

DEPARTMENT OF LANDS, PLANNING AND ENVIRONMENT NATURAL RESOURCES DIVISION

## WATER RESOURCES OF EAST ARNHEM LAND



Dhuruputjpi River

REPORT NUMBER 02/1999D U. ZAAR, G. PROWSE and I. MATTHEWS DARWIN NT SEPTEMBER 1999

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## ABBREVIATIONS

| AHD               | Australian Height Datum  |
|-------------------|--|
| ATSIC             | Aboriginal and Torres Strait Islander Commission               |
| CaCO <sub>3</sub> | Calcium carbonate  |
| CEC               | Community Education Centre                                     |
| DLP&E             | Department of Lands Planning and Environment                   |
| EC                | Electrical conductivity  |
| FATSIS            | Faculty of Aboriginal and Torres Strait Islanders Studies      |
| GIS               | Geographic Information System                                  |
| km                | Kilometres   |
| L/s               | Litres per second  |
| m                 | metres   |
| m <sup>3</sup>    | cubic metres $(1 \text{ m}^3 = 1000 \text{ L})$                |
| mg/L              | milligrams per litre   |
| mm                | millimetres  |
| ML                | megalitres (one million litres)                                |
| NLC               | Northern Land Council  |
| NLP               | National Landcare Program                                      |
| NRD               | Natural Resources Division (formerly Water Resources Division) |
| NT                | Northern Territory   |
| NTU               | Northern Territory University                                  |
| RN                | Registered number (of bore)                                    |
| TDS               | Total dissolved solids (in milligrams per litre)               |
| µS/cm             | microSiemens per centimetre                                    |

## NOTE:

Words in *italics* are defined in the GLOSSARY OF TERMS at the end of the report.

## Water Resource Maps which are described in this report

- 1. Water Resources of North Eastern Arnhem Land
- 2. Water Resources of East Central Arnhem Land
- 3. Water Resources of South Eastern Arnhem Land

### SUMMARY

The aim of the East Arnhem Land Water Study is to provide an information resource which will help land owners and land managers incorporate water resource related aspects in their planning processes. This report provides an explanation of the groundwater and surface water resources in East Arnhem Land as depicted on the Water Resource Maps which accompany this report.

The partners in the study were DLP&E, NLP, ATSIC, and NLC. The primary clients, who also assisted with the work, were the Homeland Resource Centres in East Arnhem Land.

Three Water Resource Maps were produced at 1:250 000 scale. The groundwater resource has been classified according to the supply potential. The four categories are:

- \* Lots of water / large supply \* Homeland supply
- \* Small homeland supply \* Little chance of water

Outside of some coastal zones all groundwater in the study area has shown to be fit for human consumption. The major *aquifers* exist in poorly *consolidated* sandstone and limestone.

All Dry season flows in *perennial* rivers are maintained through *groundwater discharge*. The major *aquifers* maintain the flow in the major rivers such as the Goyder River. River flow has been classified according to the minimum flow recorded or estimated at the end of the Dry season. Again there are four categories which describe river flow; from rivers which are dry to rivers with a flow of more than 100 L/s at the end of the Dry season.

The relationship between rainfall, ground water level and river flow rate was studied. Ground water level and river flows were found to vary in accordance with previous years' annual rainfall. After studying correlations it was found that rainfall from the previous 3 to 6 years influenced the *water table* levels and Dry season river flow rates. Knowing how the groundwater and river systems respond to rainfall allows predictions to be made on their future behaviour.

Other products produced from the study include a GIS, a photographic and video collection available on CD, posters outlining the study and Aboriginal Knowledge and Technical Data reports. The entire information resource aims to provide regional planners and land owners with a good starting point in the development of water resource management plans for the region.

## **1.0 INTRODUCTION**

These notes and the Water Resource Maps have been produced to improve traditional owners' and land managers' access to water resource information by providing the information in a non technical form. Previously existing information sources are insufficient in content and in form to help aboriginal landowners and land managers who do not have a technical background. The complete package produced from this study also includes posters, a GIS, a photographic and video collection and Aboriginal Knowledge and Technical Data reports. This forms a set of decision making tools which will allow homeland organisations, community councils and government departments to readily include water resource considerations in their decision processes regarding future land management and development.

The partners in this three year project were the:

- Natural Resources Division of the Northern Territory Department of Lands Planning & Environment - NRD of DLP&E
- National Landcare Program NLP
- Aboriginal and Torres Strait Islander Commission ATSIC
- Northern Land Council NLC

The major clients who also provided assistance in many ways were the:

| Anindilyakwa Land Council       | Marthakal Homeland Resource Centre            |
|---------------------------------|---|
| Dhimurru Land Management        | Milingimbi & Outstations Resource Association |
| Gulin Gulin Resource Centre     | Ngadunggay Homeland Resource Centre           |
| Gumatj Association              | Numbulwar Homelands Council Association       |
| Laynhapuy Homelands Association | Ramingining Homelands Resource Centre         |

The study area includes all of East Arnhem Land, as delineated by the ATSIC Nhulunbuy Region, and covers an area of around 57 000 km<sup>2</sup>. For the project, this area has been divided into three sectors (Figure 1) resulting in three maps:

North EasternEast CentralSouth Eastern

The North Eastern Sector was able to be covered in detail. Due to time and field access constraints the other sectors were largely limited to regional reconnaissance only.



