PRELIMINARY GROUNDWATER STUDIES
IN RANGER AREA
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CONTENTS

1.0 INTRODUCTION

2.0 HYDROGEOLOGY

2.1 Geology

2.1.1 Nanambu Complex
2.1.2 Transitional Rocks
2.1.3 Cahill Formation

2.1.3.1 Lower Member (Lower Mine Series)
2.1.3.2 Upper Member (Upper Mine Series)

2.1.4 Kambolgie Sandstone
2.1.5 Cainozoic Sediments
2.1.6 Geologic Structures

2.2 Occurrence of Groundwater

2.2.1 Shallow Aquifer
2.2.2 Weathered Rock Aquifer
2.2.3 Fractured Rock Aquifer
2.2.4 Deep/Non-carbonate Aquifer
2.2.5 Carbonate Aquifer

2.3 Groundwater Budget

2.3.1 Groundwater Flow
2.3.2 Groundwater Recharge
2.3.3 Groundwater Discharge
2.3.4 Groundwater Budget Calculation

3.0 REFERENCES

Figures
Tables
Appendix A
Appendix B
Summary

RS:DJ:311
A:a
CONCLUSION AND RECOMMENDATIONS

1) Ranger's mine site location between Gulngul and Magela Creeks, together with the presence of five permanent billabongs in the area, keeps the groundwater system saturated most of the time.

2) Groundwater is found mainly under unconfined to semi-confined and confined conditions in the shallow and deep aquifer systems. In several places it is not possible to distinguish between the two systems.

3) The construction of the tailings dam and the other water management ponds created groundwater mounds (recharge zones) from which the surface water is entering the shallow and deep aquifer systems.

4) It was found that the Billabongs are acting as groundwater discharge zone during the dry, the relationship during the wet is under study.

5) Although there are no indications that seepage from the tailings dam is moving towards the pit, it is highly recommended to drill at least two boreholes to confirm the presence of a groundwater divide or an impervious layer.

6) Seepage into the pit from the shallow and weathered zones is highly related to the increase in head in the southern part of the tailings dam.

7) Artesian pressure is developing in the northern and western sides of the tailings dam, causing the flow of some wells which are tapping deep aquifer and the top part of the weathered aquifer.
1.0 INTRODUCTION

Department of Mines and Energy and Water Resources Division's role as one of the supervising authorities under the Environmental Protection (ARR) Act, 1978 is to monitor both the surface and groundwater, which are subject to possible contamination by the uranium mining and milling operations in the Alligator Rivers Region.

This report documents the Alligator Rivers Region Unit's interpretations, comments and recommendations on the hydrogeology of Ranger area.

Water budget has been estimated for the area, however consideration must be given to the values of transmissivity and storage co-efficient-, which have been estimated from the simulation of groundwater model. Reason for this is that pump test data are not reliable or adequate to calculate these values.

2.0 HYDROGEOLOGY

2.1 Geology

Ranger area is situated in the northeast region of the Pine Creek Geosyncline, where the Nanambu Complex rocks of Archaean to Lower Proterozoic age form the basement. To understand the geology of this area, it would be necessary to know the development of the different stages of evolution of the Pine Creek Geosyncline. Stuart-Smith, et al., 1979 have described the four different stages of evolution of the Pine Creek Geosyncline, which are very briefly mentioned below.

Pre-Stage 1 is considered first, when the Archaean granotoids were exposed and formed the basement to the Pine Creek Geosyncline. Then in Stage 1, by rifting and subsidence of the Archaean basement, a north to northwest trending through (the South Alligator Trough) and two adjoining shelves (the Batchelor and Kakadu Shelves) formed. This followed by the deposition of metasediments in the geosyncline and on the shelves - Batchelor Group sediments along the western margin of the Batchelor shelf, and Kakadu Group sediments on Kakadu shelf. In the centre of the geosyncline, over most of the Batchelor Shelf and the South Alligator Trough, and also on parts of Kakadu Shelf, a thicker sequence of black shale and siltstone (which are calcareous and pyritic in places), dolomite and
calcareous sandstone were deposited. Calcareous sandstones contain peloids of dolomite, indicating some reworking of carbonate. The Stage 1 ended with felsic to mafic volcanic activity, or thinning of continental crust.

In Stage 2, the Archaean provenance areas were rejuvenated. As a result the chemical sedimentation and an influx of clastic material (Mt. Partridge Group) took place. The uplift probably caused slight warping and minor local suaerial exposure of the stage 1 sediments. Warping was probably about north to northwest-trending axes, as a slight angular unconformity beneath the Mount Partridge Group is only obvious where sediments strike east.

A tectonic event in Stage 3 caused uplift, folding, and subsequent erosion of the Stage 1 and 2 sediments, preceded a new phase of sedimentation, dominated by chemical and organic sediments (South Alligator Group), which accompanied a shallow marine transgression - initially over the Batchelor Shelf and the South Alligator Trough, and later the Kakadu Shelf. Penetration of the older sediments and Archaean basement exposed west of the Batchelor Shelf (Chilling Platform) and, possibly Nanambu High. Chemical sedimentation was temporarily interrupted by widespread felsic subaerial volcanism (Gerrowie Tuff and Shovel Billabong Andesite) centred in the South Alligator Trough. There was a major shift in the locus of tectonic activity within the geosyncline from the centre to the west represented by the Western Fault Zone and felsic to intermediate volcanism west of the Western Fault Zone resulted in an influx of flysch-type sediments into the geosyncline, indicating continued subsidence of the South Alligator Shelf and the Kakadu Shelf. At the close of sedimentation tholeiitic basalt (Zama Dolerite) was emplaced, mainly as sills, into the Early Proterozoic sediments (Ferguson and Needham, 1978).

