Boreholes: 3D geological modelling and representation

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Three-dimensional (3D) models created from boreholes provide better representation of geology and this enhances the interpretation of geology and facilitates groundwater exploration.

The process of creating 3D models using Gemcom Surpac Version 6.0.3 is discussed in this article for an area around the town of Beaufort West in the Western Cape Province of South Africa.

**Background**
The inhabitants of Beaufort West, like most people residing in the Karoo towns, are poverty stricken and lack adequate supply to surface water. Groundwater therefore provides a viable option for these communities. Groundwater exploration requires the understanding of the dynamics of groundwater occurrence and flow; where it occurs (identifying the aquifers), how much is available for extraction (storativity and pumping rates), and where to drill the boreholes.

In groundwater exploration, after an aquifer has been identified by geological interpretation, the borehole is sited and subsequently drilling follows. During drilling the borehole is logged and during this process cores or chips are extracted, recorded and analysed for every metre drilled. The colour and texture of the rock is recorded, and where cores are taken the state of the rocks, the fractures and joints are also documented.

During groundwater exploration water strikes and water levels are noted, and the groundwater is then tested for sustainability and suitability for use for domestic purposes. A cross section is compiled using the data from these borehole logs. This cross section is useful in identifying other possible/potential targets for future drilling.

The cross sections from borehole logs can only give a 2D picture, which is not always the best representation. In the case of flat terrains this representation is adequate, however where the geology is complex and thicknesses of the saturated zone (aquifer) are important, a 3D representation is the best.

The geology in South Africa is in most cases characterised by folding and faulting as well as the ever enigmatic dolerite intrusions. All these factors interfere with the groundwater flow and are the reasons why the understanding of groundwater flow dynamics is still a work in progress.

This paper investigates the use of 3D modelling to assist in the verification of the geological information from borehole data and also for providing a better pictorial representation of geological information. The availability of a better representation could assist in providing a response to the question of storativity, a sensitive issue when working at a local spatial scale. This is especially the case in the Karoo where the aquifer systems are layered, extensive and there is interconnectivity.

**Study area**
The town of Beaufort West is set within the Karoo Basin (see Fig. 1), where the geology is made up of Karoo sediments (mudstones, siltstones, shales and sandstones) that have been intruded by dolerites.

The Karoo experiences harsh climatic conditions characterised by scarce rainfall, high temperatures and high evapotranspiration rates. Temperatures can rise as high as 32°C in summer, and drop to as low as 4°C in winter. The mean annual rainfall is estimated at 236 mm and this is mainly runoff and contributes little to surface water bodies. The Karoo region is as a result a semi-arid region; hot and dry.

The study area is the 1:50 000 map sheet of Beaufort West (see Fig. 1). One of the objectives of this project was to create a 3D representation of the entire map sheet; however the sparse borehole distribution prohibited this as it would have required a lot of data interpolation. Although more than 300 boreholes were drilled in the map area most of these were not logged. This posed a challenge and necessitated the need to focus on
Data collection and pre-processing

Fig. 2 shows a planar view of the location of the boreholes used for modelling and the subsequent cross-sections created for the area. The original dataset used was acquired from the National Groundwater Database (NGDB) provided by the Department of Water Affairs and Forestry (DWAF). This data is presented in text format captured in Microsoft Excel and therefore needs to be pre-processed before being used in the modelling software package, Gemcom Surpac.

Pre-processing the data before modelling is a time consuming exercise. When geological information is captured for each borehole during logging, abbreviations/codes are used for the different rock types by technicians in order to save time. For example, the codes SNDS and SST are both used to represent sandstone by different technicians. Since the data is collected for numerous boreholes, it is important to use one abbreviation/code as a standard.

This editing is done with the assistance of an expert geologist, who has knowledge of the geology of the area. Besides the need to standardise the lithological codes used, the edits are also necessary in order to verify the depths of the lithologies and to check if the chronology of the geology, as implied by the borehole data, is correct.