Division of the study area into three sectors.





The Water Resource Maps are an interpretation of the region's *geology*, *topography*, bore data, stream flows and vegetation patterns. To produce the maps aerial photographs and satellite images were studied and field programs including drilling, test pumping, water sampling and stream gauging undertaken. The contribution from Traditional Owners, in their knowledge of the waterways, has been vital to the mapping exercise, particularly in areas where access was difficult. The maps show the generalised groundwater and surface water characteristics of the region. As there was no drilling data for large parts of the study area much of the interpretation, particularly in the second and third sectors, is based on extrapolation.

During the course of this project, much effort was expended in researching Aboriginal place names for locations on the map. Close attention was paid to spelling and cross-checking of data, but inconsistencies, errors and omissions may be evident.

All data used is held by the NRD at their offices in Darwin. Most is on public record and a lot is easily accessible. (Refer to section 6.0 for details regarding data format, location and availability.)



Within this report, words written in *italics* are defined in the glossary of terms at the end.

#### Plate 1

Using maps to discuss water resources at Balaypalay.

## 2.0 GROUNDWATER

## 2.1 The Groundwater System

To understand groundwater it helps to have an understanding of the water cycle, Figure 2. When rain falls on the ground some of it runs off into streams (surface runoff), some of it evaporates and some of it seeps into the ground (infiltration). The water that seeps into the ground wets up the soil and moves down. Some of this water may be evaporated (within a few metres of the ground surface) or used by plants and the rest will reach the *water table*. This is groundwater. This process is called *recharge* because water is being added to the groundwater system. Groundwater slowly flows from high areas to low areas through *porous* rocks and soil, usually discharging to the surface at some point. If a useful amount of water can be extracted from the rocks or soil, it is then called an *aquifer*.



Figure 2 Nature's Water Cycle showing the groundwater system.

East Arnhem Land has a humid monsoonal climate with a distinct rainy period, known as the 'Wet' season, which usually starts in November and finishes in April. During this time most of the annual rainfall occurs. From May to October, rainfall, temperature and humidity levels

are lower and this is called the 'Dry' season. Rain *recharges* the *aquifer* during the Wet, causing water levels to rise, while in the Dry, the levels fall (Figure 3). NRD have records of how the *water table* level changes over the years. This is done by measuring the depth of water in *observation* bores.





Figure 3a Variation in groundwater level



In low rainfall years, *water table* levels will rise less and discharge from springs will be less. High rainfall will result in increased *recharge*, higher *water table* levels and greater spring flows. This can be readily observed as more water flowing in the creeks and rivers in the Dry (Figure 8).

The size of the *aquifer* and the speed at which water can travel through the aquifer determine how much water can be pumped out of a bore and how the water level will change in response to pumping.

## 2.2 Aquifer Type

The different *aquifers* found in Eastern Arnhem Land have been grouped according to the *bore yield* and the *salinity* of the groundwater found within them. Each of the groundwater groupings, as shown on the legend of each map, is discussed in the following sections.

The bore *yields* stated represent typical *yields* which could be expected from bores sited using geological and local knowledge. Natural variation in the properties of rocks means that variation in bore *yield* within a groundwater grouping will occur. As such, a percentage of bores within a particular grouping may have a lower or higher *yield* than described, but most will fall within the nominated limits.

The amount of water which is safe to pump from a bore over a long period is less than that which can be pumped over a short time. Therefore, it is normally recommended that bores are pumped at lower rates than those found by *airlifting* with a drilling rig which is done in a short time.

## 2.2.1 Explanation of *aquifer* type as shown on the Water Resource Maps

The details of aquifer type are listed on the Water Resource Maps under the heading 'Groundwater Features'.

## LOTS OF WATER / LARGE SUPPLY

This aquifer type is coloured blue on the maps. These sections are large regional *aquifers* which consist of poorly *consolidated* sandstone or limestone. They provide the most substantial and reliable groundwater resources in the region. This *aquifer* type has high *porosity* and *permeability* and can supply large volumes of water. Individual bore *yields* are generally more than 10 L/s and can be up to 50 L/s with efficient bore construction. This type of *aquifer* supplies water to Nabalco, Nhulunbuy and Yirrkala.

The volume of water which can be extracted from these *aquifers* may be sufficient for long term industrial or agricultural use. However, more detailed investigation work must be undertaken before developments such as these occur. These *aquifers* naturally discharge large volumes of water throughout the year and are responsible for the *baseflow* of many of the large rivers.





### **HOMELAND SUPPLY**

This group is coloured green on the maps and makes up the bulk of *aquifers* in East Central and South Eastern Arnhem Land. In these *aquifers* groundwater occurs in networks of fractures or cracks (Figure 4). The *aquifers* tend to be localised along zones where fracturing is more intense, such as faults. The best yielding bore sites are those that have a good chance of striking lots of open cracks in the rock. Large faults may be identified on aerial photographs and/or *satellite imagery* by hydrogeologists and bores can then be sited on the most promising features.

