PRELIMINARY MODELLING OF GROUNDWATER FLOW IN THE DOLERITE AQUIFER AT NABARLEK

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1. INTRODUCTION

Water Division's principle role in the Alligator Rivers Region is that of a regulatory authority. In order to make rational administrative decisions, Water Division are involved in programmes to collect hydrological data and to model the nature of surface water and groundwater systems in the region.

The results of a preliminary modelling exercise on the dolerite aquifer in the Nabarlek minesite are presented in this report, as are recommendations for future work. This report only covers groundwater flow. Future reports will cover solute transport modelling for this aquifer.

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2. GEOLOGICAL SETTING

The Nabarlek minesite is situated within the Pine Creek Geosyncline, a Lower Proterozoic sequence of metasediments with interbedded volcanics which covers an area of about 66 000 km² to the east and south of Darwin (Needham et al., 1980). Gneissose and schistose rocks of the Proterozoic Myra Falls complex are found within the Nabarlek mine area, and these rocks have been intruded by a large, differentiated dolerite sill, the Oenpelli dolerite. This sequence is unconformably overlain to the north and south of Nabarlek by sandstones of Carpentarian age (the Kombolgie Formation) which form outliers of the Arnhemland Plateau. Figure 2.1 shows the distribution of these Proterozoic rock types in the mine area and a block diagram (Fig 2.2) shows more clearly the spatial relationships between these rocks.

Most groundwater at Nabarlek is found in fracture zones in schist and dolerite. The highest groundwater yields in dolerite are found where this rock-type has been partially weathered (AGC, 1982). This partially weathered zone can be up to 6m in thickness and is overlain by a confining, highly weathered zone consisting of clayey silts. This extremely weathered zone can be up to 10m in thickness. Fresh dolerite at depths greater than 20m also contains fracture zones, but these have a low permeability. The range in permeabilities encountered in a vertical section through the dolerite weathering profile by AGC is summarised below (see also AGC, 1982):

<table>
<thead>
<tr>
<th>LITHOLOGY</th>
<th>DEPTH RANGE</th>
<th>AV. PERMEABILITY (m³/Day/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely weathered dolerite</td>
<td>2-12</td>
<td>$3 \times 10^{-2}$</td>
</tr>
<tr>
<td>Partially weathered dolerite</td>
<td>12-18</td>
<td>3</td>
</tr>
<tr>
<td>Fresh dolerite</td>
<td>18</td>
<td>$3 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

VI. OVERVIEW OF GROUNDWATER RESOURCE

The main source of groundwater at Nabarlek is the dolerite sill, which is intruded by fresh dolerite. The dolerite sill is up to 6m thick and is overlain by a confining, extremely weathered dolerite zone. The fresh dolerite at depths greater than 20m contains fracture zones, but these have a low permeability.
Fig. 2.1
SPATIAL RELATIONSHIP BETWEEN ROCK UNITS

NOT TO SCALE - SKETCH ONLY

Fig. 2.2
3. FINITE ELEMENT MODELLING

3.1 Baseline Conditions Assumed in the Model

3.1.1 Structure of the Model

In order to simplify modelling, the dolerite aquifer was assumed to be tabular in shape. Upon this was superimposed a rectangular grid containing 256 separate elements of dimensions 120m x 120m and 297 nodal points (Fig 3.1). Groundwater discharge was assumed to take place at nodes 280 to 288. Flow modelling was carried out using the programme SEFTRAN which utilises the Galerkin finite element solution to groundwater flow (see eg. Wang and Anderson, 1982).

3.1.2 Selection of Aquifer Parameters

Transmissivity data for bores sunk in the dolerite aquifer have been largely obtained from test pumping carried out by AGC. These data together with Water Division data are summarised in Table 3.1 and bore locations are shown in Fig 3.2. Unfortunately, test pumping in this area was carried out without the use of observation bores, so storage coefficients could not be determined from these tests.

