borehole yields irrespective of topographic location.

Recharge to a well in crystalline rocks is primarily derived from precipitation which seeps into the ground within the well's immediate vicinity - Florquist (1973) suggested a radius of 600 m. Land use practices within this radius will affect the soil infiltration characteristics and consequently the recharge. Urbanisation as reflected in housing and road development leads to an increase in the percentage of impermeable area within a catchment, and since regional groundwater is limited, recharge is low and well yields are poor. The results from Obangede and Obehira wellfields illustrate this effect. The wells in Obangede are sited within the township while those in Obehira are sited dominantly in remote locations on the outskirts of the village. Inspite of comparability in other respects, yields are approximately three times higher in Obehira than in Obangede.



Water strikes, weathering depth and borehole yield have a second-order polynomial relationship with elevation. Thus these parameters increase away from the river channel reaching maximum development at a certain elevation and thereafter decrease as one approaches the break of slope.

Fig 3 Groundwater catchment and spatial characteristics in southwestern Nigeria

Optimum drilling depth

The fracture frequency decreases with depth (Figure 4). A maximum drilling depth of 70 m is recommended as over 90% of the fractures occurs before this depth.

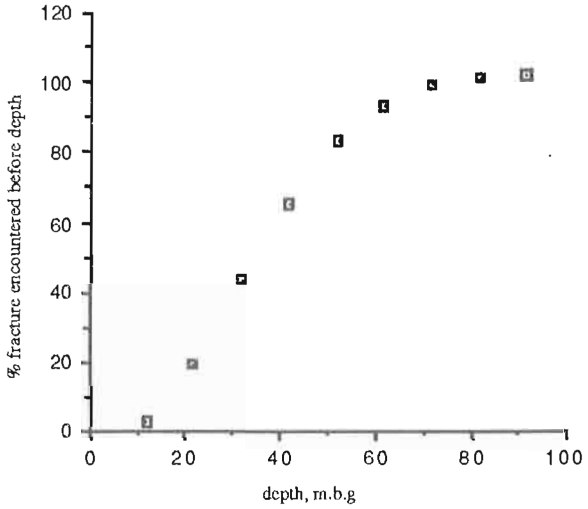


Fig 4 Variation in fracture frequency with depth

Vertical variation in regolith permeability

The permeability of the weathered regolith increases with depth and it is highest in the interface zone overlying fresh fractured rock. This is evidenced by high flow rates recorded within and immediately below this zone. In the interface, weathering is less advanced and the products are not as clayey as further up in the profile.

The water table

The water table is a sub-dued replica of the surface topography. The water table varies seasonally being deepest at the end of the dry season (April/May), and shallowest and fairly uniform during the wet season from around end of June to end of October. The fluctuation on average is about 2m.

CONCLUSION

The study has shown that good prospects exist for groundwater in the study area. Yields and other groundwater characteristics vary substantially from place to place with regional averages of between 1.8 and 4.9 litres per second. Locally, yields as high as 15 litres per second were recorded. The study indicates that topography influences the groundwater prospects as reflected in the way groundwater characteristics vary spatially. Water strikes, weathering depth and borehole yield have a second-order polynomial relationship with elevation. Thus these parameters increase away from the river channel reaching maximum development at a certain elevation and thereafter decrease as one approaches the break of slope. On individual wellfields, local variations in rock lithology/texture and recharge characteristics tend to mask this regional trend.

There is no doubt that exploitable groundwater is available. Small house-hold water requirements can be easily met through large diameter wells tapping the weathered regolith. The siting of such house-hold wells is normally constrained by the boundaries of the property, but it is important that the well be dug through the entire weathered depth including the weathering interface. As a precaution against dryness during the dry season, it is recommended that digging be undertaken towards the end of the dry season (Late February/early March) when the water table is deepest. If possible digging should continue for at least 2m below the current water table. The diameters commonly employed for dug wells in south western Nigeria vary between 1m and 1.5m. There is no reason why much bigger diameters could not be used - in India large wells are of the order of 4 - 6 m in diameter.

Bigger schemes should be preceded with detailed geological investigations. The presence of pegmatite dykes and quartzitic veins are particularly favourable and well siting should take cognizance of these. Wells are better sited upstream of such planar bodies to take advantage of their groundwater damming effect.

Wells should be sited away from built up areas since the reduction in the amount of permeable area resulting from housing and road development leads to poor recharge and well yields. The economics of transporting the water to the consumers should be balanced against the expected improvement in yield in remote locations. It may be possible that drilling two or more wells nearby to meet a stipulated demand is cheaper than the cost of pipeline and additional pumping to be incured by drilling in a remote though higher yielding location.

ACKNOWLEDGEMENT

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