3 METHOD OF INVESTIGATION

3.1 GENERAL APPROACH

Ground water development within rural South Africa was always seen as a crisis relief effort. Villages are identified as separate units, which limit the budget for ground water development. The approach to identify an area, develop the most promising ground water resource and planning a bulk water supply scheme was not followed. The approach followed during this research project deviated from the crisis management approach and may be summarised as follows:

- Identify areas with a history of rather low ground water development potential.
- Initial evaluation of existing boreholes to determine the current ground water status and daily abstraction volumes.
- Determine the yields of existing boreholes from available existing borehole information.
- Geological and geophysical surveys, including electro-magnetic and magnetic profiling, as well as detailed geological mapping based on the study of satellite imagery, aerial photographs and field work.
- Utilize the geological information to identify potentially high yielding sites (PHYS).
- Construction of additional boreholes by means of air percussion drilling, during which an estimation of the groundwater yield at each borehole is obtained.
- Determine the borehole yields and aquifer characteristics.
- Determine the chemical quality of water samples taken during the investigation.
- Compilation of a report detailing all results, including recommendations regarding production boreholes.
- Limited modelling of the aquifer characteristics.

3.2 IDENTIFYING POTENTIALLY HIGH YIELDING SITES (PHYS)

During many of the community water supply programmes the consulting geohydrologist usually have a limited budget available. Therefore instead of identifying a single target with a potentially high yield the consultant identify a number of different targets hoping to eventually strike water. In many instances the target is not intersected and the drill is shifted to the next site. Therefore a systematic approach was followed during this investigation to identify potentially high yielding sites, which incorporated the following steps:

1. Data retrieval
    - Gather geological information from the sources already mentioned.
2. Desk study
    - Study aerial photos (Scale 1: 50 000) and orthophotos (Scale 1: 10 000) . Interpret the geology and integrate it with the published geological information. During the photo interpretation it is important to identify all geological structures.
3. Field visit
    - The desk study is followed by a field visit.

4. Final evaluation

- A photo-geological map is produced with emphasis on the geological structures.
- Use knowledge of the dip, strike, estimated age, magnitude of movement, size and length of geological structures, to target *potential high yielding sites* (PHYS's).
- Locate new borehole positions with the aid of geophysics, or if outcrops are present boreholes can be positioned using dip and strike of joints and faults (basic trigonometry).

3.3 GEOPHYSICAL METHODS

A separate geophysical research project, also conducted by the Department of Earth Sciences, University of Pretoria with the emphasis on geophysical exploration techniques ran parallel to this present FRD funded geohydrological research project. The geophysical project was funded by the Water Research Commission (WRC) and the results are reported in an unpublished M.Sc by M.Combrinck (1999).

3.3.1 Air-borne methods

During this project air magnetic and air electro-magnetic data were used to identify regional linear geophysical anomalies (Figure 4).