Hydraulic conductivities can be obtained from transmissivity data presented in Table 3.1 by the expression:

\[ T = K b \]

where \( T \) = transmissivity (L\(^3\)T\(^{-1}\) L\(^{-1}\))

\( K \) = hydraulic conductivity (L\(^3\)T\(^{-1}\) L\(^{-2}\))

\( b \) = aquifer thickness (L)
Fig. 3.1

FINITE ELEMENT GRID USED TO MODEL THE DOLERITE AQUIFER.
Fig. 3.2
Assuming an aquifer thickness of 5m gives a range of hydraulic conductivities of 0.1 m³/day/m² to 20 m³/day/m². The large range in hydraulic conductivities observed here may be due in part to the fact that the dolerite aquifer is anisotropic in nature. However, as a first approximation the dolerite aquifer will be considered to be isotropic with a horizontal permeability of 2m³/day/m² (T = 10m³/day/m).

As a crude first approximation, a value for the overall vertical permeability can be estimated from the examination of bore hydrographs at Nabarlek. Water levels in most bores at Nabarlek reach a peak level two months after heavy rainfall. Assuming the water table is 5m deep gives a value for Kvertical 5m/60 days, or 0.1m³/day/m².

The lack of observation bore data from test pumping of the dolerite aquifer has made it necessary to estimate values for the storage coefficient in this area. A similar fractured rock aquifer in schistose rock to the south of the dolerite intrusive has values of S ranging between 1x10⁻⁴ and 7x10⁻⁴. The storage coefficient for dolerite should be lower than for schist (assuming a comparable fracture intensity) because of the compact nature of this rock type. Therefore the lower estimate of S of 1x10⁻⁴ will be assumed for the dolerite aquifer.

The amount of water discharging into Cooper Creek from the dolerite aquifer can be estimated using the following expression:

\[ Q = Tiw \]

where

- \( Q \) = discharge volume (m³/day)
- \( T \) = transmissivity (m³/day/m)
- \( i \) = hydraulic gradient
- \( w \) = aquifer width (m)
The dolerite aquifer at Nabarlek has a width of about 1000m and the hydraulic gradient downslope of the water management ponds is about 0.02. Therefore assuming a transmissivity of 10m$^3$/day/m gives a discharge volume of about 200 m$^3$/day. Discharge to Cooper Creek was modelled by assuming that a discharge of 200m$^3$/day took place at each of the nodes 289 to 297 in the model (see Fig 3.1).

In addition to the above values, a time constraint of 21 steps (equivalent to 225 days) was placed on the model to simulate a single dry season of groundwater flow.

3.2 Calibration of the Model

The finite element model for the dolerite aquifer was calibrated in two ways:-

(i) by matching potentiometric contours generated by the model with pre-mining contours, and
(ii) by matching drawdown-time behaviour for a point source discharge in the model with results obtained from a pump test.

Pre-mining potentiometric contours (AGC, 1978) are shown in Fig 3.3. These indicate that the groundwater regime to the east of the present day water management ponds has changed little since the commencement of mining and milling of uranium.

Groundwater contours generated by the model using the parameters defined in the previous section are shown in Figure 3.4. These contours are far steeper than the observed pre-mining contours.
WATER LEVEL CONTOURS AND FLOW DIRECTIONS
- SEPTEMBER 1978
SOURCE: A.G.C. 1978/b
Fig.3.3
POTENTIOMETRIC CONTOURS GENERATED BY THE MODEL

ASSUMING T=21 STEPS=225 days, Kx=Ky=2m³/day/m²,
Kvertical=0.1m³/day/m²; S=1 x 10⁻³

Fig. 3.4
The best fit between modelled and actual potentiometric contours occurs when a condition of anisotropy is assumed for the dolerite aquifer. There are two main reasons for assuming anisotropy in this aquifer. These are:

(i) The dolerite intrusive is a layered sill and therefore there is a well developed lamination along strike caused by variations in coarseness of the crystalline groundmass. Partial weathering of coarsely grained material has probably led to the development of permeable horizons within the dolerite body. AGC geophysical work (AGC, 1982) encountered several such permeable horizons which followed an east-west trend.

