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GS10 PROJECT: EVALUATION OF GROUNDWATER RESOURCES IN BOTSWANA.

Dr E P Wright

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Report by: Dr E P Wright. Institute of Geological Sciences

CONTENTS

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1. Requirements: Plan of operation and terms of reference.

2. Reasons for Project:

These may be summarised as follows:-

(i) Need for groundwater is obvious since there are no permanent surface water supplies except in the Okavango Region.

(ii) Annual abstraction of groundwater in Botswana has been estimated very roughly as 18 million cubic metres (UNDP Report, 1972). It is not known whether exploitation is exceeding recharge in any aquifer nor in many cases whether recharge is occurring at all.

(iii) There is a continually increasing demand for groundwater supplies for small-scale users and in relation to major planned projects, which include mineral development and new towns.

(iv) Accurate quantitative evaluation of resources would permit more efficient long-term planning.

3. Preliminary Discussion:

Groundwater investigations have been carried out by the Geological Survey since the early 1950's. Between May, 1968 and May, 1972, a United Nations team carried out a survey of water resources in Botswana combined with some ancillary local studies. Significant quotations from the Report are given below. The present project is essentially a suggested follow-up to the UN study with particular reference to groundwater.

"There is substantial scope for development of groundwater in Botswana, but future development needs to be approached systematically and scientifically. Much more work on regional, as well as local, hydrogeological problems is needed to delineate the most favourable areas. More application of scientific mapping and prospecting methods will be required. The selection and development of suitable areas must be co-ordinated with national policy on range management to avoid more damage to the rangeland which is already degrated in parts of the country."

"A great deal of valuable information is available in the files of the Geological Survey. The writer has attempted to draw on this information as a basis for his regional hydrogeological interpretation; however, a great deal more can be accomplished with a broad approach to evaluating this data."

"It is recognised that for most of Botswana and particularly the vast Kalahari region, groundwater supplies are essential if development of the country is to succeed. Therefore, the following recommendations are made:-

a) Analyse existing hydrogeologic data available at the Geological Survey and other government agencies as a beginning to an evaluation of the national groundwater situation.

b) Undertake a programme to locate and record data for the vast number of unknown boreholes in the country and provide a means for accumulating data for future boreholes.

c) Expand the existing Geological Survey programme of water level and chemical quality monitoring to include boreholes in key locations throughout the country to provide historical data for future groundwater planning and development.

d) Undertake systematic groundwater investigations utilising modern hydrological and geophysical techniques in areas of need, particularly to provide villages with an adequate quantity of potable water.

e) Undertake basic research into particular hydrogeologic problems; for example, recharge studies in the Kalahari; geochemical studies to aid in delineating areas of best quality of water; determination and evaluation of major aquifers; application of aerial photography and other remote sensing techniques to the evaluation of regional and local hydrogeological studies; application of geophysical techniques to borehole siting; and others.

f) Evaluate potential of dug wells as a source of local domestic and cattle-watering supplies in favourable areas, including the possibility of artificial recharge by water spreading and other techniques.

g) Continue investigations of sand rivers, including best methods of water extraction and possibility of water conservation by construction of 'sand storage dams'.

h) Exercise more control over borehole drilling in the country to have a knowledge of the location and records of all boreholes, and to ensure that professional standards are maintained for borehole construction.

i) Encourage private sector drilling contractors under such control to drill private boreholes and thereby relieve the Geological Survey of drilling water supply boreholes so that it may fulfil its role as a scientific agency."

The UN recommendations are sound and reasonable but the practical difficulties in carrying them out will be considerable. The reasons for this belief may be summarised as follows:-

a) There are probably more than 12,000 boreholes (verbal estimate by Mr R G Rae of T P O'Sullivan and Partners. This Company is preparing a Borehole Maintenance Proposal Scheme) in Botswana and a very large number of dug wells. The GS has records and hydrological data on some 4,000. Additionally, although these records contain valuable data, they generally lack such fundamental information as water level elevations, specific capacity, proposed production rates etc.

b) The activities of the Geological Survey re: groundwater have been mainly concerned with the siting of successful boreholes and relatively little attention has been given to more fundamental hydrogeological studies, especially any involving quantitative evaluations. This approach has resulted, I understand, in no small measure from the lack of staff but in the circumstances has considerably increased the difficulties of the present situation.

c) Groundwater in Botswana aquifers is said to occur mainly in secondary fractures. Aquifers composed of fractured rocks tend to have variable hydraulic characteristics and in consequence evaluation of total resources as well as of the fundamental response characteristics which relate to practical long-term exploitation is more problematic.