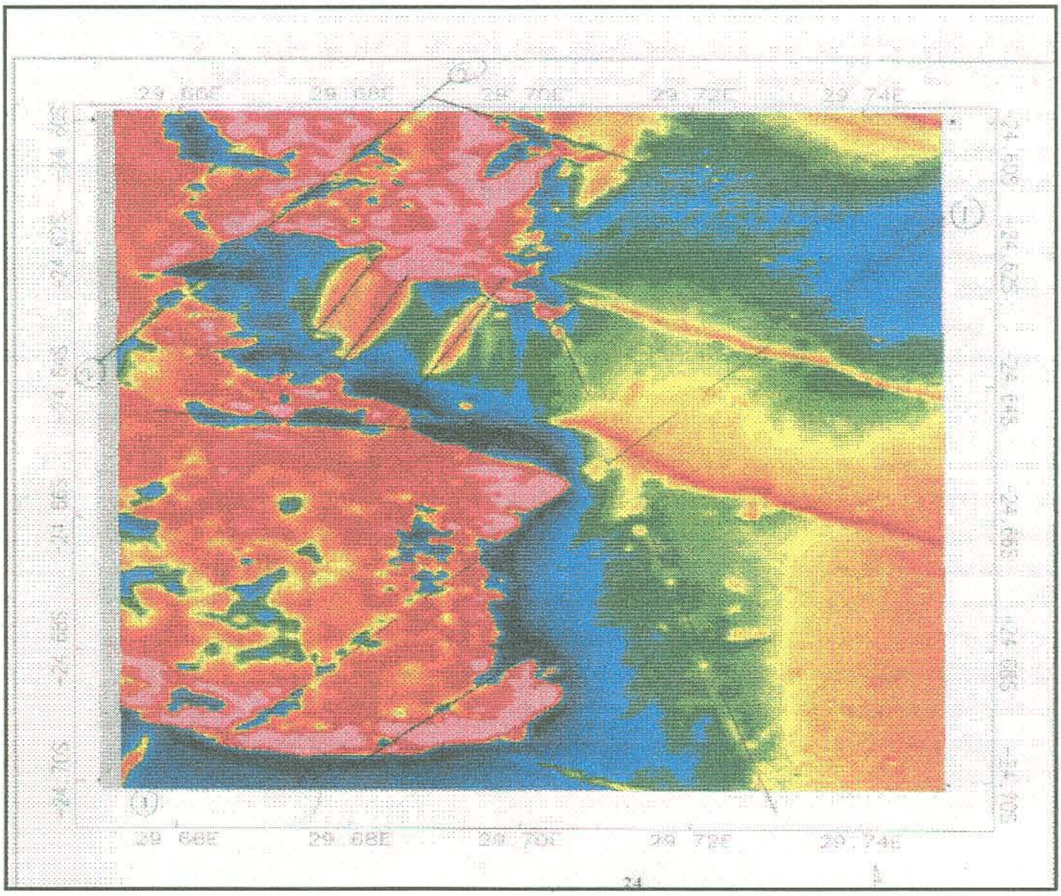

Figure 4. Air-borne magnetic data from Combrinck (1999). Indicating several linear features.

3.3.2 Magnetics

Different geological materials have different magnetic characteristic and their influences on the earths' natural magnetic field are captured with a magnetometer. The earths' total magnetic field is measured with a magnetometer. Magnetic surveys were carried out by means of a G5 Proton Magnetometer, to identify lithological changes and structural boundaries. A station interval of 5 metres was used.

3.3.3 Frequency domain electro-magnetic (EM) method

The EM-34 system was used for measurement of the terrain conductivity. Data obtained from this instrument can be correlated with data obtained from the magnetic surveys. The EM-34 is a moving-source-moving-receiver system. The transmitter consists of a coil made from copper wire. An electrical current is passed trough the coil, creating a magnetic field. The magnetic field induces an electrical current via the geological material, the induced current induce a secondary magnetic field and is measured by the receiver. The induced magnetic field is measured as mS/m.

3.4 CONSTRUCTION OF NEW BOREHOLES

3.4.1 Rotary air percussion drilling

Rotary air percussion drilling with a down-the-hole hammer (DTH) was used to drill new exploration and production boreholes. Cuttings from the percussion drill are brought to the surface via the air return and collected every metre, and described according to the lithology. Depths of water intersections are recorded, and blow lift yields measured with the aid of a V-notch weir. Casing is installed from surface, through unstable, unconsolidated or fractured material down into solid bedrock. Perforated casing sections are installed across water bearing horizons to allow ground water to flow into the borehole.

3.4.2 Core drilling

Core drilling using a hammer with a diameter of 75 mm was employed to get an undisturbed sample of the underlying material. It is a well-known tool in site investigations for amongst others, dams. It is used to identify weathering, lithology and fracture zones. The core is extracted from the borehole, measured and placed in a core box.

3.5 PUMP TEST EVALUATION

Three methods were used to evaluate the pump test results. These methods range from the most empirical method to a well advanced analytical method recently developed.

