EVALUATION OF A FRACTURED ROCK AQUIFER

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ABSTRACT

Text book methods of planning and executing an aquifer evaluation programme usually emphasise primary aquifers. The secondary or fractured rock aquifer requires a more rigorous exploration programme with emphasis on the following steps: 1 Aerial photograph, satellite imagery and structural interpretation. 2. Target geophysics and resource modelling. 3. Drilling and test pumping analysis. 4. Water balance assessment and aquifer stress analysis. 5. Aquifer modelling and management. Each step has to evaluate two types of aquifer response; the response of the ground water flowing within the fractures and the response of the ground water feeding the fractures. The first response is governed by the size, distribution and orientation of the fractures. The second response is governed by the storage characteristics of the inter fracture matrix and the weathered zones in hydraulic connection with the aquifer. The neglect of one or the other during the analysis of test pumping data leads to an incorrect evaluation of the aquifer. Different methodologies are used for large regional scale as compared to village scale ground water exploration and aquifer assessment projects.

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1. INTRODUCTION

In Southern Africa, in particular rural Africa, fractured rock aquifers are the norm rather than the exception. Standard textbook methodology for the evaluation of an aquifer usually assumes that the aquifer has predominantly primary permeability. Even international University courses in hydrogeology teach primary permeability ground water theory. This means that workers in Africa have had to devise their own approach and techniques to evaluating aquifers with predominantly secondary permeability characteristics.

African aquifer evaluation projects have tended to fall into one of two camps. The first, often state or foreign funded is the broad evaluation of a specific formation, region or drainage basin. The second is the more spatially restricted or village water supply project. This is often community funded or forms part of a larger scale drought relief programme. The objective of the large scale project is to evaluate the overall potential of a region or specific formation to supply ground water.

This type of project is favoured by planners who are then able to assess the long term feasibility of developing a region. In scientific terms the large scale project is useful in looking at the regional water balance for an area and evaluating the reliability of a resource. More significantly the large scale project can often start to estimate the ground water recharge component of hydrological cycle.

The second, village, aquifer evaluation project emphasises achieving a quick, rough estimate of available ground water often for an emergency supply. Often little cognisance is taken of the long term impact of ground water abstraction or of the reliability of the ground water supply.

Both types of project require different methodologies. However although the methodologies are different this does not mean that they are exclusive.

2. RECORD KEEPING

Significant benefits can accrue from one type of project to the other if fundamental scientific principles are adhered to. This includes not just good but superb data collection and reporting. Any information collected should be well documented and archived.

Records should preferably carry the name of the person collecting the data so that in years to come future projects can not only determine the reliability of the data but also refer back to the original worker for comment and personal experience.

Record keeping has been emphasized in recent years with the development of large data base programs. The better data bases are the ones which include a data field for comment. Programs which only allow the entry of "smoothed" data often lose the additional benefit of retaining the field worker's observation of unusual detail.

Another problem with data bases is that they often only accept the name of a geological formation or sequence as opposed to a simple description of the rock type ie Stormberg lava is accepted by some bases but not its hydrogeological description ie " Basalt, black to red, fine grained, amygdaloidal, frequent bedding planes and erosion surfaces". In hydrogeology the rock type, it's degree of weathering and fracturing is far more important than slotting the rock type into a particular classification scheme for formations.

The bottom line is that all information collected during either a large scale study or a village water supply project should be written up and archived in such a way that the hydrogeological characteristics of the borehole or a formation can be easily retrieved.

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This means retaining field records as well as entering data onto a data base.

3. METHODOLOGIES FOR AQUIFER EVALUATION

The methodologies behind the large scale evaluation and the village water supply are similar in that a rigorous scientific approach must be maintained. The large scale evaluation is often more thorough because of the longer time periods and larger budgets allowed but the village water supply can often follow the same steps within a project but on a smaller scale. Because we are usually dealing with ground water transmitted along fractures accurate structural mapping should form the basis of both types of evaluation investigation. The methodologies are listed in detail.

4. LARGE SCALE AQUIFER OR REGIONAL EVALUATION

The objective of a large scale project is usually to evaluate the overall potential of a region or specific formation to supply ground water. Other objectives such as, how to optimise borehole siting in a region, are often included within the project.

The following steps in a large scale or regional investigation are considered the best approach.

a) **Aerial photograph, satellite imagery interpretation and the establishment of a surveyed plan of the area.**

The development of a global positioning system (GPS) has made it relatively easy to locate in the field the structures viewed on aerial photographs, satellite imagery and even airborne geophysical plans on the ground to a high level of accuracy. It is essential that any ground water investigation collects information and records the location of the monitoring point according to latitude and longitude. Accuracy of the GPS can be as good as 50 m in the horizontal plane. The GPS has the capability of accuracy in the vertical plane of 10 m but at this stage this is not available to civilian users. With time this accuracy will be available to the field worker.

b) Airborne geophysical survey and the structural plan

In particular magnetic surveys have proved themselves invaluable for the structural mapping of an area. Two examples are the Serowe investigation done by the Swedish geological survey and the current Mmamabula project under the French geological survey and the Botswana government. High levels of resolution coupled with accurate location on the ground has produced structural plans of a high standard. Soil mapping can also be done from a combination of all the remote sensing tools. This can be used for locating features on the ground and for possible use in recharge calculations.