(ii) The Oenpelli dolerite at Nabarlek forms part of a large synformal structure. An east-west trending, axial-plane fracture set has probably been developed in the dolerite as a result of this folding, and these fractures probably provide permeable zones for the movement of groundwater.

A good match between modelled and actual pre-mining contours is achieved if values of Kx (parallel to strike) of 20m³/day/m² and Ky (normal to strike) of 2m³/day/m² are assumed together with values of S of 1x10⁻⁴ and a K vertical of 1x10⁻¹ m³/day/m². Discharge to Cooper Creek from the dolerite aquifer was assumed to be 200m³/day. Groundwater contours assuming these conditions are shown in figure 3.5.
POTENTIOMETRIC CONTOURS GENERATED BY MODEL
ASSUMING T=21 STEPS=225 days, Kx=20m³/day/m², Ky=2m³/day/m²,
S=1 x 10⁻⁴, Kvertical=0.01m³/day/m².
A second way to check the calibration of the model is to match the drawdown-time behaviour at a point discharge in the model with the results of a pump test. Only one pump test has been carried out by Water Division on a bore in the dolerite aquifer (Bore RN 20006; see figure 3.2) and drawdown-time results for this test are shown plotted in figure 3.6. Bore RN 20006 was subjected to a constant discharge test with a pumping rate of 0.65 L/S, and so a point discharge of this rate was included in the model. Drawdown-time results for this model run are also shown plotted in figure 3.6.

Agreement between test pump and model results is poor at times less than 100 minutes because the standing water level in bore RN 20006 responded much more rapidly to pumping than model values. However, at times greater than 100 minutes, there is a good match between the two data sets. It is very difficult to match up pump test and model results at small time values, because drawdown behaviour is largely a function of bore design for the first few minutes after pumping commences.

3.3 Modelling of seepage from the Water Management Ponds

The water management ponds at Nabarlek have been in operation since 1980 and seepage from these ponds has led to the formation of a groundwater mound. Q.M.L. (1983) estimated that seepage from these ponds in 1983 would be 324 m$^3$/day, with 284 m$^3$/day being contributed by EP2. Potentiometric contours generated by the model assuming a seepage rate from the water management ponds of 300 m$^3$/day are shown in figure 3.7. These compare well with observed groundwater contours for August 1982 Fig 3.8 as both the shape of the contours and hydraulic gradients are similar.

Q.M.L. estimate that seepage from the water management ponds will increase to nearly 400 m$^3$/day in 1986. Figure SA3/2:TJ
COMPARISON BETWEEN DRAWDOWN - TIME BEHAVIOUR FOR THE MODEL & RESULTS OF TEST PUMPING BORE 20006

- PUMP TEST DATA
- MODEL DATA  $K_x=20\text{m}^3/\text{day}/\text{m}^2$, $K_y=2\text{m}^3/\text{day}/\text{m}^2$, $K_v=0.05\text{m}^3/\text{day}/\text{m}^2$, $S=1 \times 10^{-4}$

NOTE: Constant discharge test for 20006 (pumped) 17/4/79  
$Q=0.039\text{m}^3/\text{min}$.  

Fig. 3.6
MODELLED POTENTIALMETRIC CONTOURS

ASSUMING SEEPAGE IS OCCURRING AT A RATE OF 300m$^3$/day FROM THE WATER MANAGEMENT PONDS. PARAMETERS ASSUMING
K$_{Vertical}$=0.1m$^3$/day/m$^2$, K$x$=20m$^3$/day/m$^2$, K$y$=2m$^3$/day/m$^2$, S=1 x 10$^{-4}$, T=225 days,