Figure 4 Movement of water through fractures when pumping a bore.

*Aquifers* can also be present where the upper rock layers have been heavily weathered. Weathering is a near-surface effect only, and drilling depths are seldom more than 50 m. Fractures and weathering effects tend to decrease with depth. *Yields* from fractured and weathered rock *aquifers* tend to be low; between 0.5 - 5.0 L/s. The degree of interconnection of *aquifers* varies depending on the amount of fracturing and/or weathering and this makes it difficult to predict the quality and quantity of groundwater in different areas. This means that bores drilled close together can have very different *yields* and water quality.

## SMALL HOMELAND SUPPLY



This group is coloured light green on the maps. The *aquifers* here are mainly small and isolated with occasional *yields* up to 1 L/s. They consist of two distinct types. On the East Central map, the *aquifer* is confined to a thin layer of sandstone, capping a low plateau. This thin layer is underlain by *impermeable* siltstone. Small supplies may be possible from sites on top of the plateau.

Plate 2 Sandstone on plateau in East Central Arnhem Land

On the North Eastern and South Eastern map, it is more common to strike small areas of very *permeable* and *porous* alluvial sand which occurs as valley infill among granite rocks. Short term *yields* can sometimes be more than 5 L/s, but due to the small size of the *aquifer*, the long term *yields* may be much less than this.

## LITTLE CHANCE OF WATER

This group is coloured orange on the maps. The area is underlain by shales, muds and clays in the East Central sector and granites in the North Eastern and South Eastern sector. These rocks are poor *aquifers* with only small, isolated supplies available. Most bores drilled into these rocks are dry.

Within the shales, muds and clays water supply prospects are very low to nil. Further drilling is not recommended. Within the granite areas, drilling should be targeted at the fractured and weathered portions. Hydrogeologists should be consulted prior to drilling as careful site selection increases the likelihood of obtaining a useable supply.

The current success rate for bores drilled into this unit is low and further drilling is not expected to be significantly more successful. Maximum *yields* of less than 0.5 L/s are expected.

## SAND DUNES

Although not separately detailed on the Water Resource Maps, aquifers can also occur in



**Plate 3** Sand dunes with spring flow at Emirreba (Eight Mile Beach) Groote Eylandt

sand dunes. They are often in 'fossil' dunes as well as those currently on the beachfront. The sand is very *porous*, but usually only small volumes of water are available for extraction because salt water intrusion from the sea may become a problem once water is pumped from the *aquifer*.

These systems can however sometimes supply large volumes of water if managed carefully. For example, Numbulwar's water supply is drawn from calcareous coastal sand dune sediments 1 km north west of the community. The annual *sustainable yield* of this system is estimated to be 2000 m<sup>3</sup>/day, or more than 20 L/s (Tyson et al, 1991).

## 2.3 Water Quality

Rain water naturally contains a small amount of salt. When this water seeps through the ground, it dissolves part of the soil or rock and so becomes more salty. It also becomes more salty when part of it is evaporated away. Near to the coastline or tidal streams, fresh water in *aquifers* can become mixed with sea water. This can happen naturally on a seasonal basis, or when water is pumped from an *aquifer* close to the ocean.

A measure of the saltiness of water is its *Total dissolved solids* (*TDS*). This measures the amount of salt in milligrams (mg) in one litre (L) of water. Good drinking water is said to have a *TDS* of less than 1000 mg/L and fair drinking water of less than 1500 mg/L. Water is also described as being 'hard' or 'soft'. 'Hard' water requires more soap to produce suds than 'soft' water. This is mainly caused by the presence of calcium and magnesium in the water. Water having more than 150 mg/L *hardness* can deposit scale in pipes. Another measure of the saltiness of water is it's *electrical conductivity*, *EC*. The more salt, the more

conductive the water is for an electric current. *EC* is measured in microsiemens per centimetre,  $\mu$ S/cm.

The great majority of groundwater in east Arnhem Land has a low TDS and is fit for human consumption. Most of the bores which have supplied salty water have been drilled close to the sea or salty mangrove and swamp areas. These waters can be distinguished by high sodium and chloride concentrations.

pH is a measure of the hydrogen ion concentration. A pH of less than seven means that the water is acidic. A lot of the groundwater naturally has a low pH, caused by high levels of dissolved carbon dioxide. This means that it is acidic and corrosive to metal bore casing and pipes. But it is still suitable for consumption as long as plastic bore casing and pipes are used to distribute the water. Alternatively, the water can be treated by aeration as is done for the Nhulunbuy water supply. This involves releasing the water to the atmosphere to allow the carbon dioxide gas to escape which causes the pH to increase.

It should also be noted that pH measurements taken from *airlifted* water during the drilling process does not give a true indication of the pH - and therefore the corrosiveness - of the water.