In view of the urgency attached to this Project for reasons outlined in (2) above, a decision requires to be taken as to whether to commence a systematic groundwater inventory or to concentrate immediately on studies of selected hydrogeological aspects and on resources investigations in localised areas. Although the latter approach would provide results of more immediate significance, it needs to be recognised that these would have been obtained without benefit of a background knowledge of more broadly-based hydrogeological considerations which could have a significant bearing on the problems concerned. Additionally the difficulties resulting from the lack of a systematic and scientifically based regional analysis will increase as time goes on. For these reasons it is recommended that systematic regional analysis be commenced at an early stage in the project but that it should be initiated in flexible fashion with due regard for practical priorities and to become associated with more particular special studies as soon as possible. The recommended GS 10 project is, therefore, phased. Phase 1 could be initiated by the Geological Survey, staff permitting and be continued when the additional Project staff become available. As far as possible planning for the second phase should be made in advance. In all these considerations, it requires to be realised that the fundamental aim of the Project is the quantitative evaluation of resources so that the main emphasis will be on the recognition and determination of those parameters which can most readily provide this information. It should be remembered, however, that the minimum data required for adequate evaluation is a function of the variability of the controlling parameters. If the variability is great, it may be impracticable to carry out the investigations on the appropriate scale of magnitude unless the need is proportionally great. It is important, therefore, as a preliminary measure to use all indications (geochemical, geophysical, geological, hydrological) to ascertain the likely degree of variability in the significant aquifer parameters in deciding upon the feasibility of making a quantitative evaluation of an aquifer's resources. Botswana aquifers are known to be variable in physical characteristics and water quality. It is precisely on account of this variability that more broadly based studies utilising all readily available sources of information must be made in order to obtain information on the controlling parameters.

4. Aims of the Project

4.1. Phase 1

i) To define and locate aquifers within the basic geological framework and as far as possible ascertain the controlling boundary conditions within and between major aquifer units.

ii) To determine and record data on the occurrence of groundwater within the aquifers which will relate to the following aspects:- origin, quality, available storage (to include all grades of quality), recharge rates, discharge rates both natural and artificial etc.

iii) To define and commence (or continue) specific studies on significant aspects which are of most importance in the context of the resources evaluation and exploitation of the Botswana aquifers. These studies could, where feasible, be carried out in areas of particular local importance. They include:-

a) Extent and significance of fracturing in those aquifers mainly affected, to include consideration and preliminary testing of most appropriate methods of aquifer analysis.

b) Infiltration studies in Kalahari sands including localised studies such as the use of radioactive isotopes, changes in observation well levels in relation to rainfall, and more regional analysis (flow net, geochemical patterns etc).

c) Further developments in geophysical techniques including remote sensing.

iv) To produce a series of hydrogeological maps for each aquifer or significant interval of an aquifer having due regard for three dimensional variations. These would include:-

a) piezometric surfaces maps
b) depth to water table
c) hydrogeochemical (electrical conductance, total dissolved solids, significant geochemical ratios etc)
d) saturated thickness

e) lithofacies variations
f) structural
g) specific capacity variations etc.

The maps and sections can be used along with information from (i) - (iii) to evaluate general hydrogeological conditions in the aquifers and to form the basis for the more quantitative Phase II studies.

4.2. Phase II

i) To select areas for more detailed evaluation on the basis of the results in Phase I combined where feasible with local planning requirements. Test drilling might be required (a) to obtain information on favourable areas indicated by the regional studies, or on deeper levels in an aquifer than heretofore examined; (b) for detailed aquifer testing, age relations etc.

ii) Studies in Phase I (iii) would be continued as need be and possibly expanded with the added facilities provided by test drilling.

iii) Quantitative/qualitative evaluation of the groundwater resources of all aquifers. Modelling in selected aquifers could be carried out if the information and the requirements merit this detailed approach.

5. Methods

i) Analysis of relevant geological and hydrological data from the files in the Geological Survey. Careful consideration should be given to the reliability or representativeness of the data in these records (well locations, water and lithological samples, well water levels and any other hydrological measurements) by reference to the techniques used to collect the data and the personnel concerned (geologist, geophysicist, technical assistant, driller etc). Opportunity should be taken at an early stage to improve where necessary and where feasible the general techniques of measurement and recording.

ii) Preparation of a groundwater inventory in order to improve and up-date the existing records. This would require the locating and siting on suitable scale maps of any additional well, borehole, spring etc. not in the GS Records. Basic hydrogeological and well completion details should be ascertained and noted as far as possible. The following additional information is also required on all wells both new and previously recorded:-

a) Ground and well head elevations;

b) Current static water level;

c) Measurement of specific capacity;

d) Estimate of total abstraction since completion and estimates of annual production rates and measurements of current pumping rate and drawdown.

e) Measurement of specific electrical conductance and temperature of discharge; obtain sample from selected wells for geochemical analysis.

f) Selective well logging, probably mainly electrical conductance and temperature and less frequently other logs such as flow velocity, neutron, gamma-ray etc.

g) Notes on site conditions, type of pump, presence of other wells nearby in same or other aquifers which may permit carrying out of an aquifer test.

iii. Commencement of plotting of data on maps. The plots should relate to particular aquifers (different symbols can differentiate different aquifers) and for convenience can extend over districts or suitable map sheets etc.

iv. The specific studies should be related most closely to the final objectives namely the resources evaluation and taking into consideration the feasibility and timing of the studies and the availability of relevant ancillary data. Some rather specialised aspects have been listed above and these will need to be considered in relation to the more systematic regional hydrogeological appraisal.

