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BACK TO BASICS, THE QUEST FOR GOOD HYDROGEOLOGICAL DATA

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ABSTRACT: The development of complex ground water modelling codes and the increased capability and computer based models means that the collection of accurate and pertinent data has become even more important.

The development of modern hydrogeology is described. Checklists and pit falls in field investigations are given with specific emphasis on the measurement of hydraulic heads underground and monitoring preparation for test pumping.

The use of point piezometers, as against the rising tendency to install open hole monitoring boreholes, is emphasised.

INTRODUCTION

Mr. Chairman, delegates and honored guests, it was with great please I received the invitation to give the Keynote address to the ground water session of this August gathering.

In South Africa the science of Hydrogeology is often synonymous with borehole siting for small-scale rival water suppliers, detailed catchment management studies for the clean up of contaminated aquifers.

Ground water distribution and flow in the fractured hard rocks of Southern Africa is complex. This has often meant that geotechnical investigations have, out of absence of reliable data, had to assume “dry slopes” or to ignore the ground water component completely.

Some 85% of Southern Africa aquifers are fractured hard rocks. The majority of textbooks on hydrogeology for engineers or standard hydrogeological primers describe primary aquifers in great detail but cover little of the behaviour of fractured rock ground water.

Fractured rock aquifers are complex and difficult to predict both in occurrence and behaviour. Low budget investigations do not encourage the use of multiple measuring points that are necessary to achieve a through understanding of the hydrogeological regime.

The development of complex numeric codes and powerful computer run models means that multiple point measurements have become more, not less, critical to the interpretation and simulation of ground water behaviour.

Added complexity arises when the fractured hard rock aquifer is under investigation because of mining activity. The development of underground workings creates areas for ground water storage and movement thereby creating new or enhancing existing aquifers.

Complexity is increased because the juxta position both natural and man-made ground water occurrence needs to be understood. The man made aquifers are also significantly controlled by time dependent factors such as the artificial enhancement of sigma 3 stresses, which can then affect the anisotropy of an aquifer.

A final complication in the understanding of in situ ground water storage and movement is the use of off-the-shelf data interpretation computer packages. Basic skills like pressure plotting are being lost through the unquestioning use of contouring software, test pumping analysis progress and mini hydrogeological models.

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Everyone seems aware of the dangers of the default settings inherent in every package but little seems to be done avoiding misinterpretation. My recommendations are that all solutions to complex ground water problems should first be subjected to simpler arithmetic analysis. This would give an answer approximate to one order of magnitude.

The additional detailed complex modelling could then be used to fine time the solution a more accurate approximation.

The word approximation is used intentionally. Hydrogeology has never been or intends to be an exact science. An order of magnitude is often the most approximate and reliable accuracy for values of Hydraulic conductivity, storage and transmissivity.

This is not to say that the field values, on which a first approximation is based, should be anything less than accurately and unambiguously measured.

This paper seeks to address the basic need for unambiguous, specific, detailed and accurate measurement of ground water data. Only by ensuring the collection of not just good but **superb** field data can ground water engineers hop to achieve realistic predictions of ground water behaviour.

DEVELOPMENT OF HYDROGEOLOGY AS A SCIENCE

Hydrogeology or Geohydrology is a relatively new science. It originates from the experiments of Henri D'Arcy in France in 1856. The reason for his experiments was to determine the rate of flow of water through different materials with the objective of improving the sewage handling for the rapidly growing city of Paris. From this inauspicious start the basic equation underlying **all** ground water work was developed.

D'Arcy's law

$$Q = K \text{ x } A \text{ x } \left(\frac{\Delta h}{\Delta l}\right)$$

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Definition

Hydraulic conductivity = Discharge rate per unit area under c hydraulic gradient of 1.

Dimension

$$\mathbf{K} = \frac{Qx\Delta l}{Ax\Delta l} = \frac{(L^3/T)(L)}{(L^2)(L)} = (L/T) \qquad \mathbf{2}$$

$$\mathbf{K} = \frac{kpg}{\mu} \qquad \mathbf{3}$$

Where p =
g =
μ =

Thiem

In the late 1880's Thiem developed an application of D'Arcys law applicable to the drawdown and pumping rates of individual boreholes:

$$Q = KiA = K \text{ x } \frac{\Delta h}{\Delta r} \text{ x } 2\Pi rb \qquad \mathbf{4}$$

And

$$Q = \frac{2\Pi T(h_2 - h_1)}{In(r_2 / r_1)} = \frac{2\Pi T(H - h_w)}{In(R / r_w)}$$

$$= 2\Pi Ts \qquad 5$$

Where

b	=
r_w	=
R	=
r_1	=
H	=
h_1	=

This work was used for predicting borehole behavior under pumping conditions until the mid 1930's. Its significance is that it showed discharge as directly proportional to Transmission and drawdown and that discharge is relatively insensitive to the radius of the borehole.

Theis

The Theis equation moved away from a single borehole and reflected the flow of water through an aquifer. The solution was developed from the theory of heat flow (which was written in the same era) and is written as:

$$h_o - h = s = \frac{Q}{4\Pi T} W(u)$$

where

W(u) is the well function as calculated by Theis.

The Theis equation is famous for its list of controlling limitations e.g.

- Flow is laminar
- Aquifers homogenous
- Aquifer is isotropic
- Aquifer extends to infinity
- Aquifer thickness does not vary
- Borehole is fully penetrating

Once this major break through for the prediction of water levels under differing pumping rates and for the different hydraulic conductivities and aquifer thicknesses hydrogeology leapt forward.

Once the basic model was understood then many variables could be introduced leading to the multiplicity of type curves developed by Hatush (date), Cooper Jacob (date), Stallman (date), Papadopulos (date) and others.