3.5.1 Rule of thumb method

It is a widely used method and is used to calculate sustainable production yields. It takes into account the total volume pumped and the total time until 100% recovery is obtained. The production yield is then calculated. If full recovery is not obtained this method is worthless. The different parameters are calculated as follows:

1. Total time(TT) = pump time + recovery time
2. Total volume (TV) = pumping rate x pumping time
3. Yield = TV/TT
4. Production Yield = Yield x Factor of Safety (70%)

3.5.2 Recovery method

Similar to the rule of thumb method and also commonly used is the recovery method. This method also only allows for the calculation of a production yield. When using this method the recovery is plotted against t/t' on a semi-log graph (Figure 5). The recovery period and the production yield can be calculated as follows:

1.t/t' = (total time pumped(x)+ recovery(y)) / (total time pumped(x))
2.t/t' = 1.5
3.x+y/x = 1.5
4.y = 1.5
5.If pumping cycle is 24 hrs (1440 min), then
recovery period = 1440 min/y
= 1440/1.5
= 960 min
6.Pumping period = 1440 min - 960 min
= 480 min
7.Litres pumped = time x pumping rate
= 480 x 60 x 3
= 86400 litres
8.Pumping rate (24hrs) = volume/time
= 864001 / 86400s
= 1 l/s
9.Recommended yield = 1 x Factor of Safety
= 0.70 l/s

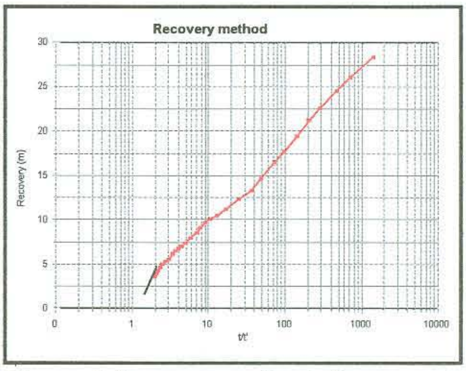

Figure 5 Recovery method. Recovery is extrapolated and t/t' is between 1 and 2.

The advantage of the recovery method over the rule of thumb method is that the recovery does not need to be 100%. The graph can be extrapolated and t/t' can still be obtained.

3.5.3 F.C._method

The Flow Characteristics Method is a method which was recently developed by the University of the Orange Free State in conjunction with the Department of Water Affairs and Forestry and the Water Research Commission. The method calculates the 1st and the 2nd derivatives at each data point of a semi-log draw-down plot (Cooper-Jacob). Therefore at each data point the slope gradient is obtained and a S- and a T-value can be calculated. Accurate production yield can be calculated using various boundary conditions.

The FC_Method is written in Microsoft Excel as a micro-programme. It basically consists of seven sheets, *viz*: Data, sustainable yield, risk analysis, derivative plots, diagnostic plots, maps and chemical analysis.

Together with the borehole name and constant discharge rate, the constant draw down and the recovery test data are entered into the data sheet (Figure 6).

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow											
Borehole: GR2											
Q (l/s)=	28					Recovery data					
t (min)	s (m)	avg s'	avg s"	S	avg T	Time t'	Res_s	t/t'	Wl rise	s'	Rec_T
0.50	4.09					0.5	12.69	8601	4.11		
1.00	4.52					1	12.71	4301	4.09	0.03	
1.50	4.8	2.41	-1.92			1.5	12.67	2868	4.13	0.17	
2.00	4.89	1.10	-1.43	1.00E-05	413.29	2	12.66	2151	4.14	0.35	1414.5
2.50	4.97	0.98	-0.40	1.00E-05	441.02	2.5	12.59	1721	4.21	0.52	1063.8
3.00	5.1	0.91	-0.30	1.00E-05	499.08	3	12.57	1434	4.23	0.40	945.3

Figure 6. Example of data sheet as step 1 in the FC_Method.

The first (s') and second derivative are calculated and plotted, with the draw down on a log-log scale. From the derivative a S-value and estimated average T-value can be obtained. The S-value, however is dependant on the effective radius (r_e) which is entered during step 2 (Figure 7).

FC-METHOD : Estimation of the sustainable yield of a borehole				
Borehole:				
Extrapolation time in years = (enter)	3	1576800	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	1.5	1.7	Estimate of effective re	
Q (l/s) from pumping test =	4.97	0.07	Estimate of tc of WBS	
sa (available drawdown), sigma_s = (enter)	51.8	5	Sigma_s from risk analysis	
Annual effective recharge (m) =	0.007	53.80	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	4320	47	End time and drawdown of test	
Average maximum derivative = (enter)	16.6	16.6	Estimate of average of max deriv	
Average second derivative = (enter)	0	0.0	Estimate of average second deriv	
Derivative at radial flow period = (enter)	9.22		Read from derivative graph	
	T-early[m2/d] =	8.52		
T and S estimates from derivatives	T-late [m2/d] =	4.73	T-average =	6.25
(To obtain correct S-value, use program RPTSOLV)	S-late =	6.90E-04	S-estimate could be wrong	

Figure 7. Step 2 with the FC_method.