During Stage 4, the east-west compression of the geosyncline resulted in more deformation and metamorphism and partial anatexis of the Early Proterozoic sediments and some subsequent igneous activities. Deformations and metamorphisms were mainly controlled by the original basement configuration such as the position of basement highs, the South Alligator Hinze Zone, and thickness of the sedimentary
pile. The resultant force resulted in folds trending north to northwest and non-cylindrical axes. During this period the Nanambu High was reactivated and partly migmatized to form the Nanambu Complex. The folded sediments were draped around it to form complex refolded synclinal structures. A marked foliation developed parallel to the axial plane of these folds, and gave rise to the dominant schistosity. Relict isocinal fold noses are preserved in the more competent quartz-rich bands in mica-schist. Lineaments in Nanambu Complex, trend generally in two directions northeast-southwest and northwest-southeast; and some in north-south direction as well as in east-west direction. But, change in lineament directions in many cases are relative to its location, i.e. almost parallel to the foliation strike.

Origin of uranium deposits have been studied by Hegge, et al. (1979), which is described here, briefly. Primary uranium mineralisation occurs in a series of coalescing lenses just below the graphitic unit which tends to form a well defined hanging wall. The orebody has been divided into two major host rock types - the Upper Mine Series (UMS) and the Lower Mine Series (LMS). The uranium deposit appears to be structurally controlled with a minimum of chemical control. There is a strong evidence that the deposit is located in a collapse structure developed in silicified carbonate of the LMS and extending into the overlying chlorite schist and microgneiss of the UMS. The source of the chlorite in the ore zones is believed to be those sections of the LMS which demonstrate post-metamorphic re-crystallisation.

Geology of the Ranger area has been studied in details by Needham and Stuart-Smith (1979) and this is summarised below.

These sediments are chronostratigraphic and not the lateral equivalent facies as described by the earlier workers. Small Archaean domes are surrounded by Early Proterozoic metasediments and minor volcanics.

The Lower Proterozoic sedimentation was followed by the Middle Proterozoic (Carpentarian) deposition of conglomerate, sandstone and some minor igneous activities, which are uncomfortable with the Lower Proterozoic sediments. Finally, the Cainozoic sediments covered the area. Which represent the
present soil profile. Figure 2.1(a) shows the geology of the Ranger Mine area, and Table 2.1(i) shows the stratigraphy and lithology of the area. A fence diagram has been drawn from the available records of borehole logs, see Figure 2.1(b).

**TABLE 2.1(i) Stratigraphy & Lithology**

<table>
<thead>
<tr>
<th>Symbol-Lithology</th>
<th>Formation/Group</th>
<th>Era</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cz1</td>
<td>top soil, gravel, sand clay, laterite</td>
<td>Tertiary</td>
<td>Cainozoic</td>
</tr>
<tr>
<td>PhK</td>
<td>sandstone</td>
<td>Kambolgie Sandstone</td>
<td>Middle Proterozoic</td>
</tr>
<tr>
<td>Po</td>
<td>schist</td>
<td>Nourlangie Schist</td>
<td>Lower Proterozoic</td>
</tr>
<tr>
<td></td>
<td>(1800Ma)</td>
<td>Zamu Dolerite</td>
<td>Lower Proterozoic</td>
</tr>
<tr>
<td>Pdz</td>
<td>dolerite</td>
<td>Cahill Formation</td>
<td>Lower Proterozoic</td>
</tr>
<tr>
<td></td>
<td>(1800 Ma)</td>
<td>(2400-1800Ma)</td>
<td></td>
</tr>
<tr>
<td>PnC</td>
<td>schist, pegmatite, amphibolite, carbonates, chert</td>
<td>Nanambu Complex (2500-1800)</td>
<td>Archaean to ( - )</td>
</tr>
</tbody>
</table>


2.1.1 **Nanambu Complex APn (2500-1800Ma)**

Nanambu Complex rock types range in age from the Archaean to Early Lower Proterozoic and they are divided into three groups (Needham & Stuart-Smith, 1979) based on the age, metamorphism and geological structure as follows:

1. 2504-2400 Ma: Oldest known rocks in Alligator Rivers Region. Massive to foliated granite, white to light grey, coarse to medium grained, with quartz, microcline, plagioclase and/or biotite. Muscovite may be as abundant as biotite.
in the more massive varieties and almadine is a rare accessory. The foliation is generally northerly and vertical, and augen can be seen in vertical sections parallel to the foliation where the foliation is strongly developed.

(ii) 1980-1800Ma: Well foliated gneiss. Augen and granulobastic textures are common indicating characteristic of almandine-amphibolite metamorphic facies. Common minerals are quartz, K-felspar and/or plagiocase and biote. Mucovite may be present, but subordinate to biotite.

(iii) 1800Ma: leuco-gneiss, schist and migmatite - transitional to Mount Beasdoll Gneiss. Coarse and massive pegmatite consists essentially quartz, alkali-felspar and plagioclase, giving the rock a weak foliation. At places leucogneiss is interbedded with biotite schist and this shows a gradation of leucogneiss into meta-arkose of the Kakadu Group, indicating a metasedimentary origin.

These three groups of Nanambu Complex rocks in the Ranger mine area occupy domes within the metasediments, which suggest that the Archaean granite was reactivated (i.e. uplifted and metamorphosed with the enclosing rocks during 1800Ma orogenic event) to form a mantled gneiss dome, and also they are transitional into the Cahill Formation (Lower Proterozoic age).