## 2.3.1 Relationship between water quality and *aquifer* type as shown on the Water Resource Maps

## LOTS OF WATER / LARGE SUPPLY

The water from the high yielding sandstone *aquifer* (for example at Baniyala and Nhulunbuy) has a low *TDS*, typically less than 50 mg/L, a *pH* of around 5 and is classed as 'soft' (generally less than 10 mg/L of Calcium Carbonate,  $CaCO_3$ ). The water quality is consistent in this sandstone *aquifer* even though it is widely distributed.

Bore and spring water sourced from the high yielding limestone *aquifer* (in the Emu Springs region) has a *TDS* greater than 200 mg/L with CaCO<sub>3</sub> concentrations of more than 150 mg/L. This water has a *pH* of around 7 or higher. The water from these *aquifers* are suitable for all uses.



Plate 4Chert rock type which originated from limestone, East Central Arnhem Land. Water<br/>dissolves part of this rock type resulting in high calcium carbonate concentrations.



## HOMELAND SUPPLY SMALL HOMELAND SUPPLY

The smaller *aquifers* are in many different types of rocks and in some, groundwater quality is directly related to the underlying rock type. However, there are too many to list and it is sufficient to categorise the groundwater throughout this area as low *TDS*, low *pH* water. Generally, this groundwater has a *TDS* which is higher than the *TDS* of the high yielding sandstone water and lower than the high yielding limestone water (shown on the maps in blue).

## **3.0 SURFACE WATER**

Surface water is water stored (such as in billabongs, lakes and river pools) or water flowing on the earth's surface (such as rivers). It is sourced not only from rainfall and rainfall *runoff* but also from beneath the ground, from groundwater. The groundwater contribution to a stream is known as *baseflow* (Figure 5).



Figure 5Baseflow input into a stream - as diffuse flow.<br/>(from Watson and Burnett, 1993).

When examining the flow in a river it is often divided into two components: rainfall *runoff* and *baseflow*. It is the *baseflow* component which keeps rivers and creeks flowing through the long Dry season. Figure 6 depicts the variation in flow for the year 1991 in Yirrkala Creek. The two flow components are easily distinguished on the graph.



Resources Gauging station GS8260054



Plate 5Yirrkala Creek downstream from the weir, near the Natural Resources<br/>*Gauging station* GS8260054. This is where flow is measured.

Natural Resources Division have recorded the variation in river height and flow at a number of sites (gauging stations) in East Arnhem Land. The record from these gauging stations has been used to correlate river flows with groundwater level and rainfall.

## 3.1 Minimum Flows

In order to know what quantity of water can be sustainably pumped out from a river it is necessary to know what the minimum flow is. There is much variation in the minimum flow of a river. For example Figure 7 shows the flow at Yirrkala Creek since 1970. Around 1977 the minimum flow in Yirrkala Creek was high - about 400L/s. And around 1972 and 1993 the minimum flow in the creek was low - less than 100L/s.



Figure 7Flow at Yirrkala Creek from 1970 to 1999Recorded at Natural Resources Gauging station GS8260054

This variation is due to the variation in rainfall. When the rainfall record was analysed for the East Arnhem Land area, it was found that more than just the previous years rainfall influenced the minimum flow in a river. For example, in Yirrkala Creek and other rivers in North Eastern Arnhem Land, it was found that in any year the last 6 years rainfall impacted on the minimum flow. This correlation can be seen in Figure 8: the 6 year *moving average of rainfall* at Yirrkala shows the same trend as the minimum annual *water table* level and the minimum annual flow in Yirrkala Creek. For ease of reference, all graphs in Figure 8 are vertically aligned in water year. Notice the low points on each graph in 1971/72 and 1992/93 and high point in 1976/77.



Figure 8 Correlation between rainfall, *water table* level and river flow at Yirrkala

This reflects how rainfall affects the groundwater level which in turn affects the flow in the river. When there has been a period of high rainfall years the *water table* level rises causing higher flows in rivers in the Dry season. When there has been a period of low rainfall years the *water table* level falls resulting in lower flows in the rivers in the Dry season (Figure 8,9).

## High *water table* = large flow in river

## Baseflow Baseflow Water table



Low water table = low flow in river

Figure 9 Affect of *water table* level on river flow (adapted from Fetter, 1994)

This means that even if there has been high rainfall recorded in a particular Wet season it does not necessarily mean that in the following Dry season there will be high *baseflows* in the river. For example, referring to Figure 8, there was a moderately high amount of rainfall in 1988-89, yet the *water table* and minimum river flow did not increase significantly. This is because in the 6 years prior to 1989 there was moderately low rainfall.

*Water table* level and minimum annual river flow for each Water Resource Map sector correlated differently with rainfall at Yirrkala:

| North Eastern Arnhem Land                | 6 year moving average of rainfall at Yirrkala        |
|--|--|
| East Central Arnhem land                 | 5 year <i>moving average</i> of rainfall at Yirrkala |
| Groote Eylandt (in South Eastern sector) | 3 year moving average of rainfall at Yirrkala        |

These differences are likely to be due to differences in *geology* and *topography* which affect groundwater behaviour. The Yirrkala rainfall record was chosen for correlation analysis because of its long record<sup>1</sup>. These correlations are graphed on each of the respective Water Resource Maps. The strong correlations indicate that the long term variation of annual rainfall is consistent enough throughout East Arnhem Land to allow the long term trends in minimum flow in all rivers in the region to be broadly correlated to the rainfall at Yirrkala.