The significance of this correlation may be considered as follows. Details of the Botswana aquifers have been summarised in the UNDP Report (op. cit.). The majority appear to have water mainly contained in joints and fissures; perhaps two only, the Karroo and the Kalahari Beds, having primary porosity. The Karroo has probably both. The distribution of fissures and joints can sometimes be such as to allow the aquifer to be treated as a hydraulically continuous body albeit with varying transmissibility and porosity but not of an extreme order of magnitude. Such aquifers can be analysed by appropriate classical techniques such as pumping test, flow net analysis etc. and treated in regional fashion. In other cases, and this could also apply locally within a statistically homogeneous body, transmissibility and porosity may be considerably greater in a local unit such as a shear zone. This zone could be treated as a localised aquifer and analysed accordingly. Analytical methods would need to relate to the geometry and hydraulic boundary conditions and the recognition of the boundaries and interrelations with the main aquifer may become apparent from the analysed drawdown data collected during a pumping test. In the case described above it may be possible to treat the zone as a strip aquifer, possibly leaky with recharge occurring through fissures in the main body intersected by the local zone. A predictive mathematical model could be prepared and calibrated by subsequent longer-term observations.

The importance of establishing the controlling hydrogeological conditions should be apparent from the above discussion. Indicative information can be obtained from a variety of sources and it may be necessary to be selective for reasons of time and convenience. Plotted piezometric head data can be indicative of hydraulic continuity even within a fissured aquifer but it may be time consuming to obtain (since ground elevations are not normally available in the GS Records) and interpretation may be difficult if abstraction data is also unknown. Geochemical plots can also be indicative and in the present circumstances may be easier to produce for the preliminary analysis. Changes in well water levels can readily be made and there is some available data in the GS Records. Many factors can control head changes and the interpretation will depend on the technical feasibility of establishing these controls.

The discussion has been elaborated in some detail in order to illustrate the approach which is recommended to be adopted. It is clearly impracticable to make a comprehensive ground water inventory of Botswana without the deployment of a substantial staff provided with all necessary equipment. Despite this difficult requirement, initiation of such a survey is to be recommended which could be weighted in accordance with the known geological conditions or assessed on the basis of such regional features as can be more readily plotted and analysed.

v. Geophysical Methods

Surface geophysical methods have been used extensively and it would appear very successfully in locating potable water supplies in Botswana. A variety of techniques have been used but most notably electrical resistivity. Geophysical methods are expected to continue to be useful in the future although they may become progressively less applicable as more detailed information from drilled holes becomes available. In connection with the current project, it would seem an appropriate time to take stock of the available records and to attempt closer correlations with the actual geological/hydrogeological features. Calculated resistivity values from analysis of surface measurements could be checked against data from down-hole logging measurement and their overall significance considered in a broader hydrogeological context. Fresh water underlying saline water is by no means an uncommon phenomenon although contrary to the general rule, and resistivity data requires careful and accurate quantitative analysis to detect such occurrences. A particular example of the importance of correlating geophysical data in a hydrogeological context may perhaps be illustrated by consideration of the geophysical investigations in the vicinity of the proposed Botswana-Zambia Highway. Boreholes drilled in the vicinity of located fissure zones yielded saline water whereas those in intervening areas yielded fresh water. A possible explanation of the feature is that upward leakage is occurring from a saline horizon of higher piezometric head. It would be important to determine the depth, extent and head relationships of this saline zone and the characteristics of the aquiclude between it and the upper fresh water zone.

vi. Hydrogeochemistry

The role of geochemistry will become more apparent after the basic available data has been analysed in relation to the various aquifers and presented in map form. The possible importance of geochemical trends in indicating fundamental hydrogeological conditions has been emphasised. The need to measure total water resources whether fresh, brackish or saline is also to be emphasised.

One particular aspect in which studies have already been carried out at some depth and are still continuing is in age determinations of groundwater using radioactive isotopes. These studies are being conducted by the Nuclear Physics Research Unit of the University of Witwatersrand in association with the Botswana Geological Survey. The value of such investigations could be greatly increased by close association with the regional and local hydrogeological studies planned in this project and a close collaboration is to be recommended.

vii. Establishment of a regional hydrometic network.

This should provide routine measurements in selected wells of static head (periodic or continuous recording), electrical conductance of discharge accompanied by more detailed geochemical evaluation following any significant changes (in conductance), discharge rates and specific capacity. Measurements should be made in selected production wells and also in observation wells specifically drilled for the purpose. Continuous metering of discharge in selected wells by pipe flow recorders is to be recommended in order to confirm production estimates by pump attendants (estimates based on time and discharge rates). Data of a varying degree of detail and complexity could be provided by pump attendants according to need and the attendant's capability. Project staff would need to co-operate closely with Water Affairs in this aspect of the programme.