2.1.2 Transitional rocks

The transition from metamorphosed Lower Proterozoic supracrustal rocks, through migmatite, to granotoids and deep-seated granulites (Page, et al., 1979), gave rise to the transitional rocks between the Nanambu Complex and the Cahill Formation. These are metasediments produced by the contact metamorphism, and were subjected to structural deformations. These rock types are schist, gneiss and pegmatite, and occur between the tailings dam and the mine pit, where the contact boundary between the Nanambu Complex and the Cahill Formation exists with the northerly trend.
Along this contact a prominent shear zone trends parallel to the contact boundary, where the rocks are highly sheared and this zone is known as smear zone.

2.1.3 Cahill Formation PnC (2400-1800Ma)

This member has a sequence of interbedded pyritic carbonaceous mica schist, chloritised felspathic quartzite and quartz schist, para-amphibolite and calc-silicate. Carbonaceous schist appears to be derived from a magnesium carbonate-bearing sediment similar to pyritic carbonaceous dolomite, shale and siltstone as found in the Masson Formation of Namoona Group. Therefore, the correlation between them appears to be possible.

Marble, para-amphibolite, calc-silicate and chert are products of metamorphism of original calcareous sediments, which were deposited in possibly deeper marine environment. Silicification of carbonate in the Ranger Orebody No. 1 suggests an earlier period of near-surface weathering. Fresh carbonate rocks are found to the south of the Ranger Orebody No. 1, near the Mount Brockman escarpment.

2.1.3.2 Upper Member/Upper Mine Series (UMS)

Upper Member consists of interlayered felspathic quartz schist, felspathic quartzite, minor mica schist and quartz-felspathic gneiss, and some minor carbonate lenses are also found. Quartzite are cross-bedded and fine-grained.

Quartz felspar gneisses are medium grained, foliated and banded. Mica quartz schists are distinguished from quartzo-felspathic rocks only be a greater proportion of mica and a lower felspar content. Mica schist is markedly kinked and contains boudinage structures; hence suggesting that the forces affected these rock types were tensional, which normally results in open fractures. Therefore, hydroteologically this structure is worth noting. As mentioned before, Upper Mine Series sediments are psammatic, a metamorphosed sequence of well bedded felspathic arenite and siltstone, minor conglomerate and thin bands of pelites. High proportion of iron and aluminium bearing silicates in the schists suggests that they represent metamorphosed iron rich pelites and detrital sediments.

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2.1.4  Kambolgie Sandstone Formation PhK (1648-1400Ma)

Kambolgie Sandstone Formation of the Middle Proterozoic (Carpentarian) age comprises of an Upper and a Lower Sandstone unit separated by basalt of Nungbalgarri Volcanic Member. In places, the Upper Sandstone unit contains a thin basaltic member, Gilruth Volcanic Member (Needham and Stuart-Smith, 1978). Sandstones are medium to coarse grained, moderately well sorted, sub-rounded to sub-angular quartz grains in a matrix of an amorphous fibrous clay or iron oxide minerals. Friable varieties are devoid of a matrix and quartzite varieties may have either interlocking grains or a fine quartz cement. Hydrogeologically it is worth noting that these sandstone grains are interlocked and cemented together resulted by the regional metamorphism. This process reduced the permeability of this sandstone to very low.

Other rock types are fine ferruginous siltstone and conglomerate containing well rounded quartz cobbles up to 200mm. But, the sandstone above the volcanic member is generally more homogenous, and conglomerate beds are less common. Throughout the areas, sandstones are cross-bedded and ripple marked, and also of 'alpha' type, hence indicating its origin as shallow fresh water deposition. Kambolgie Sandstone outcrops form spectacular escarpments in the area.

2.1.5  Cainozoic Sediments

The Cainozoic sediments cover most of the present surfaces, except the areas of Kambolgie Sandstone outcrops. They consist of top soil, ferricrete, laterite, clay, gravel and sand, and derived mostly by the weathering of older rocks in the area. Along Magella and Gulungul Creeks, these sediments are mostly sand resulted from the weathering of the Kambolgie Sandstone, up to a maximum depth of 50m, but the average depth is about 10m. Away from the Magella and Gulungul Creek area, the Cainozoic sediments are mostly clay, sandy clay, laterite and ferricrete, and the average depth is about 4m. Most of the grounds, higher than the flood area are, covered with laterite and sandy clay.

2.1.6  Geological Structures

Due to poor exposures of Nanambu Complex and
Cahill Formation rocks in this area, structural interpretation is based mainly on aerial photos, borehole geological logs, regional geological maps, and a fence diagram, see Figure 2.1(b), which has been prepared for interpreting the structures. Geologic structures have also been described by Needham and Stuart-Smith (1979), which have been mentioned below.

Lineations in the Lower Proterozoic rocks are usually long and straight, and have mostly vertical or dip-slip displacements, which in many places developed parallel to the regional northwest-southeast trending schistosity. Most of the faults were initiated during the 1800Ma deformation, but displacement of Carpentarian (Middle Proterozoic), mesozoic and younger rocks on some indicate reactivation at later dates. The Kambolgie Formation and Nanambu Complex are both closely fault- bounded.

The shear zone along the contact between the Nanambu Complex and the Cahill Formation trends almost north-south, varying only locally. Intrusives in the area followed mostly the geologic structures (zones of weakness), hence the structures controlled the dimensions, trends and attitudes of intrusives in most cases. These intrusives are now significant with respect to the study of seepages, especially around the tailings dam and retention ponds.

As mentioned before, the metamorphism produced a zone of transitional rocks between the Nanambu Complex and the Cahill Formation; and consequently resulting in intense shearing of this zone followed by the chloritization, and providing channelways for the Fe- and Mg- rich fluids, hence hydrogeologically it is worth noting. Later, haematization took place, vein-filling mineral and it also replaces ferromagnesium minerals, and forms pseudomorphs after magnetite.