## 3.2 Mapping minimum flows on the Water Resource Maps

River flow on each of the Water Resource Maps was plotted according to its minimum flow. In establishing the minimum flow to be mapped the long term variation in flow was taken into account. In analysing rivers with a streamflow record it was found that the recorded minimum flow often occurred in 1971-72. This is a clear low point in the long term record. For rivers in which flow was measured for the first time (during this project), the long term trend was also taken into account by correlating the time when the measurement was taken in relation to the long term record of rainfall and other rivers in the region.

The categories of some rivers have been estimated from anecdotal evidence or scientific interpretation as some areas were inaccessible, sacred or were not visited due to time constraints. This is particularly relevant to sectors 2 and 3. There are four categories of minimum flow shown on the Water Resource Maps. Details of each category follows:

River with a flow of more than 100 L/s at the end of the Dry season.



These rivers can provide a very large water supply. Although the category minimum is 100 L/s some of the rivers have an annual minimum flow in excess of 1000 L/s. Angurugu Creek fits into this category. It supplies water to the towns of Angurugu and Alyangula as well as to GEMCO.

Plate 6 Angurugu Creek.

River with a flow of between 10 and 100 L/s at the end of the Dry season.



Plate 7 Giddy River - Guwatjurrumurru

This category indicates supplies suitable for larger homelands and potentially communities, depending on the river. The Giddy River and Yirrkala Creek fit into this category. In the past Yirrkala Creek has provided the water supply to Yirrkala community which has a peak demand of 12 L/s continuous.

<sup>&</sup>lt;sup>1</sup> Yirrkala rainfall record was obtained from the Meteorological Bureau rain gauge DR014502 at Yirrkala. Missing data has been obtained from correlations with Gove Airport, Nabalco Mine Site, Nhulunbuy P.O and Angurugu rain gauges.

River with permanent waterholes and flows of up to 10 L/s at the end of the Dry season.



This category indicates potential supplies suitable for homelands. It includes rivers which cease to flow but contain permanent waterholes. Some of these waterholes would have adequate storage to supply a small homeland throughout the Dry season. In cases where the river does not contain large pools and ceases to flow, it may still provide an adequate small supply if there is sufficient input from groundwater. An example of a creek in this category is Bularriny Creek near Bularriny as its flow drops below 10 L/s.

Plate 8 Bularriny Creek.

River which is dry at the end of the Dry season.



These rivers are not suited to supply water throughout the year. Annie Creek, upstream and southwest of Emu Springs is an example of this type of river.

Plate 9 Annie Creek, south west of Emu Springs.

## 3.3 Wet season variation in streamflow

In the Wet season, the flow in a river increases due to rainfall *runoff*. The increase in flow at a point along the river is dependent on the rain that has fallen in the *catchment* upstream from that point. The larger the *catchment*, the bigger the increase in flow. As can be seen in Figure 10 the Durabudboi River has the larger *catchment* area resulting in a larger amount of rainfall *runoff* and river flow in the Wet Season compared with Yirrkala Creek. The flow in the river is bigger because the area that catches the rainfall is bigger. In brief:

## **BIG** CATCHMENT = **BIG** WET SEASON FLOW

## SMALL CATCHMENT = SMALL WET SEASON FLOW







Plate 10 Undertaking a flow gauging on the Durabudboi River. A current meter is used.

On the Water Resource Maps *catchment* boundaries for entire river systems are marked on the 'Surface Water *Catchment* Map'. The variation in river flow over the year is graphed for a number of rivers on each of the Water Resource Maps.

Note that in the Dry season the flow in the two rivers in Figure 10 are very similar. This is because they rely on *groundwater discharge* in the Dry Season. Sandstone *aquifers* maintain Dry season flows in both these rivers.

*Catchment* boundaries are useful in relating Wet season flows and water quality at different points within a *catchment*. For example an increase in *turbidity* in a stream could be due to eroding soils from a rough track in its vicinity. It could also be due to cattle or pigs disturbing the zone along the stream by trampling or digging up the soil, loosening it and allowing it to wash away with the rain. *Turbidity* can destroy otherwise healthy habitats. This is why cattle and pigs should always be kept away from the river banks - the riparian zone.

## 4.0 INTERACTION OF GROUNDWATER AND SURFACE WATER

There is a lot of groundwater/surface water interaction in eastern Arnhem Land due to large regional *aquifers*, high annual *aquifer recharge* and contributing geological factors. This interaction takes place in the form of *groundwater discharge* as discrete, individual springs or diffuse flow (as shown in Figures 5 and 9) into creeks and rivers.

Springs are natural outflow points for groundwater, occurring where the watertable is at or above the ground surface. Many of these are shown on the accompanying Water Resource Maps. The smaller springs may only form small pools, while others maintain large permanent river flows as discussed earlier. Flows can range from seepage to more than 100 L/s and generally decrease as the Dry season progresses. Some springs dry up before the start of the next Wet. Rivers and creeks that are still flowing at the end of the Dry season are groundwater fed by springs and diffuse flow.