6. Related Investigations

i. A number of groundwater investigations have been carried out in selected areas, notably Lobatse, Serowe, Orapa etc. either by the GS, by private consultants or by United Nations personnel during the recent resources survey. A discussion of these investigations is included in Technical Report No. 2 of the UNDP Report Series. These investigations should be given careful consideration as to whether related or follow-up studies are to be recommended. An illustration may be informative. In the Lobatse groundwater basins, resources calculations have been based on volumetric calculations of saturated thickness and recharge rates based on an assumed 4-5% infiltration of rainfall. The actual reports have not been studied but the UN Report notes that the estimated percentage infiltration is possibly too high. A cross-check on the calculation may be desirable and an obvious line of approach could be an evaluation of well water level changes. These would need to be considered in terms of recharge - throughput - artificial abstraction - specific yield, and the resolution of the analysis would depend on the variability of the aquifer structure in relation to measurement frequency.

ii. Investigations in process include notably the exploration for coal by British Petroleum and Shell. These investigations include test drilling and it would seem desirable to make full use of such activities as far as is possible. BP have expressed a willingness to consider carrying out additional measurements and tests of hydrogeological significance in their exploration holes. Additionally since water supply is likely to be of fundamental importance to coal development, special studies by the Companies concerned are likely to be required to evaluate available resources. It would be important to ensure that these are carried out in proper scientific fashion, and that they will provide maximum information within the accepted scope of the investigations.

7. Staff Requirements

7.1. Project Staff

These should include one senior and one assistant hydrogeologist on contract for two years with a possible extension for a further two years. Two technical assistants should be assigned as support staff supplemented by 2-3 additional assistants on a part-time basis from the Geological Survey. During the Phase I investigations particularly, the need will be for several junior assistant staff provided with adequate transport and equipment to carry out basic surveys under the control and guidance of professional hydrogeological staff.

7.2. Counterpart Staff from the Geological Survey.

The importance of counterpart staff is stressed both in the specialist fields (geophysicist/geochemist) as well as in the general hydrogeological field. The close support and collaboration of the Geological Survey would provide the local knowledge and expertise. It would also permit initiation of basic studies prior to recruitment of Project staff and ensure subsequent continuity of the Project work. It is emphasised here that the specialist studies (geochemist/geophysicist) should preferably be carried out by individuals with some hydrogeological background or alternatively by those prepared to make a considerable background study of the relevant aspects.

Supporting GS staff:-

i. Hydrogeologist
ii. Two or more hydrogeological/technical assistants
iii. Geophysicist/Hydrogeologist
iv. Geochemist/Hydrogeologist
v. Office, laboratory and cartographic staff as required.

7.3. Ancillary Staff

i. Surveyors, possibly supplied from the Survey Department. A basic need during the Phase I studies will be a controlled survey of ground and well head elevations using sophisticated barometric techniques. The surveyors could prepare a fairly detailed network of surveyed points and additional elevations could be tied in by the Project/Counterpart Staff during the course of their basic investigations.

A pilot levelling project for one month has been agreed to by the Survey Department. Further work of this type will be necessary which may be carried out in part by Survey Department staff, but in part also perhaps by contract recruited or 'consultant' staff.

ii. Occasional visits by specialists are to be recommended. These are likely to be in the specialist fields of geophysics, geochemistry or surface hydrology (ie infiltration studies). A particular case in point relates to the operation of the down-hole geophysical logger. This is a most important item of equipment which is expected to have a significant role in the Projects investigations. If GS staff are unable to make this equipment operative, it would be essential to obtain the services of someone else to do so.

iii. Temporary staff either on recruitment or by temporary secondment from other Government Departments, District Offices etc. to assist in the intensive groundwater inventory studies.

8. Equipment

A provisional list of required equipment is given below. The list includes two categories, one of basic survey equipment and the second, provision for specialised studies, notably infiltration research. In deciding upon survey requirements, consideration has been given to the need to supply several parties operating independently during the groundwater inventory stage. Numbers of individual items are provisional and may be revised in relation to available supply in the Botswana Geological Survey. Costs (10.2) are approximate but probably within 10%. Equipment that may be provided from Geological Survey supplies is indicated.

8.1. Equipment for basic survey

i.	Surveying altimeters (Wallace & Tiernan)	4
ii.	Base Barographs	2
iii.	Survey Equipment as required - Theodolite etc. (GS)	-
iv.	Electric water level measuring devices	10
v.	Water level recorders	10
vi.	Electrical conductance/temperature probes with 1000 feet cable	2
vii.	Surface geophysical and down-hole logging equipment (GS)	-
viii.	Electrical Conductance Bridges (surface samples)	2
ix.	Flow velocity logger	2
x.	Pressure transducer devices	2
xi.	Depth Samplers (large/small)	2/4

xii.	Long wheel base L/R complete with radios	4
xiii.	Camping Equipment etc. (GS)	-
xiv.	Pipe flow meters	10
xv.	Water filtration set for field chemistry	2

8.2. Equipment for special studies (mainly infiltration)

i. Automatic weather station ~~with radio transmitting facilities~~.

ii. Lysimeter installation materials and operative equipment.

iii. Soil moisture and potential measuring equipment, including neutron probe.