All the values in the yellow blocks can be altered. The exploration time must be entered in years. Enter the estimate effective borehole radius and the available draw down. Sigma_s is a safety factor and reduces the available drawdown to give a working drawdown. The average maximum derivative must be checked on the derivative plot (sheet 4).

The second derivative is usually close to zero and the value at radial flow can be obtained from the derivative plot were the s' shows a horizontal green line (Figure 8). A basic solution is given from a best to worst case scenario (Figure 9).

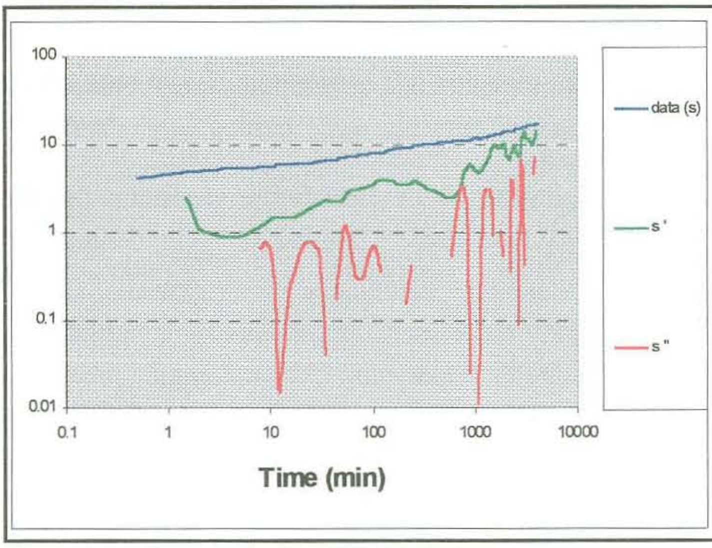

Figure 8. Derivative plot from FC_Method.

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)

(No values of T and S are necessary)

	No boundaries	1 no-flow	2 no-flow	Closed no-flow
		Maximum influence of boundaries at long time		
sWell (Extrapol.time) =	61.92	94.88	127.84	226.71
Q_sust (l/s) =	16.28	10.62	7.88	4.45
	Best case	→	→	Worst case
Average Q_sust (l/s) =	**8.82**			
with standard deviation=	5.00			

(If no information exists about boundaries skip advanced solution and go to final recommendation)

Figure 9. Basic solution for FC_Method.

3.6 WATER BALANCE MODEL

In South Africa communities will not only dependant on ground water as an emergency supply, but will have to use it as a bulk water supply. If ground water is used as an alternative source the aquifers must be able to cope with large abstraction volumes. A steady state water balance based on recharge was therefore compiled using Bear's single cell example (Bear, 1979). The water balance is calculated by adding the rainfall infiltration, river base flow and inflow from other aquifers and subtracting it from the abstraction from wells,

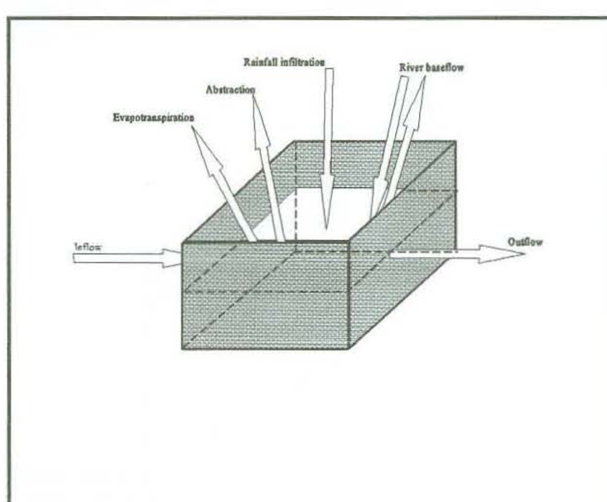

Figure 10. Single cell water balance based on Bear.

evapotranspiration, river base flow and out flow to other aquifers(Figure 10).