2.2 Occurrence of Groundwater

The classification of aquifers in the Ranger mine area is based initially on the lithology, with two major types of aquifers. (A) Carbonate aquifers and (B) Non-carbonate aquifers. These aquifer types are further subdivided on factors such as stratigraphy, structure, depth and weathering, and are described below:
(A) Carbonate aquifer

This aquifer occurs in the carbonate and cherty rocks of the Lower Mine Series of the Cahill Formation (the Lower Proterozoic age) and is semi-confined to confined.

(B) Non-carbonate aquifers include followings:

(i) shallow aquifer,
(ii) weathered rock aquifer,
(iii) fractured rock aquifer, and
(iv) deep aquifer.

It should be noted that at places, some aquifers may be the combination of two or more of the above types (i.e. weathered and fractured; fractured and deep; deep and carbonate; and so on). Thus, in regard to contaminants these combined types of aquifer would be of paramount importance in this area. Each aquifer has been described separately in the following sections. However, the description of one type of aquifer may be influenced by another type, because it may be a combination of two types. Table 2.2(i) [TRANSIVITY; 1] gives the pump test results and Table 2.2(ii) [AQPERVERDATA; 1] gives the bore location and aquifer descriptions.

2.2.1 Shallow Aquifer

This forms a continuous water table aquifer within the top soil, alluvial sands, gravel, ferricrete and laterite sequence. Water level fluctuation in this aquifer is directly affected by the change in the atmospheric pressures in the area. The average fluctuation of water level is about 5m from the dry to the wet season. Aquifer depth ranges from a minimum of about 0.5m to a maximum of 26.0m. Soil profile and its permeability have been described by Kellet, 1979 as follows.
### TABLE 2.2.1(i) Soil Profile

<table>
<thead>
<tr>
<th>Soil Horizon (top to bottom)</th>
<th>Thickness (m)</th>
<th>Permeability Range</th>
<th>(m/s) Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Alluvial sand Clay</td>
<td>0-0.75</td>
<td>10-3 to 10-4</td>
<td>pervious</td>
</tr>
<tr>
<td>(B) Ferricrete, rounded pisolitic iron hydroxide nodules.</td>
<td>0-2.0</td>
<td>10-4 to 10-5 decreasing to &lt;10-7 at base</td>
<td>pervious to semi-pervious</td>
</tr>
<tr>
<td>(C1) Sandy quartz</td>
<td>up to 8</td>
<td>2x10-5</td>
<td>pervious</td>
</tr>
<tr>
<td>(C2) Clay, sericite, quartz</td>
<td>up to 7</td>
<td>2x10-4 to 10-6</td>
<td>pervious to semi-pervious</td>
</tr>
<tr>
<td>(D) Decomposed rocks Sand drain infill</td>
<td>up to 20</td>
<td>10-7</td>
<td>impervious</td>
</tr>
<tr>
<td></td>
<td>1 to 5x10-3</td>
<td></td>
<td>Highly pervious</td>
</tr>
</tbody>
</table>

Bureau of Mineral Resources (B.M.R) carried out investigation drilling across the Magella and Gulungul Creeks and south of the Ranger mine during 1979, and these included many shallow bores. The following descriptions of soils were obtained from those bore logs:

Soil horizon (A) is light grey sand with low organic content. Ferruginous and pisolitic towards the base.

Soil horizon (B) is ferricrete, rounded pisolitic iron hydroxide nodules, quartz cemented by red-brown ferruginous clay. Ferricrete may be poorly consolidated.

Soil horizon (C1) is mottled reddish-brown and white sandy with detrital quartz grains.

Soil horizon (C2) is pallid zone, buff-brown clay, sericite, fine quartz.
Soil horizon (D) is gradational with above essentially decomposed rock.

Laterites contain a considerable amount of water and range in depth from 5m to 10m. Between laterite and weathered rock there is a layer of sandy clay and silty clay, which occurs in many areas. This layer has a very low permeability, therefore it might act as an aquiclude in certain localized areas (Whitehead B.R., 1980).

Hydrological parameters of the shallow aquifer have been obtained from the pump tests and borelogs as shown below:

(i) transmissivity \( (T) \) ranges between 10m³/day/m and 100m³/day/m.

(ii) thickness \( (b) \) of the aquifer varies between 2.0m and 25.0m.

(iii) depth of the aquifer ranges between about 0.5m and 26.0m.

Permability of materials under the tailings dam site described by (Coffey & Partners, 1979) are:

1.5 x 10⁻⁵ m/s alluvial sands
1.2 x 10⁻⁴ m/s upper soil horizons
1.2 x 10⁻⁶ m/s to x 10⁻⁷ m/s for sandy clays
1.0 x 10⁻² m/s to 10⁻³ m/s for gravels

Importance of this aquifer may be emphasized on the basis that this aquifer is the zone through which seepage from the management ponds will travel, before entering into the deeper aquifers or being discharged to the surface water system. The area being in the tropic, monsoon rains are heavy only during a short period (December - March) and the recharge of the shallow aquifer is rapid, resulting in high fluctuation of water level. The fluctuation of water level in this aquifer will effect oxidation-reduction process and in turn, this will greatly expediate the cation-anion reactions.

2.2.2 Weathered Rock Aquifer

Depth of weathering in the area varies considerably due to its situation and the rock types. Geologic structures control the depth of
weathering very much. The depth of weathered rock aquifer varies considerably in this area, ranging from almost the ground level to about 52m, mostly in schistose rocks of both the Cahill Formation and the Nanambu Complex.