9. Drilling

The object of drilling would mainly relate to the installation of observation wells either as part of a proposed hydrometric network or for exploration and analytical studies resulting from the Phase I investigations or associated with the special research aspects. Most test holes would be expected to be of small diameter, less than 6 inches, and mainly open hole in consolidated formations. Casing will be necessary in unconsolidated formations and to hydraulically separate aquifer units for differential consideration.

10. Timing and Cost Estimates

10.1. Programme

Details of staff and provisional timings with regard to Project and GS counterpart staff are shown in the accompanying bar diagram Figure I. GS staff should be requested to produce fairly comprehensive monthly progress reports during the pre-Project Phase I stage. This will assist the Project staff when it comes to preliminary planning. In the early reports, full and comprehensive details should be provided of all relevant GS equipment, giving scope and current operational status. It may then be possible to order the additional equipment required and to have it available before the Project staff arrive. A gap of some eight months is assumed in this diagram between current date of this report and arrival of Project staff.

10.2. Provisional Costings

Provisional costings have been provided under three main headings, staff costs, equipment and drilling. In all categories, there are some uncertainties, mainly because the scope and requirements cannot readily be determined at the present time but are expected to be evaluated during the Phase I programme. This particularly refers to drilling and the special studies although the latter might well be initiated to some extent, eg equipment purchase, during the Phase I. Drilling costs are based on a very general estimate of footage and casing requirement. Provisionally it has been assumed that it will be better to use contract drilling expertise to obtain flexibility of rig type and timing. If on further investigation it should appear likely to be difficult to obtain a suitable contractor at the times required, it might be preferable to purchase a high powered air/percussion rig such as the COP-6 or the Schramm. The question of crew availability would need to be taken into account, possibly to the extent of including contract hire of a tool pusher.

Summary of estimated costs:-	Approximate costs (sterling)	Totals
a. Equipment		
i. Basic equipment including transport	25,000	
ii. Special equipment (infiltration studies)	15,000	
		35,000
b. Staff		
i. Professional 8 man years	80,000	
ii. Technical Assistant 8 man years	20,000	
iii. Local recruitment for intensive groundwater inventory (? Botswana Government plus temporary secondments other Departments).	15,000	
iv. Special studies and contract work:-	15,000	
1. Levelling surveys		
2. Visits by specialist staff		
		130,000
c. Drilling		
Estimated cost of drilling and completing 20 small diameter observation wells (generally less than 20 cm diameter and 160 m deep); mild steel or PVC casing and screen to total depth; allowance for cleaning and pump testing.		180,000
d. Drilling Rig		
Air percussion rig complete with basic equipment and tools, high power compressor (100/250 psi; 600/1400 dfm), trailer and towing trucks; one tool pusher for one year but other drilling crew not included.		110,000
e. Modelling (as required) in U.K.		5,000

11. Recommendations for preliminary studies by GS staff in pre-Project Phase 1.

11.1. Pilot Survey of ground and well head elevations (Geological Survey in co-operation with the Survey Department).

It is suggested that this survey should be done in the Ngwaketse and Kgalagadi Districts since it is understood that some hydrogeological work has already been planned in the former area. The aquifers concerned include the Transvaal and Waterberg Systems, Karroo and possibly Basement. Levelling should be carried out by controlled barometric traverses using a base barograph and manually read base altimeters (2) for drift correction, and two altimeters for each field party. Side traverses can be commenced and closed upon the line of accurately levelled positions on the Kanye-Tshane Road. Other check points could include re-occupiable positions set up during the Kalahari gravimetric survey. The Survey Department has offered to provide three parties complete with vehicles, observers, tentage etc. and to supply four altimeters and a base barograph. The observers will be organised and measurements checked by a Survey Department Technical Officer. The period of this pilot scheme is suggested by the Director, Survey Dept. to extend for one month. The general selection of traverse lines and boreholes should be made by the GS Hydrogeologist in close co-operation with the Survey Dept. Technical Officer. The Hydrogeologist could also proceed with a programme of basic hydrogeological data collection on boreholes as time permits. Water level data could be measured by Survey Department observers if this can be done conveniently and easily (e.g. wells in equilibrium, accessible etc.) but such work should not be allowed to delay the prime purpose of the survey. The accuracy of the levelling is expected to be in the range ± 2.5/5m. Whether this is sufficient for the hydrogeological requirements cannot be determined at the present time until information become available on piezometric level variations. The data already obtained from the boreholes in the Karroo in the central Kalahari can be considered in this respect. For the pilot project, it would seem advisable to extend the survey over as large an area as possible within the time limits imposed. Subsequent projects can then be defined more closely on the basis of information on the overall range of significant levels.