DISCHARGE TO COOPER CREEK IS ASSUMED TO BE 180m$^3$/day.
Fig. 3.8

LEGEND

- - - - ROAD

- - - - - - FRACK

- - - - CREEK

- - - - - - - - BORE

60  - - - - POTENTIOMETRIC CONTOUR

POTENTIOMETRIC SURFACE CONTOURS FOR DEEP GROUNDWATER
3.9 shows contours generated by the model assuming 400m$^3$/day input. Groundwater contours under these seepage conditions are steeper than those generated at a seepage rate of 300m$^3$/day.
MODELLED POTENTIOMETRIC CONTOURS
ASSUMING SEEPAGE IS OCCURRING AT A RATE OF 400 m$^3$/day
FROM THE WATER MANAGEMENT PONDS. PARAMETERS ASSUMED
$K_x=20$ m$^3$/day/m$^2$, $K_y=2$ m$^3$/day/m$^2$, $S=1 \times 10^{-4}$, $T=225$ days.
DISCHARGE TO COOPER CREEK ASSUMED TO BE 180 m$^3$/day.
4. RECOMMENDATIONS FOR FURTHER WORK

Further modelling should be carried out on the dolerite aquifer at Nabarlek to examine the effect of time periods greater than a single dry season on the groundwater regime. This will require modifications to be made to the finite element programme used so that the programme can "switch" from dry season conditions to a wet season recharge event. Modelling of this aquifer should also eventually deal with solute transport in order to predict the fate of contaminants seeping from the water management ponds.
REFERENCES


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## TABLE 3.1 HYDROGEOLOGICAL DATA FOR BORES SUNK IN DOLETITE AT NAPARLIR

<table>
<thead>
<tr>
<th>BORE RN</th>
<th>REDUCED LEVELS (m above NHD)</th>
<th>WATER CUTS (m below ground level)</th>
<th>AIRLIFT YIELD (L/s)</th>
<th>TRANSMISSIVITY (m²/day/m)</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>9373 (OB1D)</td>
<td>71.31 72.85</td>
<td>6.0</td>
<td>0.5</td>
<td>4.6</td>
<td>QML monitoring bore</td>
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<td>9374 (OB2D)</td>
<td>72.85 72.48</td>
<td>16.0</td>
<td>1</td>
<td>3.3</td>
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<td>9375 (OB3D)</td>
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<td>11.0</td>
<td>2</td>
<td>15</td>
<td>&quot; &quot; &quot;</td>
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<tr>
<td>20123 (OB4D)</td>
<td>71.80 72.15</td>
<td>15.0</td>
<td>1</td>
<td>8</td>
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<td>20124 (OB5D)</td>
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<td>20125 (OB6D)</td>
<td>76.03 76.70</td>
<td>19.0</td>
<td>0.5</td>
<td>0.7</td>
<td>&quot; &quot; &quot;</td>
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<td>20126 (OB7D)</td>
<td>76.62 77.06</td>
<td>18.0</td>
<td>1</td>
<td>10</td>
<td>&quot; &quot; &quot;</td>
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<td>20127 (OB8D)</td>
<td>75.83 76.41</td>
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<td>-</td>
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<td>20130 (OB11D)</td>
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<td>4</td>
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<tr>
<td>20131 (OB12D)</td>
<td>68.83 69.46</td>
<td>Nil</td>
<td>60</td>
<td>Seepage only</td>
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<td>20120 (OB13D)</td>
<td>70.69 71.16</td>
<td>17.0</td>
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<td>25</td>
<td>&quot; &quot; &quot;</td>
</tr>
<tr>
<td>BORE RN</td>
<td>REDUCED LEVELS (m above AHD) level</td>
<td>WATER CUTS (m below ground) level</td>
<td>AIRLIFT YIELD (L/s)</td>
<td>TRANSMISSIVITY (m³/day/m)</td>
<td>REMARKS</td>
</tr>
<tr>
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<tr>
<td></td>
<td>Natural Surface</td>
<td>Top of casing</td>
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<tr>
<td>9442 (TB17)</td>
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<td>9861</td>
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<td>8.0</td>
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<td>20006</td>
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<td>20558</td>
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</table>

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