Structural plans must be dynamic in that they include not only the location of faults, dykes, fractures and other lineaments but also the dominant direction of tectonic movement. Tensional features are potentially more likely to transmit ground water than compressional features. Also folding has a significant impact on the location and movement of ground water.

Field mapping and verification is essential for the confirmation of the structural plan.

c) **Borehole, spring and pan census**

There are few areas in Southern Africa which do not already have some form of habitation, often with water supplies obtained from existing boreholes or from pans or springs. To understand the distribution of ground water in an areas it is essential to map an area for existing water points and relate them to the structural interpretation. It may be possible, for example to identify certain fractures or lineaments which already have been targeted for borehole sites but not yet identified within their hydrogeological context.

Where possible seasonal water levels should be measured, coupled with rainfall records, this can provide valuable information for the estimation of ground water response to rainfall events. Again this can be used in assessing ground water recharge from rainfall.

d) **Surface geophysics**

The objective of using surface geophysics is to confirm the airborne geophysical interpretation and to devise an approach to the siting of exploration boreholes. Techniques already in use include magnetics, electro magnetics, gravity, HLEM, resistivity profiling and soundings.

If an accurate survey plan is available and a GPS is used to tie in the survey lines a very high level of confidence in the actual position of anomalies can be obtained.

e) **On going monitoring of ground water dynamics**

A minimum monitoring requirement is the set up or upgrading of a rainfall and evaporation monitoring station. As stated above borehole water levels should be monitored for seasonal variation.

A water level map is an integral part of understanding the flow regime of a region. This should also be supplemented by monitoring of ground water movement through the unsaturated zone.

f) Establishment of an initial aquifer "model"

Prior to exploration drilling a conceptual model of ground water occurrence should be drawn up. This should include the structural detail of water bearing lineaments and the source of the ground water feeding into them. The exploration phase should be designed to site and test boreholes so as to fill in any gaps in understanding in the initial conceptual model. Some hydrogeologists have used geostatistics as a tool for optimising the placement of exploration boreholes. A thorough understanding of the geological structure is more likely to give the best design for an exploration drilling programme.

g) Exploration

The proof of any fractured rock aquifer is in the drilling. The drilling exploration program should be designed to investigate all types of lineaments and also the country rock. Long term abstraction in fractured rock aquifers is also dependent on the hydraulic characteristics of the country rock. Most fractured rock aquifers are made up of major lineaments which receive ground water from minor lineaments which in turn are fed by even the lowest permeable country rock. It is therefore important to determine the background permeability of the country rock if an estimate of the long term yield of a fractured rock aquifer is to be obtained.

The objective of the exploration phase is to prove or disprove the model drawn up in f). Through comparison with an ideal the true hydrogeological characteristics of a fractured rock aquifer can be assessed.

Exploration includes drilling, down hole logging, test pumping, water quality sampling and isotopic analysis. Each parameter collected should be designed to provide insight into the overall character and response of the aquifer to pumping. Pumping test analysis should take into account that the initial response of the aquifer is governed by the size distribution and orientation of the lineaments or fractures. The second or delayed response is governed by the storage characteristics of the inter fracture matrix and the weathered zones which are in hydraulic connection with the aquifer.

h) Water balance assessment and aquifer stress analysis

Prior to computer simulation and mathematical modelling. It is important to look at the overall balance of the ground water in the region and it's relative importance within the hydrological cycle.

i) Numerical modelling

The objective of the numerical modelling is to estimate the possible recoverable resources from the regional aquifer. It can be used to simulate the aquifer response to abstraction, wellfield development and environmental impacts. The success of a numerical model is firmly controlled by the use of data that is representative of the region. A fractured rock aquifer is very difficult to simulate unless there is a sound knowledge of the geological structure. An alternative is the black box approach which leans heavily on the use of the ground water level response to rainfall approach.

5. VILLAGE AQUIFER EVALUATION

The objective of a village aquifer evaluation project is usually the provision of a ground water supply as cost effectively as possible. The main difference between the regional evaluation and the village aquifer evaluation is not in the scope of work but in the scale of work. The same steps are required to achieve an understanding of the aquifer and to provide an assessment of reliable and available yield. All fractured rock aquifers should be structurally mapped to a high level of confidence.

The evaluation of a fractured rock aquifer for a village water supply should therefore include the following activities.

- Establishment of base plan using existing maps or GPS assisted plan
- Borehole, spring, pan survey, location and water levels
- Aerial photograph, satellite image and airborne geophysics interpretation
- On site field mapping and drawing up of structural plan
- Surface geophysics, if warranted
- Drawing up of initial conceptual model of ground water location and movement
- Drilling of target zones, test pumping of significant boreholes
- Analysis of test pumping taking into account the "delayed response" common to fractured rock tests
- Water quality analysis, isotope analysis
- Assessment of the origin of ground water and it's reliability as a ground water supply
- Construction of a final conceptual model
- Water balance assessment

Numerical modelling is not often warranted for a small scale abstraction scheme but the information collected during a village investigation may be vital to the modelling of a regional scheme and therefore should not be ignored. The list of activities for the evaluation of a village supply fractured rock aquifer is not exhaustive. Should any of the above be omitted a hydrogeologist runs the risk of not having done a thorough evaluation and therefore not gained an understanding of the local ground water regime.

6. CONCLUSION

The methodologies behind the evaluation of a fractured rock aquifer are slightly different for large and small scale investigations. The main similarity is the necessity of a thorough understanding of the geological structure in both cases.

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