Cooper Jacob

The most useful derivative of the Thies model was the Cooper Jacob approximations. They asked what would happen if for all practical intents and purposes, the cone of drawdown did not stop expanding but expanded at a slower and slower rate or, for all practical intents and purposes, and insignificant amount with each lapse of time.

This led to the most useful equation:

$$T = \frac{2.3Q}{4\pi\Delta s}$$

This provides a very useful rule of thumb for predicting test pumping response and planning testing schedules.

Numerical modelling

Numerical modelling has developed from the early analogue models, which used either resistors and capacitors or sand filled water tanks, to powerful codes capable of simulating complex aquifers and flow regimes with often added dimension of ground water quality.

FEFLOW and Aquisim

Amongst these are a multitude of home-developed models developed from spreadsheet applications.

Most problems can be broken down to achieve an estimate through use of D'Arcys law as it addresses the fundamental questions of discharge rate (Q) or speed of flow (K).

COMMON DENOMINATOR

The common denominator amongst both aquifer modelling and test pumping is the need for accurate, relevant data. D'Arcys law still lists the most important factors

Q	flow
A	cross sectional area of the aquifer
i	ground water gradient
K	hydraulic conductivity
S	storage

DATA COLLECTION

The methods avaialbe for collecting the above information are

- Water level measurements in mamsl or datum
- Pressure hand measurements
- Air lift yield measurement during or after drilling
- Laboratory testing of hydraulic conductivity and porosity
- Packer testing
- Test pumping

Water levels and head measurements

In most cases accuracies of 0.5cm are adequate. However it's important to know what is being measured. Figure 1 illustrates the different water levels measured in a rock mass. An open hole will give a hybrid water level representing a mixture of all the water levels within the rock mass.

Point piezometers are absolutely vital to ensure that a water level or head measurement can be assigned to a specific site. The diameter of the point piezometer is also important. Table 1 lists the lag times for measuring the response of a water level in a point piezometer.

Geological Setting

Again an open borehole is of almost no use if the geological log is not available. Down hole geophysical logging can often make up for the absence of a geological log that was done at the time of drilling, but will not replace an accurate combined drill and geological log that was made at the time of drilling. Figure 2 is a drilling log which lists all the required information during percussion drilling.

INSERT Figure 2: Standard Drilling Logs

Of concern is the use of software logging packages in which insufficient data fields are available for hydrogeological information.

Table 1: Difference in response times between piezometers

K cm/sec	Open Piezometer 35mm ID	Reduced Piezometer 6mm ID (at point of measurement)
	Days	Days
$1x10^{-8}$	131	23
$1x10^{-7}$	13	2.3
$1x10^{-6}$	1.3	0.23

Calculated from

$$\text{Time lag} = \frac{r^2/n\ (L/R)}{2LK}$$

where Time lag: elapsed time before piezometer record c37% of head difference between its rest water and new level induced by sudden addition or removal of water.

Source: Atkinson 1996

Air lift Testing

The air lift testing method is described in Preece & Morton 2002, also of this conference. Suffice to say when compressed air is readily available it is an inexpensive method of obtaining comparable blow-out yield from boreholes with unknown yields. When combined with an eductor pipe different sections of the borehole can be tested and values for transmisitivity obtained.

Test Pumping

Prior to testing it is important that background water levels are obtained to establish if there is a trend to the rest water levels in both the pumping and observation boreholes. Figure ** shows two possible scenarios both of which impact on the analyses of the test.

Examples of real life tests that were affected by external factors are:

1. Test pumping at a brewery near Newlands in Cape Town. The water levels were affected every afternoon at 3pm when borehole-fed sprinklers at the nearby stadium were activated.
2. A chalk aquifer outside of London gave elevated water readings when trains ran past the observation borehole.
3. Water levels in the central Kalahari in boreholes penetrating the Ntane sandstone fluctuate 9cm between full moons.

It is very necessary to distinguish between "noise" and trend.

Accuracy in all aspects of test pumping is strongly recommended. Figure * is a standard all purpose test pumping sheet which has adequate space for all relevant data including a sketch of the site and diameters and depths of boreholes and casing strings.

(INSERT KLM test pumping sheet – Ismail)

To achieve a meaningful pumping test it is important to

- Establish clear objectives for the test

- Use the Theis equation to estimate possible drawdowns and plan observation borehole tests
- Use the Hrorsler equation to estimate response / lag time for observation borehole diameter
- Site observation boreholes and observers strategically
- Number boreholes for ease of interpretation eg.1E (20) = no. 1 borehole 20m east of PW
- Get as many pre-pumping water levels as possible so as to establish a trend (preferably at least one week)
- Pump hard and long!
- Use detailed log book and data sheets to collect data
- Get recovery data to at least within 5% of the initial rest water levels
- Plot and analyse the test pumping data during the test and do not stop the pump until the objectives have been met.

Common mistakes in pumping tests are: (Atkinson, 1996)

- Mechanical or power failures of the pump(s)
- Poorly constructed or badly developed observation boreholes
- Poor data collection (indifferent of poorly trained personnel)
- Inadequate equipment, e.g. Water level dippers, un-calibrated flow meters and cheap stopwatches.
- Absence of sufficient pre-test water level data
- Stopping the test too soon
- Recycling of piped water back into the borehole

Strongly recommended is the collection of pH and conductivity during the test, particularly at changes in plot curvature. Full cation / anion analyses are recommended for the start and end of each constant discharge test.

DATA PRESENTATION

Modern computers and off-the-shelf software have made it very easy to analyse data. It is also easy to misinterpret data because of the default settings in most programs.

CLOSURE

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