11.2. Preliminary data collection, plotting and analysis.

Brief notes of the general activities of the Counterpart Staff during the pre-Project Phase I period are given below. It is not intended to be exhaustive and it is to be hoped that the staff themselves will be able to add to and formalise these items in a more detailed manner after a preliminary assessment of the available data.

i. Hydrogeologist: There appears to be comparatively little data in the existing records which can be expressed in map form other than the assignment of a borehole to a particular aquifer and the preparation of a depth to water table map,* combined perhaps with some utilisation of well depths and initial yield figures. More important work can probably be carried out in updating the data collection along the lines described in 4.iv. The hydrogeologist should also be responsible for organising the Survey Department's pilot levelling project. He should measure static (equilibrium) water levels in as many of the surveyed wells as possible and prepare a report on the project. The report should include an assessment of general borehole status and indications of the type of measuring equipment suitable for the range of site conditions encountered. It may be necessary for example to carry equipment for cutting access holes into wellhead structures.

The hydrogeologist could also commence the co-operative activities with other Government Departments which will prepare the way for a comprehensive inventory of groundwater abstraction. The country should be subdivided into convenient units and a list of boreholes and their locations (map) provided to the local organisations who will assume responsibility for the preliminary survey. These authorities should provide such information on any borehole or well as they are conveniently able to do so (current discharge rate, general abstraction rates, water levels perhaps sample for conductance/analysis). Boreholes/wells not in the GS Records should be located as precisely as possible. This preliminary survey would permit the carrying out of a more precise survey to be made more efficiently and economically. The final survey would probably be incorporated into the main Phase I or II activities. It should also be appreciated that this type of data input from local level should not be regarded as a once only operation. To an extent that would eventually be determined, it should be regarded as a continuing process to monitor groundwater abstraction and quality.

ii. Geochemist. There is fairly extensive data in the GS Records which could be presented in map form relating units - tds, specific electrical conductance. appropriate chemical ratios etc. to the relevant aquifer, and attempting correlation as far as possible with lithology, groundwater flow patterns etc. Such maps could constitute valuable indications of basic hydrogeological conditions.

* The value of this map would be greater for areas with contour topographic control.

iii. Geophysicist. General requirements have been indicated and may be summarised as follows:-

a. Assessment of previous records and correlation of exploratory probes with results of subsequent drilling. Some re-analysis of raw data may be necessary.

b. Presentation of correlative results in accessible form so that ready reference can be made for background information on the relevant physical characteristics and constants for a particular area and within an aquifer with due consideration for the effects, where any, of variations in water quality.

c. In all additional work, attempting closer correlation of exploratory measurements with subsequent borehole data including the results of various down-hole logging devices.

iv. Technical Assistants: It is envisaged that several technical assistants are likely to be required during the four years Project activity. These should preferably be local recruits who have some qualifications in mathematics and/or physics at either A or O level. It is strongly recommended that numbers be recruited as soon as possible so that they are able to undergo preliminary training by GS staff. In view of the future need of Botswana in this field of work, one would expect that encouragement would be given to suitable individuals to extend their studies to degree or post graduate standards.

12. Project Work

General aims and suggested methods have been given. Further brief notes on a few specific aspects are included for consideration here.

12.1. Hydrology of Fractured Rocks

Water resources of fractured rocks tend to be difficult to evaluate quantitatively as they are frequently heterogeneous in consequence of preferential directions and degree of fracturing. Special analytical techniques may be necessary and the amount of information necessary for proper evaluation increases proportionally with the degree of heterogeneity. It is important, therefore to ascertain the general conditions of groundwater flow and the general variations in water chemistry as this will give an indication of the basic continuity of the aquifer and assist in deciding the most appropriate analytical techniques.

In the case of the Botswana aquifers some information is available, but is very limited. Information on the locations of significant shear and fracture zones has been obtained by various geophysical means. The use of such techniques is to be recommended and studies should be extended and systematised. Other techniques such as remote sensing should be also considered.

It should be remembered that these techniques mainly respond to fracture systems which have a surface expression and which are therefore likely to be vertical or steeply dipping. Shallow dipping or horizontal systems require a different determinative approach, mainly associated with drilling and down-hole logging. To a lesser extent, surface geophysical methods can be employed if a horizontal fracture zone results in a suitable physical anomaly. Air/percussion drilling is particularly useful in exploratory work since the discharge rates during drilling below the water table afford a valuable indication of variations in permeability with depth. It is important, therefore, to ensure that this type of information is recorded accurately during drilling. Other data which can be readily obtained during drilling by this method include variations in water quality and temperature, piezometric head changes (measured during any cessation of drilling with due regard to probable attainment of equilibrium) and the general formational characteristics (size and abundance of fissures) which are reflected in the general response and behaviour of the drilling rig.

The collection of the varied data from such sources will form the necessary background to more detailed and sophisticated analytical studies and calculations.