Extent of weathering was noted in excavations during the first stage of the construction of the tailings dam (Coffey and Partners Pty Ltd, 1973), these are briefly mentioned below:

chainage 430m - extremely weathered amphibolite band within highly weathered granite and biotite gneiss.

chainage 810m - 10m wide pegmatite dyke is highly weathered.

chainage 1450m & 1500m - extremely weathered gneisses and schists.

chainage 2940m - highly to extremely weathered granite gneiss, biotite schist and dolerite dyke.

chainage 3220m & 3400m - mostly highly weathered to extremely amphibolite and mottled schist and gneiss, and also pegmatite.

During the second stage of the tailings dam construction (1982), excavated floors and walls were not mapped geologically. However, during August - September, 1985 when excavations were carried out along the northern wall and floors for the third stage of the tailings dam construction, they were geologically mapped. Followings are the descriptions of the geology of the excavations:

chainage 332.7m - 407.7m - mostly extreme to highly weathered granitic scist and slightly weathered to fresh pegmatite. Seepage flows were observed near the contact of the above two rock types near chainage 333.0m.

chainage 682.0m - 792.0m - granitic gneiss and some granitic schist. Seepage flows were seen to be more prominent towards the eastern side (i.e. closer to the chainage 682.0m).

chainage xxxxm - xxxxm - amphibolite is
extremely weathered to highly weathered. But, showed no sign of any significant seepage as described before in the report (Coffey and Partners, 1979).

Hence, it appears that the seepages along the northern wall of the tailings dam are common through these weathered rocks, while the high hydraulic gradient near the chainages 430m and 810m increased the seepage rate. Seepage through the highly weathered biotite-schist zone on the western side of the tailings dam is under study. The weathered rock aquifer is widely spread over the area.

2.2.3 Fractured Rock Aquifer

Fractures and faults, which are also known as secondary porosities, constitute permeable zones for groundwater occurrences in the area. Most of the rocks in this area are affected by the intense folding, faulting and fracturing, while the schistose rocks are more susceptible and they are more deformed than any other types of rock. Thus, making fracturing schists highly permeable aquifer in this area.

Numerous bores have been drilled on the geologic structures in this area with the help of aerial photos, geology and geophysics (viz. RN 8009, 9468, 9722, 20096, 20099, 20535, 21030, 21033, 22931, 22943, 22946, 22949, etc.

Importance of the fractured rock aquifer may be emphasised by the fact that all the seepages reaching this aquifer will find its path easily to other aquifers especially if fractures are connected to each other and/or if rocks are weathered, which is often the case.

In fractured rock aquifers, transmissivity (T) ranges between 20m³/day/m and 229m³/day/m, and the storage co-efficient (S) between 2.8 x 10⁻⁴ and 5.0 x 10⁻⁵, calculated from the pump test data. Values of transmissivity (T) are as high as 470m³/day/m in fractured carbonate aquifer, as calculated by Burgess and Associates, 1985.

Due to lack of geological information of many bore holes, it is difficult to define whether the aquifer is in the fractured rocks, weathered or even deep aquifer. Some pump test data show the behaviour of the fractured rock aquifer,
although the logs indicate it as deep aquifer (viz. RN 7243, 8708, 9468, 22921, etc).

2.2.4 Deep Aquifer

Deep aquifers occur in both the Nanambu Complex rocks and the Cahill Formation non-carbonate rocks. Rock types are shale, pegmatite, amphibolite, granite, granite-gneiss and various types of schist. Apart from the permeability, factors such as the depth of weathering, texture and attitude of each different rock types affect the depth of aquifers and the hydraulic conductivity of each rock type, considerably. Hydraulic conductivity in schist is normally higher than that of any other rock types due to its schistosity. If weathering and fractures are present, then this aquifer can be very permeable.

Permeabilities in Nanambu Complex rocks, estimated by Coffey and Partners, 1979 are:

- Granite gneiss 2 x 10⁻⁷ and 5 x 10⁻⁷ m/s (in weathered).
- Schist to 1 x 10⁻⁷ m/s.

Transmissivity values obtained from the pump test data range between 17.2 m³/day/m and 369.0 m³/day/m and the storage co-efficient ranges between 1.5 x 10⁻³ and 3.7 x 10⁻⁴.

2.2.5 Carbonate Aquifer

Carbonate rock aquifers in this area are semi-confined to confined and occur to the east of the Nanambu Complex rocks. They extend from the south, near Mt. Brockman to the north of Corndol Billabong. Carbonate rocks of the Lower Mine Series are often highly fractured and faulted, and when this is the case, they are the best aquifers (viz. RN 9722, 22943, 22946, 22949, etc). A new borefield is being developed in these aquifers near the anomaly number 5, north of Mt. Brockman. The investigation drilling in the carbonate aquifers during 1983-84 by Ranger Uranium Mines Ltd showed a number of major shear zone and fault system, which make this aquifer highly permeable.

The results of the pump test data available provided following values: transmissivity (T)
range from 83.0 to 470m3/day/m and the storage co-efficient (S) from 1.0 x 10-1 to 7.8 x 10-3 in the carbonate rock aquifers (Burgees and Associates, 1985). Values used in the simulation of the groundwater model used are 150m3/day/m and 2.0 x 10-1 for the transmissivity and the storage co-efficient, respectively.

The general depth of the carbonate rocks from the ground surface vary from 20m to 60m (more when mine pit is deepened). However, in bore RP2/4 (north wall of the RP2), it is about 1.5m from the ground surface, while in bores RN 23520 and RN 23521, north of the Coonjimba Creek. It is at the depth of about 3m from the ground surface.