After editing, the data has to be divided into the following three tables, which are required for modelling with the software product:

- Survey table, which contains survey information on the hole for example the depth of the borehole, the dip and the azimuth.
- Collar table, stores information on the location of the borehole, its maximum depth and whether the hole is linear or curved.
- Sample table, which shows the composition of rock types at different depths for each borehole.

The creation of a sample table was the most time-consuming as it required the manual editing of one borehole at a time. Table 1 shows the original format of the data and Table 2 shows the required format for input into the sample table in the modelling software.

Results

After the database tables are imported into the modelling software, the boreholes can be displayed graphically and printed. Fig. 3 shows a planar display of the boreholes.

Fig. 4 shows the captured boreholes and the corresponding geological logs where different rock types/lithologies are represented by different colours. Referring to Fig. 2, a section of the boreholes is shown below.

For each borehole the aquifer was identified based on the criteria set out; good transmissivity, porosity and permeability. A correlation was made for each section, joining horizons of one borehole to another (see Figs. 4 and 5) using the section digitising facility in the modelling software. These similar geological units (polygons) from adjacent sections were then linked and, using the solid modelling function, were joined to represent the aquifers (see Fig. 6). This correlation within a single section is done at a local scale and is then extended from section to section. This was done to get the lateral extension of the horizons that form the different aquifers.

Fig. 6 shows the created 3D model of the three identified aquifers.

**Table 1: Original data format of boreholes.**

<table>
<thead>
<tr>
<th>Borehole_ID</th>
<th>Geol</th>
<th>Dry</th>
<th>Hnum</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>'3222BC00139'</td>
<td>4 m</td>
<td>ALL</td>
<td>-37 m</td>
<td>MS + SS</td>
</tr>
<tr>
<td>'3222BC00139'</td>
<td>3 m</td>
<td>ALL</td>
<td>-14 m</td>
<td>SS</td>
</tr>
</tbody>
</table>

**Table 2: Format for sample table as required by modelling software.**

<table>
<thead>
<tr>
<th>Borehole_ID</th>
<th>Depth_From</th>
<th>Depth_To</th>
<th>Geology</th>
</tr>
</thead>
<tbody>
<tr>
<td>'3222BC00139'</td>
<td>0</td>
<td>4</td>
<td>ALL</td>
</tr>
<tr>
<td>'3222BC00139'</td>
<td>3</td>
<td>43</td>
<td>MS</td>
</tr>
<tr>
<td>'3222BC00139'</td>
<td>37</td>
<td>49</td>
<td>MS + SS</td>
</tr>
<tr>
<td>'3222BA00206'</td>
<td>0</td>
<td>3</td>
<td>ALL</td>
</tr>
<tr>
<td>'3222BA00206'</td>
<td>3</td>
<td>14</td>
<td>MS</td>
</tr>
<tr>
<td>'3222BA00206'</td>
<td>14</td>
<td>28</td>
<td>SS</td>
</tr>
</tbody>
</table>
Conclusions and recommendations

The modelling software has mainly been used for modelling in the mining sector but this paper describes its application in groundwater exploration for the identification of aquifers. The software can handle real observed data. 3D models provide a way of checking the accuracy of collected boreholes data, managing it and displaying it for decision-making process. The created 3D model can be exported from the modelling software and visualised at different scales and angles in software programs like Microsoft Word or Powerpoint for easy presentation to decision-makers.

3D geological representation could assist in providing information on the storativity, at a local spatial scale. This is especially the case in the Karoo where the aquifer systems are layered, interconnected and extensive. The use of 3D modelling in this project resulted in the delineation of three aquifers. These aquifers are the top sedimentary aquifer 1 (AQ1) that is restricted to not more than 20 m depth, a secondary fractured rock aquifer (AQ2) associated with dolerite intrusions and is found at depths greater than 50 m, and a third deeper aquifer (AQ3) that occurs at depths of 80 – 90 m.

One of the challenges encountered during modelling was the lack of borehole data to accurately model a large area. Due to errors in the data, field verification and expert knowledge are vital before a model can be accepted as a correct representation of reality.

References

[4] National Groundwater Database, Department of Water Affairs and Forestry, Pretoria

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