The abstraction volume can be calculated by adding together the volumes abstracted from hand pumps and motorised pumps.

The Ngwaritsi River is considered to contribute significantly to the recharge of the Nebo Aquifer. In order to determine the inflow from or outflow to the river, Darcy's law was used. According to his law, the flow rate (q) from or to the river is given by:

$$q = K\, dh/dl$$

Where, K is the hydraulic conductivity (m d^{-1}), dh is the head difference and dl the lateral distance. Therefore dh/dl represents the piezometric gradient (Figure 11). For the purpose of this assessment, assumptions were made in terms of the lateral distance (dl) and the head difference (dh). The abovementioned equation gives the flow rate in $m^3\ m^{-2}$ of surface area. The contact area between the river and the aquifer is defined by the linear distance of the river across the aquifer (L) and the average width of the saturated part of the river channel (W). The total flow rate from or to the river is determined from,

$$Q_{river} = qWL$$

The number of wet and dry days in a year were also included in the assessment to determine the inflow to and outflow from the river. It was assumed that during the dry season, the head in the river is lower than the head in the aquifer and that losses from the aquifer to the river would occur and vice versa.

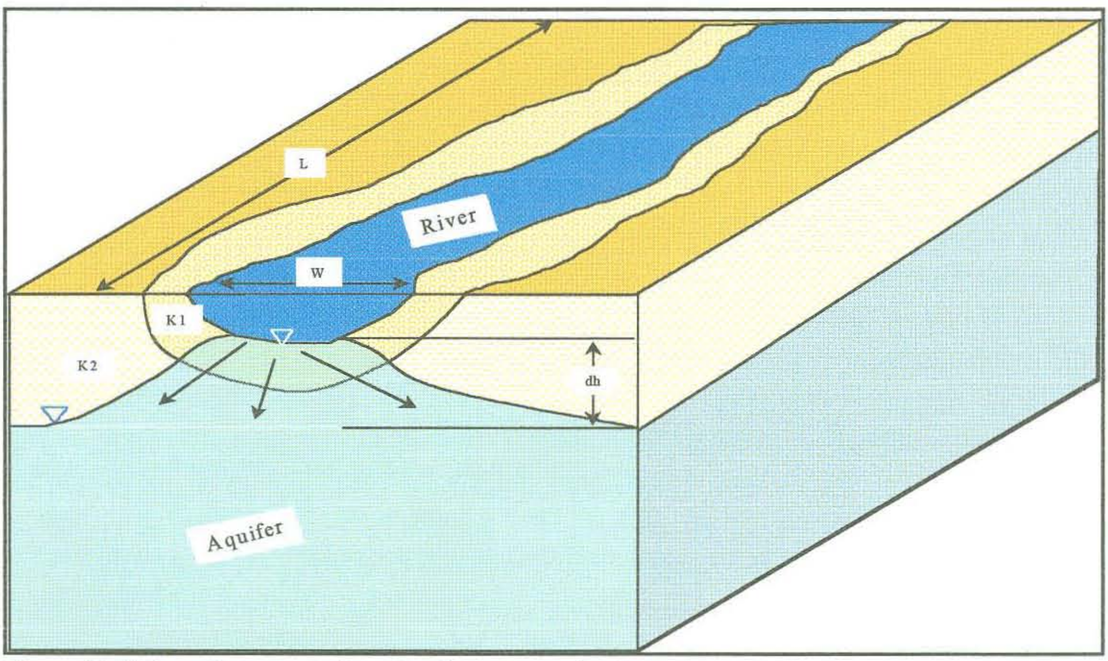

Figure 11. Schematic presentation of recharge from the river.

The Nebo Granite Aquifer is mainly recharged by rainfall. The recharge is calculated as a percentage of the mean annual precipitation (MAP) and is calculated as follows:

Recharge = MAP x (%recharge) x surface area

There are many variables and certain assumptions must be made, but Bears' single cell approach may give a preliminary result which can be used as a starting point for management of the source.