2.3 GROUNDWATER BUDGET

2.3.1 Groundwater Flow

The direction of groundwater flow in this area has changed since the start of the mining operation. The original direction of the groundwater flow was to the north, and the west from the then proposed tailings dam site; to the north and the east from the then proposed mine and milling plant site. Since their construction and use, a groundwater mound started to build up underneath the tailings dam and consequently, the hydraulic gradient increased immensely, changing the direction of the groundwater flow. Increase in depth of the mine, does not seem to have affected the original trends of groundwater flow indicating the possibility of the presence of semi-impervious boundary surrounding the pit (as in the case of Nabarlek).

The first peizometric contours were prepared by Coffey and Partners (1979), which show the groundwater move to the north from the tailings dam and mine pit. The regional movement of the groundwater present is to the north, following the general trend of creeks and topography.

Piezometric contours were prepared, see Appendix A Figure 2.3.1(a-1), for the different periods from April, 1981 to March, 1984 to determine the groundwater flow directions and the hydraulic parameters.

The gradient to the north is generally low and this slows down the groundwater movement, which
builds up the pressure causing the groundwater to seep out into the creeks and to the low lying areas. This process contributes a reasonable amount of groundwater to the surface and the creeks.

2.3.2 Groundwater Recharge

Recharge to the aquifers may be attributed mostly to the rainfall, and the seepages from the management ponds in the mine area. The average annual rainfall in the area is about 1600mm and the recharge of the aquifer is usually rapid. The water level fluctuation in the area is in the order of about 4m. It is a well known fact in the Alligator Rivers Region that most of the recharging waters (from rainfall) will be discharged into the creeks, however this quantity depends mainly on the amount of rainfall. In very wet season, there will be more runoff and more recharge; while in dry years, these volumes will be less. Recharge of the groundwater by the rainfall is about 10% of the total rainfall, and the discharge from the management ponds is 3000 m³/day/m. Increase in groundwater storage has been calculated from the piezometric contours and shown below.

Increase in storage from Aug 1982 - March 83 = 452,250 m³. 
Increase in storage from Sept 1983 - March 84 = 3,407,750 m³.

2.3.3 Groundwater Discharge

Discharge from the aquifers is due to the following factors:

(i) seepage into the creek and on to the surface,

(ii) evapotranspiration,

(iii) pumping of (production and dewatering) bores, and

(iv) the groundwater base flow.

One of the major factors of groundwater discharge being the seepage, was calculated from the piezometric contours, is shown in Table 2.3.3(i-iv). From these calculations, it can be seen that during April 1981, the maximum
groundwater discharge was towards the north. The average seepage from the tailings dam during the wet season (1981-1984) was 1436m³/day/m, while during the dry season for the same period was 1195m³/day/m. The average seepage from the tailings dam during April 1981 - March 1984 was 293m³/day to the weathered and deep aquifers.

In April 1981 data were available for the area surrounding the tailings dam only. More data were available during August, 1981 and therefore, the discharge towards the Magella Creek and the Georgetown Billabong from the west were also calculated, however there is no data available to calculate discharge from the eastern side, therefore the total groundwater discharge into the Magella Creek and Georgetown Billabong could not be calculated for August, 1981. By this time, a new trend of groundwater movement started to emerge.

The groundwater seepages into the mine pit is about 531m³/day, see Table 2.3.3(iv). Seepages into the mine pit during the wet season (1981-1984) was at an average of 210 and 337m³/day, from the west and the southeast directions, while during the dry season for the same period this amounted to approximately 420m³/day. In December, 1981 the seepage into the mine pit was lower than that of August, 1981, but the discharge from other areas increased. The 1982 water level map showed a water mound to the north of the plant area with a higher gradient to the east and northwest. 1983.

In August 1982 the water levels to the northwest of retention ponds increased by 4m, but the level along the Magella Creek remained close to 10m (A.H.D.), which was 12m (A.H.D.) in January 1982. This level reduced to 8m (A.H.D.) in December 1982. Also, in the northwest area from the retention ponds the water level reduced by 2m (A.H.D.). Therefore, the seepage from the tailings dam and the seepage into the mine pit decreased. Piezometric contours along the Magella Creek again increased to 12m (A.H.D.), from December 1982 to January 1983, which increased the seepage into Djalkmara Creek and Georgetown Billabong. Also, seepage from the tailings dam increased rapidly.

In March 1983 seepage into the Georgetown Billabong showed a slight increase, which appears to be due to the recharge by the rain
water, which is usual during the wet season.

During June 1983 the seepage into the mine pit increased, which were due to the increase in seepage from the tailings dam and also, from the south-east direction. Water level along the Magella Creek remained at 12m (A.H.D.). Seepages into the creeks decreased slightly.

In September 1983 the water level along the Magella Creek reduced to 10m (A.H.D.) again and the hydraulic gradient to the north of the tailings dam also reduced. But, the seepage into the mine pit increased from the tailings dam area also increased, thus increasing seepage into RPl. This was reflected by the high artesian pressures in borehole 7243 which is flowing most of the year with noticeable increase during the wet. During December 1983 except that the decrease in water level to the northeast of the plant area and less seepage into the mine pit and less discharge into creeks.

During March 1984 water levels along the Magella Creek and around the mine pit increased by 4m (A.H.D.) and 6m (A.H.D.), respectively. This did not increase the groundwater discharge rate into the Georgetown Billabong, but increased the seepage into creeks and RPl.