12.2. Infiltration Studies

Until recently it was believed that no direct recharge of underlying aquifers occurred under present-day climatic conditions whenever a persistent cover of sand of Kalahari type exceeded 25 feet (Boocock and Van Straaten, Records of the Botswana Geological Survey, 1957/58). The general concept was that the moisture deficiency developed in the surface sands by evapotranspiration from the vegetative cover was always sufficiently in excess of rainfall intensity with resultant absence of recharge to the main reservoir below. The general concept appears reasonable except in the correlation with sand thickness rather than with a more directly related characteristic such as vegetation type and degree of cover. If no correlation of these latter features exists with a minimum sand thickness of 25 feet, it is difficult to see why no recharge will occur when this thickness is exceeded. However, recent isotopic studies on groundwaters in the vicinity of Orapa Pan and elsewhere in Botswana by the Nuclear Physics Research Unit of the University of Witwatersrand have shown that recharge can occur through this thickness of sand.

Further research on possible recharge to the main aquifers which underlie the Kalahari is clearly desirable but infiltration studies through the sand cover must be considered in their proper context as possibly one of the relevant processes. This requires that the aquifers and the overlying Kalahari Beds must be studied separately and together to determine their appropriate hydrogeological characteristics and inter-relations both under conditions of natural flow and of artificial discharge. Natural recharge to the aquifers could be from outcrop as well as through the Kalahari Beds. These relations will be made apparent from the basic hydrogeological studies proposed (piezometric head and geochemical maps etc) and initial appraisal may show merit in carrying out more sophisticated studies of flow movements through the poorly permeable Kalahari Beds under natural head differentials using temperature profiles.

The possibility of induced recharge into an aquifer by leakage under artificially created heads will also need to be considered. Such induced recharge could be undesirable, if the water quality in the overlying Kalahari Beds is poor.

It should be recognised that much basic information on the entire geological sequence is essential prior to setting up detailed infiltration studies. These should then be set up initially at sites where recharge, either natural or induced, is likely to be a significant factor in resources availability. Instrumentation will be fairly expensive (lysimeters, climatic, soil moisture and potential measurements, vegetation and soil characteristics etc) and difficult to maintain in a remote area. Very careful planning will be necessary.

12.3. Data Collection and Recording

In view of the large number of unrecorded boreholes and the scale of the proposed studies which are to include a groundwater inventory and the preparation of a comprehensive series of maps, careful consideration should be given as to whether a more advanced system of data recording, possibly using computerised techniques, should be introduced at this stage.

13. Conclusions

1. A broadly-based, systematic and essentially quantitative approach to groundwater resources evaluation in Botswana is recommended. Project staff should consist primarily of one senior hydrogeologist who has broad experience and who is analytically oriented plus an assistant hydrogeologist. The project staff should be engaged for a two year period with a possible extension for a further two years. Additional support staff (2) of technical assistant/scientific assistant grade should also be assigned to the Project.

2. A considerable emphasis is placed on local input to the Project for reasons of appropriateness, efficiency, economy and continuity. If such local input, particularly from the Geological Survey is not forthcoming, additonal Project staff might be required. Initially these should be of junior, non-professional grades but eventually additional professional staff might be required for short or longer term periods as the need is decided upon.

3. Local input from the following sources is recommended:-

   a. Botswana Geological Survey. A significant counterpart contribution from the GS is requested in order to obtain the advantages of local knowledge and expertise, to ensure continuity of the Project as regards the Survey's activities, and to permit preliminary background studies to be commenced immediately. The following staff are recommended to be assigned on a variable time basis (see bar chart).

      i. Hydrogeologist
      ii. Hydrogeophysicist
      iii. Hydrogeochemist

   It is appreciated that neither hydrogeophysicists nor hydrogeochemists are available as such in the Survey. The work should preferably be given to individuals of the appropriate disciplines who are prepared to make the necessary ancillary studies within a hydrogeological context. Additional support staff of technical assistant grade will be necessary, particularly for the hydrogeologist and to a lesser degree for the other two assignments.

   b. Other Government Departments or Divisions as follows:-

      i. The Survey Department
      ii. The Water Affairs
      iii. Ministry of Mineral Resources and Water Affairs Planning Division
      iv. Ministry of Agriculture
      v. Water Apportionment Board
      vi. District Officials including Rural Development Planning etc.
      vii. Borehole Maintenance

   The Survey Department will be concerned mainly with the levelling activities required in connection with borehole inventories. All other Departments/Divisions will be concerned with the initial information survey of boreholes and wells and to a greater or lesser extent with the continuing supply of basic information on borehole abstraction and sample data.

c. Research organisations such as the Nuclear Physics Research Unit of the University of Witwatersrand.

d. Mining Companies (BP, Shell, Anglo-American) whose operations require the use of large supplies of water.

e. Private Hydrological Consultants engaged by Government or private companies to carry out local investigations. It is important to ensure that these investigations are designed to provide maximum data within the scope of the particular investigation concerned. Governments are sometimes reluctant to employ such professional organisations on account of the cost, and indeed these can sometimes be excessive and unnecessarily high if the consultants are given a free hand. However careful control and supervision of such activities both in the planning and subsequent operative stage by experienced personnel of the Geological Survey may enable such work to be carried out at reasonable cost and at the same time gain the advantage of the flexibility and expertise of the consultant organisations as and when required. This type of approach may most efficiently permit the deployment of the limited resources of the Geological Survey within a number of localised projects of immediate need and at the same time to carry out more fundamental studies to provide the background information needed for the local investigations.