## 4.1 Large groundwater discharges

All large *groundwater discharges* come from the sandstone or limestone *aquifers* marked blue on the maps. These are extensive regional aquifers with large amounts of water in storage and are responsible for the Dry season flows of the (Habgood) Baralmana, Angurugu, Dhalinybuy (Cato), Dhurputjpi (Durabudboi), Goyder and other large rivers. The storage in the limestone is low compared to the sandstone, and it appears that much of the groundwater in the limestone unit is a result of leakage from the overlying sandstone unit.

## 4.2 Water Quality

The water quality of *groundwater discharges* are directly related to the *geology* of the *aquifer* supplying that particular spring. As discussed earlier the waters from the large sandstone *aquifers* are recognised by a TDS of less than 50 mg/L while that from the large limestone system has a TDS of more than 200 mg/L. The water quality of the other *aquifers* tend to lie between these two end-points.

Figure 11 shows the major creeks and rivers with the end of Dry season water quality subdivided into three groups. The three groups represent the large sandstone *aquifers* (low TDS water), the large limestone *aquifers* (high TDS water) and the other *aquifers* (moderate TDS water).



Figure 11 Baseflow water quality - rivers with flow over 100 L/s

## 4.3 Spring type

The location of springs is determined either by the position in the landscape, the *aquifer* location, the rock type or a combination of these factors. In eastern Arnhem Land, there are many different occurrences of springs, a few of which are described below.





# Soil Clay Sandstone

Figure 13 Spring type 2



Figure 14Spring type 3

## SPRING TYPE 1

An example of spring type 1 is Yirrkala Creek. The *baseflow* for this creek is provided by poorly *consolidated* sandstones which have a lot of water in storage. This water seeps out of the sandstone at about the level of the stream and provides the flow during the Dry season (Figure 12).

## SPRING TYPE 2

Streams, such as the Cato River, obtain most of their flow from point source areas where the river bed has cut down through a clay confining layer. This allows water from the underlying poorly *consolidated* sandstone *aquifer* to rise to the surface and provide the dry season *baseflow*, as shown in Figure 13.

### **SPRING TYPE 3**

Another type of spring occurs at the headwaters of the Woolen River where a thin layer of *permeable* sandstone lies above low *permeability* shale. Water seeps out at the contact between the two rock types. This type of spring is shown in Figure 14.



SPRING TYPE 4

Along the south-east coast of the Wessel Islands chain, there are springs which occur at the gently dipping contact between sandstone and shale. They represent overflow from the sandstone *aquifer*. This type of spring is shown in Figure 15.

Figure 15 Spring type 4

Although the classic definition of 'springs' states that the watertable will be at or above the ground surface, this distinction is not recognised on the East Arnhem Land Water Resource Maps. If a shallow well has to be hand dug down to the *water table* to access the water, it is considered to be a spring area. This definition has been used so as to avoid the many complex terms used by the aboriginal people for the varying types of spring.

The long Dry season in the Top End means that rainforests and other dense vegetation groups, exist only in pockets where increased moisture levels are present all year round. Hence rainforests are often an indicator that a spring is present or the *water table* is close to the surface. Many of the springs and permanent rivers in Arnhem Land are fringed with rainforest vegetation and are important parts of unique local ecosystems.



Plate 11 Rainforest with spring on the flood plain north west of Gurrumuru.

## 5.0 SUSTAINABILITY OF WATER SYSTEMS

Water levels in bores, *baseflows* in rivers and springflows are all dependent on rainfall. Hence, a knowledge of past climatic variations is essential in determining if current usage from bores and river *baseflow* volumes can be maintained. The sustainable yield is that amount of water which can be extracted without long term adverse effect on the environment or the resource.

Rainfall is variable with a pattern of wet and dry periods being normal. As discussed earlier, for the East Arnhem region, the rainfall record from Yirrkala was correlated with water table levels and minimum river flows. This rainfall record is available from 1936 and is thought to be representative of the region. The lowest annual rainfall recorded was about 800 mm and the highest 2200 mm. The average annual rainfall is approximately 1340 mm.

### 5.1 Sustainability of *aquifer* systems as marked on the Water Resource Maps

## LOTS OF WATER / LARGE SUPPLY

This type of *aquifer* is marked on the Water Resource Map on the Gove Peninsula. It is tapped by a borefield and supplies water to the township of Nhulunbuy and to the Nabalco Alumina refinery. This is one of the highest producing borefields in the Northern Territory. Large scale extraction began in the early 1970's and has gradually increased to the present day extraction rate of 30 ML/day (350 L/s).

The *yield* of the *aquifer* that is sustainable needs to take into account the affect of a number of high rainfall years on the amount of water in storage. For example, referring to Figure 8a, the average rainfall at Yirrkala between 1973 and 1978 was more than 500 mm above the long term average. This resulted in a four metre rise in the minimum annual water table level in bore RN 7980, Figure 8b. This additional amount of groundwater in storage doubled the Dry season flow rate in the perennial streams which drain this aquifer (Figure 8c). This emphasises the need for long term water resource data. If pre 1973 data had not existed the decrease in water levels and stream flow rates from 1980 to 1993 could have been blamed on over exploitation of the groundwater resource rather than natural variation.