From the piezometric contours it can be seen that a groundwater divide between bores RN 22900 and RN 22935 exists, trending north-south and this appears to start again from the area to the east of bore RN 22919 (or to the west of RP4) with the same trend (north-south) and, in the far north this changes direction to the N-NW. Groundwater flow from the tailings dam to the mine pit is not clearly understood, because there is no information between the tailings dam and the mine pit and there is no doubt whether these two groundwater divides are continuous or not. This groundwater divide appears to be the major one in the area.
<table>
<thead>
<tr>
<th>Direction</th>
<th>Seepage from the Tailings Dam</th>
<th>Seepage into the Mine Pit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>W</td>
</tr>
<tr>
<td>April 81</td>
<td>22</td>
<td>108</td>
</tr>
<tr>
<td>Aug 81</td>
<td>37</td>
<td>62</td>
</tr>
<tr>
<td>Dec 81</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>Jan 82</td>
<td>51</td>
<td>85</td>
</tr>
<tr>
<td>April 82</td>
<td>70</td>
<td>103</td>
</tr>
<tr>
<td>Aug 82</td>
<td>116</td>
<td>89</td>
</tr>
<tr>
<td>Dec 82</td>
<td>41</td>
<td>83</td>
</tr>
<tr>
<td>Jan 83</td>
<td>79</td>
<td>82</td>
</tr>
<tr>
<td>March 83</td>
<td>58</td>
<td>124</td>
</tr>
<tr>
<td>June 83</td>
<td>69</td>
<td>110</td>
</tr>
<tr>
<td>Sept 83</td>
<td>42</td>
<td>95</td>
</tr>
<tr>
<td>Dec 83</td>
<td>49</td>
<td>91</td>
</tr>
<tr>
<td>March 84</td>
<td>58</td>
<td>106</td>
</tr>
</tbody>
</table>

Average (Q) | 58   | 93   | 74   | 62   | 293   | 210  | 337  | 531   |

RS:DJ:311
A:a
### TABLE 2.3.3 (ii)

<table>
<thead>
<tr>
<th>Direction</th>
<th>Djalkmara Creek</th>
<th>Georgetwon Billabong</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E</td>
<td>W</td>
</tr>
<tr>
<td>Aug 81</td>
<td>71</td>
<td>74</td>
</tr>
<tr>
<td>Dec 81</td>
<td>150</td>
<td>250</td>
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<tr>
<td>Jan 82</td>
<td>127</td>
<td>191</td>
</tr>
<tr>
<td>April 82</td>
<td>218</td>
<td>277</td>
</tr>
<tr>
<td>Aug 82</td>
<td>109</td>
<td>52</td>
</tr>
<tr>
<td>Dec 82</td>
<td>177</td>
<td>284</td>
</tr>
<tr>
<td>Jan 83</td>
<td>284</td>
<td>387</td>
</tr>
<tr>
<td>March 83</td>
<td>250</td>
<td>223</td>
</tr>
<tr>
<td>June 83</td>
<td>200</td>
<td>209</td>
</tr>
<tr>
<td>Sept 83</td>
<td>363</td>
<td>158</td>
</tr>
<tr>
<td>Dec 83</td>
<td>191</td>
<td>272</td>
</tr>
<tr>
<td>March 84</td>
<td>196</td>
<td>288</td>
</tr>
</tbody>
</table>

| Average (Q) | 195 | 222 | 417 | Average (G) | 411 | 370 | 781 |

RS:DJ:311
A:a
<table>
<thead>
<tr>
<th>Direction</th>
<th>E</th>
<th>W</th>
<th>S</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 81</td>
<td>221</td>
<td>213</td>
<td>367</td>
<td>801</td>
</tr>
<tr>
<td>Dec 81</td>
<td>467</td>
<td>320</td>
<td>400</td>
<td>1187</td>
</tr>
<tr>
<td>Jan 82</td>
<td>305</td>
<td>476</td>
<td>576</td>
<td>1357</td>
</tr>
<tr>
<td>April 82</td>
<td>260</td>
<td>414</td>
<td>428</td>
<td>1102</td>
</tr>
<tr>
<td>Aug 82</td>
<td>389</td>
<td>312</td>
<td>394</td>
<td>1095</td>
</tr>
<tr>
<td>Dec 82</td>
<td>291</td>
<td>114</td>
<td>268</td>
<td>673</td>
</tr>
<tr>
<td>Jan 83</td>
<td>341</td>
<td>179</td>
<td>324</td>
<td>844</td>
</tr>
<tr>
<td>March 83</td>
<td>349</td>
<td>273</td>
<td>428</td>
<td>1050</td>
</tr>
<tr>
<td>June 83</td>
<td>218</td>
<td>101</td>
<td>189</td>
<td>508</td>
</tr>
<tr>
<td>Sept 83</td>
<td>218</td>
<td>101</td>
<td>189</td>
<td>508</td>
</tr>
<tr>
<td>Dec 83</td>
<td>226</td>
<td>149</td>
<td>401</td>
<td>776</td>
</tr>
<tr>
<td>March 84</td>
<td>328</td>
<td>167</td>
<td>340</td>
<td>834</td>
</tr>
</tbody>
</table>

Average (G) | 304 | 246 | 368 | 918   |
Followings are the average values of discharge/seepage from the various sites (from April, 1981 to March, 1984) calculated from the piezometric contours:

<table>
<thead>
<tr>
<th>Total(Q) Average Discharge</th>
<th>Tailings Dam</th>
<th>Mine Pit</th>
<th>RPl</th>
<th>Djalkmara Creek</th>
<th>G'Town B'bong</th>
</tr>
</thead>
<tbody>
<tr>
<td>m³/day</td>
<td>293</td>
<td>589</td>
<td>927</td>
<td>417</td>
<td>781</td>
</tr>
<tr>
<td>m³/year</td>
<td>106,945</td>
<td>214,985</td>
<td>335,070</td>
<td>152,205</td>
<td>285,065</td>
</tr>
</tbody>
</table>

2.3.4 Groundwater Budget Calculation

Groundwater flow, recharge and discharge are the major factors for the calculation of the groundwater budget and, these have been discussed in previous sections. Earliest values available to construct piezometric contours, are for the period immediately after the wet season (April, 1981). At this time a groundwater mound at a the SW corner of the tailings dam had already developed, see Appendix A Figure 2.3.2(a). Aquifer discharge values have been calculated for both the dry and wet seasons (from April, 1981 to March, 1984) for the areas surrounding the tailings dam and the mine pit. Hydraulic gradients were also calculated from the piezometric contours. The groundwater discharge values are given in Tables 2.3.3(i – iv).