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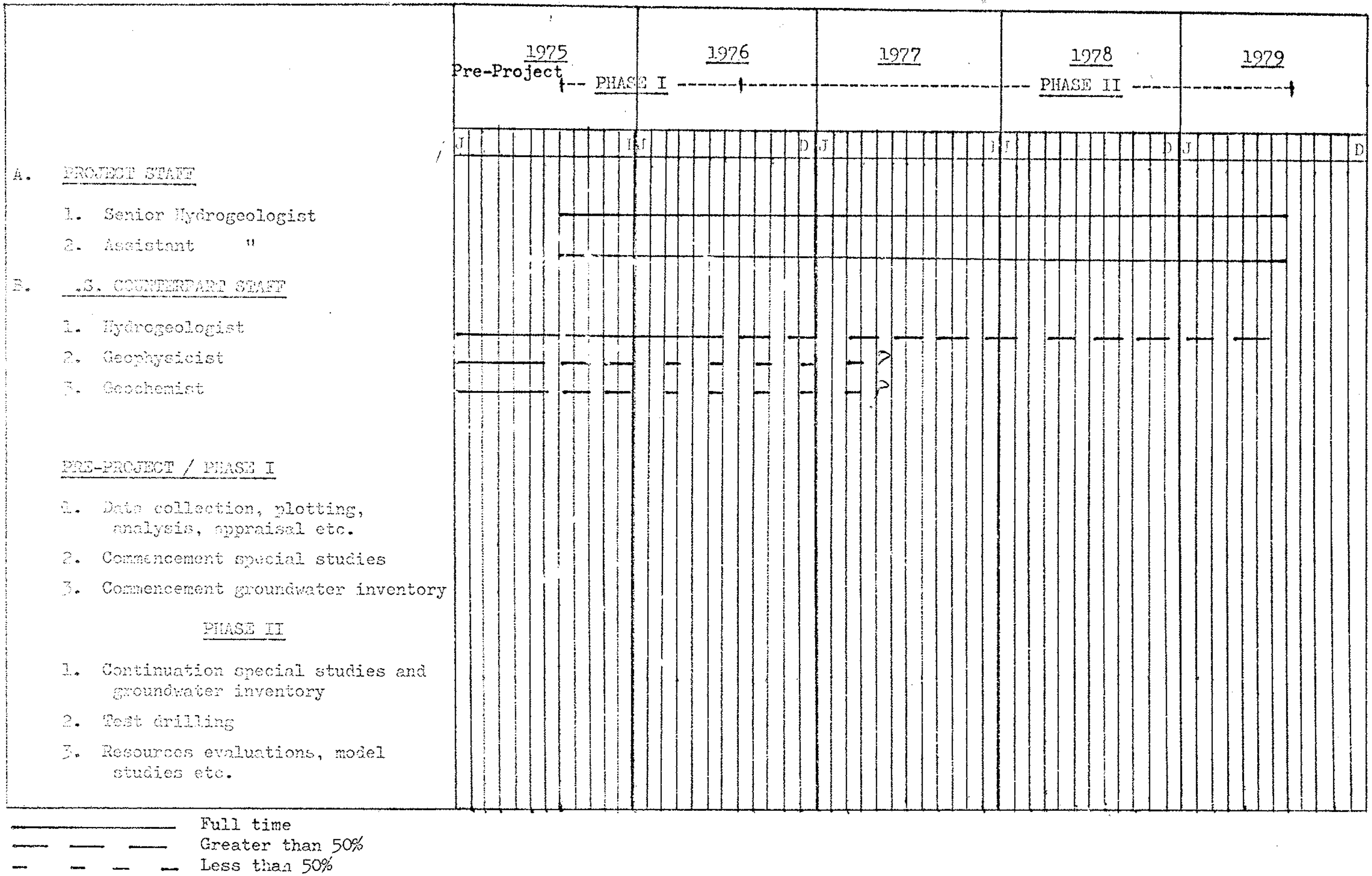
Dr E P Wright


1975
1976
1977
1978
1979
Pre-Project
PHASE I
PHASE II
J
D
A. PROJECT STAFF
1. Senior Hydrogeologist
2. Assistant "
B. .S. COUNTERPART STAFF
1. Hydrogeologist
2. Geophysicist
3. Geochemist
PRE-PROJECT / PHASE I
1. Data collection, plotting, analysis, appraisal etc.
2. Commencement special studies
3. Commencement groundwater inventory
PHASE II
1. Continuation special studies and groundwater inventory
2. Test drilling
3. Resources evaluations, model studies etc.
Full time
Greater than 50%
Less than 50%