The water for Angurugu, Alyangula and the manganese mine and processing plant on Groote Eylandt is drawn from a similar high-yielding *aquifer*. This *aquifer* is also responsible for the large *baseflow* of Angurugu Creek.



Plate 12 'The Gardeners' at Baniyala. The community is reliant on groundwater.

A sandstone *aquifer*, similar to that at Gove, is also tapped at Baniyala, but despite high instantaneous *airlift yields* being available, the long term *yield* at this location has been estimated to be only about 5 L/s. If a lot more water was pumped, sea water might be drawn into the *aquifer*. If

significant borefields are to be established within 10 km of the coast

in this region, great care should be taken, and extensive planning done to reduce the possible effects of *salt water intrusion*.

Although there are no high yielding production bores in the other areas of this aquifer type, it is presumed that, away from the coastline, high yielding bores and large borefields could be constructed if and when the need arose.

## HOMELAND SUPPLY

SMALL HOMELAND SUPPLY

## LITTLE CHANCE OF WATER

Compared to the 'large supply' *aquifer type*, all others marked on the map have limited *permeability*. Some of the *aquifers* have a large amount of water in storage, but the low *permeability* of the *aquifer* means that the water flows into bores at low rates. If there are one or more years of below average rainfall and therefore reduced *recharge*, pumping *drawdowns* may increase and the bore fail.

When pumping from small *aquifers* with little water in storage, bores tend to fail at the end of each Dry season. The *aquifer* is then *recharged* during the subsequent Wet season. Most of the time, bore performance will return to normal.

## 6.0 ABORIGINAL KNOWLEDGE

The aims of the East Arnhem Land Water Study was not only to provide a scientific assessment of groundwater and surface water in the region but also to explore the social and cultural significance of water to the Aboriginal people. In doing so cultural issues may be included in water resource management.



During the course of the study many Aboriginal people provided extensive help with locating water sites and explaining their historical behaviour. This information has been invaluable, particularly when such a vast area is covered and some regions have access difficulties.

Plate 13 David describing water level changes

In order to make the maps as pertinent and user friendly to the local people as well as other land managers, many Aboriginal place names were documented. Whilst recording place names it was realised that there exists an incredible wealth of knowledge.

In undertaking a cross-cultural study, it is hoped that common understandings will develop between Aboriginal people and land managers about water in East Arnhem Land. This seeks to provide a balanced and comprehensive approach to the study.

## 6.1 How information was gathered

On most field trips NRD officers were accompanied by Traditional Owners who imparted their knowledge on water resources and place names as sites were visited, or by group discussions referencing topographic maps, aerial photography, satellite imagery and the



Water Resource Maps. Information was recorded through written notes, tape recordings and video. Place name locations were recorded directly onto maps or with use of a GPS - (Global positioning system).

Plate 14 Waturr using the GPS at Gangan

Tape and video recordings were undertaken in various Aboriginal languages as well as English. Translations were done at the time of the recording. When the translations were brief a more detailed translation was undertaken in Darwin. Staff and students at FATSIS NTU helped tremendously with this task. Transcriptions in various Aboriginal languages were also undertaken and recorded in Aboriginal (Yolngu) orthography (way of spelling).

## 6.2 Where the information is recorded

A separate report has been written titled 'Water Resources of East Arnhem Land - Aboriginal Knowledge'. This contains translated and transcribed responses from Traditional Owners. The report also contains lists of place names and their location.

Some place names are recorded on the Water Resource Maps which accompany this report.

Cultural and historical knowledge recorded on video tape has been transformed into digital format and is included in the photograph collection available on CD.

Three posters have been printed which explore Aboriginal cultural, historical and water use aspects. They are titled 'Learning about water - Aboriginal/Yolngu knowledge' and each poster relates to one of the three sectors.







**Plate 15 a,b,c** Dhalnganda and David at Belmi (Raragala Island), Larrtjannga at Yangunbi, Jimmy and Ursula at Elkayamanja (Groote Eylandt).

## 7.0 WATER RESOURCE DATA, LOCATION AND AVAILABILITY

The three Water Resource Maps which accompany this report are stored by the NRD in digital form as MicroStation "Design Files". This data is available to interested parties. The data is also available on a CD-ROM as ESRI shape files and can be viewed using the program ArcExplorer which is also included on the CD. This effectively forms a GIS in which individual components of the map can be viewed and manipulated.

An extensive photograph collection and some video footage was built up during this project. These have been digitised and are available on CD.

A report has been written titled 'Water Resources of East Arnhem Land - Technical Data'. This report provides information on NRD reports written on East Arnhem Land, a summary of all bores and their major ion chemistry for the region, and information on surface water gauging stations including water quality and minimum flows. The report is also available on CD.

As mentioned earlier, a report titled 'Water Resources of East Arnhem Land - Aboriginal Knowledge' has been written. It includes translated and transcribed responses from Traditional Owners and lists of place names recorded. It is also available on CD.

Copies of the bore completion reports submitted by drillers are held in Darwin in both digital and paper form and are available on request.