Aquifer properties have been obtained from the pump test data and the bore log information. In many case, pump test data can not be relied upon because of the poor construction of bores and/or incorrect analysis or poor recording of data. The care has been taken to avoid these type of data in the groundwater modelling.

Transmissivity and storage co-efficients of different aquifers in the area were calculated from the pump test data, shown in Table 2.2(i) [TRANSIVITY; 1]. There are at least five different transmissivities and storage co-efficients have been calculated and their range are shown below:

RS:DJ:311
A:a


<table>
<thead>
<tr>
<th>Aquifer Type</th>
<th>Transmissivity (T) m³/day/m</th>
<th>Storage Co-efficient (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbonate rock</td>
<td>83.0 - 470.0</td>
<td>1.0 x 10⁻¹ - 7.8 x 10⁻³</td>
</tr>
<tr>
<td>shallow</td>
<td>4.0 - 101.6</td>
<td>9.3 x 10⁻³ - 2.4 x 10⁻³</td>
</tr>
<tr>
<td>weathered</td>
<td>7.7 - 175.0</td>
<td>6.9 x 10⁻⁴ - 1.3 x 10⁻³</td>
</tr>
<tr>
<td>fractured rock</td>
<td>20.0 - 229.0</td>
<td>5.0 x 10⁻⁴ - 2.8 x 10⁻⁴</td>
</tr>
<tr>
<td>deep</td>
<td>15.0 - 369.0</td>
<td>2.4 x 10⁻⁵ - 1.5 x 10⁻⁵</td>
</tr>
</tbody>
</table>

For the investigation of the flow direction and other hydraulic properties of the groundwater in the Ranger Mine area, initially seepage rates for each area were calculated for both the dry and the wet season from the available data.
REFERENCES


RS:DJ:311
A:a


MEEHAN, BURGESS & YEATES. (1983) - Stage II Construction of Tailings Dam, Piezometric Pressure Control, June, 1983. Ranger Uranium Mine Pty Ltd.


LIST OF FIGURES

Figure 1(a)  Area Location Map
Figure 2.1(a) Geology Map
Figure 2.1(b) Fence Diagram
Figure 2.3.2(a) Piezometric Contours April 1981
Figure 2.3.2(b) Piezometric Contours August 1981
Figure 2.3.2(c) Piezometric Contours December 1981
Figure 2.3.2(d) Piezometric Contours January 1982
Figure 2.3.2(e) Piezometric Contours April 1982
Figure 2.3.2(f) Piezometric Contours August 1982
Figure 2.3.2(g) Piezometric Contours December 1982
Figure 2.3.3(h) Piezometric Contours January 1983
Figure 2.3.2(i) Piezometric Contours March 1983
Figure 2.3.2(j) Piezometric Contours June 1983
Figure 2.3.2(k) Piezometric Contours Sept 1983
Figure 2.3.2(l) Piezometric Contours December 1983
Figure 2.3.2(m) Piezometric Contours March 1984

LIST OF TABLES

Table 2.1  (i)  Stratigraphy & Lithology
Table 2.2.1(i)  Soil Profile
Table 2.2.  (i)  Pump Test Data [TRANSIVTY;1]
Table 2.2  (ii)  Aquifer Description
[AQFERATA; 1]
Table 2.3.3  (i-iv)  Groundwater Discharge.
[SEEPAGE; 1]
Table 2.3.4  (i)  Transmissivity & Storage Coeff.
Ranger
Table 2.3.4  (ii-xi)  Water Budget Calculations

RS:DJ:311
A:a
APPENDIX A

Figure 2.3.1 (a-1)      Piezometric Contours

APPENDIX B

Keys to the symbols in water budget calculations.

T = Transmissivity (m³/day/m)
i = Hydraulic Gradient (distance/head difference)
w = Width of the aquifer flow (m)
Q = Amount of water flow (T x i x w) m³/year
S = Storage Co-efficient
A = Area (m²)
RF = Rainfall (m/year)
TF = Total rainfall over certain area (RF x A)
PE = Pan Evaporation (m/year)
EF = Evaporation Factor
TE = Total Evaporation = (PE x EF x A)
SE = Total Seepage [(Q + TF) - (TE)]
APPENDIX A
LEGEND

~26~
PIEZOMETRIC CONTOURS
(METRES) A.H.D.

0 9468
BORE WITH REGISTERED NUMBER

PIEZOMETRIC CONTOURS
APRIL 1981
LEGEND

25
PIEZOMETRIC CONTOURS
(METRES) A.H.D.
0 0468
BORE WITH REGISTERED
NUMBER

PIEZOMETRIC CONTOURS
APRIL 1982
LEGEND

~26~
PIEZOMETRIC CONTOURS (METRES) A.H.D.

0 9468
BORE WITH REGISTERED NUMBER

PIEZOMETRIC CONTOURS
AUGUST 1982
LEGEND

26
PIEZOMETRIC CONTOURS
(METRES) A.H.D

0 9468
BORE WITH REGISTERED
NUMBER

PIEZOMETRIC CONTOURS
JUNE 1983
LEGEND

### P PIEZOMETRIC CONTOURS
(METRES) A.H.D.

| BORE WITH REGISTERED NUMBER |

**Fig 2.3.2(m)**

**PEIZOMETRIC CONTOURS**

**MARCH 1984**