Detailed information on NRD *gauging stations* is kept on the NRD 'HYDSYS' database. All river height, flow data and water quality is available upon request.

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## 9.0 FURTHER WORK

Due to time and access difficulties no on ground reconnaissance was able to be done for some rivers. Further work in this regard is necessary to validate estimated data. These areas include: parts of the Goyder, Koolatong, Rose, Baiguridji, Walker, Buckingham, and Woolen rivers.

Due to early onset of the wet season the drilling program for the South Eastern Sector was cut short in the final year. This requires completion for validation of groundwater systems for this sector.

In the course of gathering data for this project a determined effort was made to use the wealth of local knowledge from the traditional owners. However there is still more work to be done in this area, especially in documenting place names correctly and describing water resources in terms of Aboriginal culture and their links to the land.

This project has managed to give an overview of the water resources in East Arnhem Land and their general behaviour. With the growing demand for knowledge about water resources in the area, for varying feasibility studies and catchment management, further work is recommended to more comprehensively understand the resource and its dynamics:

- rating tables were done for low flow analysis but need to be completed to the maximum recorded stage
- rainfall records need to be fully processed and included in the data base
- total water balances for aquifer systems and river flows (environmental flows) need to be established
- flooding characteristics assessed for floodplain management

With moves being taken toward better self determination and as ranger programs across Arnhem land gain impetus, it would be pertinent to train Aboriginal people so they can participate in this work. In doing so, water resource issues would be better communicated to the Aboriginal community who would then be able to make more informed decisions.

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## 11.0 GLOSSARY OF TERMS

**Airlift Yield:** The rate at which water is extracted from a bore with compressed air as drilling takes place.

**Aquifer:** A body of rock which is sufficiently permeable to conduct groundwater and to yield useable quantities of groundwater to bores and springs

**Baseflow:** The groundwater contribution to a stream. Baseflow often maintains the flow in a stream over the Dry season.

Catchment: Area in which rainfall collects to form the supply of a river

**Consolidated:** Any process whereby soft or loose earth materials become firm, for example the cementation of sand or the compaction of mud.

**Current meter:** A device for measuring water velocity, consisting of a propeller that turns at a rate dependent on the water's velocity.

Drawdown: The lowering of the water level of a well as a result of the withdrawal of water.

**EC:** Electrical conductivity, the ability of water to conduct electricity. It is directly related to the salt content of the water.

**Gauging station:** Site on a stream where direct observation of water velocities, heights and volumes are made and recorded. *Pictured – gauging station recording river height*.

Geology: science of earth's crust, rocks, strata etc



**Groundwater Discharge:** The release of groundwater to the surface by seepage, evaporation or transpiration (from plants).



**Hardness:** A measurement of the level of calcium carbonate in water. Results in increased quantities of soaps necessary to lather.

**Impermeable:** An impermeable soil, rock or sediment is that in which fluid (water) is unable to pass through.

**Laterite:** A residual rocky material formed through prolonged weathering, probably under warm, wet conditions.

Monitoring/Observation bore: A bore used for measuring groundwater levels.

**Moving average** of rainfall: Average of number of previous years rainfall. Explanation by example: To calculate the 6 year moving average - for the 1993/94 water year Add rainfall from previous 6 water years:

1993/94 + 1992/93 + 1991/92 + 1990/91 + 1989/90 + 1988/89 = TotalDivide Total by 6: Total/6 = 6 year moving average for 199/94

Perennial: A stream, lake or waterhole which retains water throughout the year.

Permeability/Permeable: The ability of water to move through soil or rock.

**pH:** A measure of acidity or alkalinity. A pH of 7 indicates neutrality - non corrosive to metal.

**Porosity:** The total amount of pore space in a soil or rock.

Porous: Containing pores and able to absorb water, air or other fluids.

Recharge: Addition of surface water to an aquifer to become groundwater.

Runoff: Rainwater that leaves an area as surface flow.

Salinity: The degree to which water contains dissolved salts.



Saltwater intrusion: movement of salt water into fresh water aquifers.

**Spring:** Outflow points for groundwater where the watertable is near or above the ground surface.

**Standing Water Level:** The level below ground surface, to which groundwater rises in a bore.

Sustainable: maintain (without adverse effect)

**Topography:** The shape and height of the land surface.

**Turbidity:** Relative measure of the clarity of the water. The greater the turbidity, the murkier (muddier) the water.

**Total Dissolved Solids:** A measure of the salinity of water, the amount of salt dissolved in the water, usually expressed as milligrams per litre.

Satellite Imagery: Digital 'photographs' taken from satellites orbiting the Earth in space.

**Water table:** Level of the surface of the groundwater. It is often measured in observation bores.

**Water quality:** Physical, chemical biological characteristics of water and how they relate to it for a particular use.

**Water Year**: In the NT water year splits the year from September of one year to August of the next year. This is so that the total Wet season rainfall is accounted for.

**Wetland:** Land with a wet spongy soil where the water table is at or above the ground level for at least part of the year.

**Yield:** Amount of water which can be supplied by an aquifer or pumped from a bore over a certain time period.