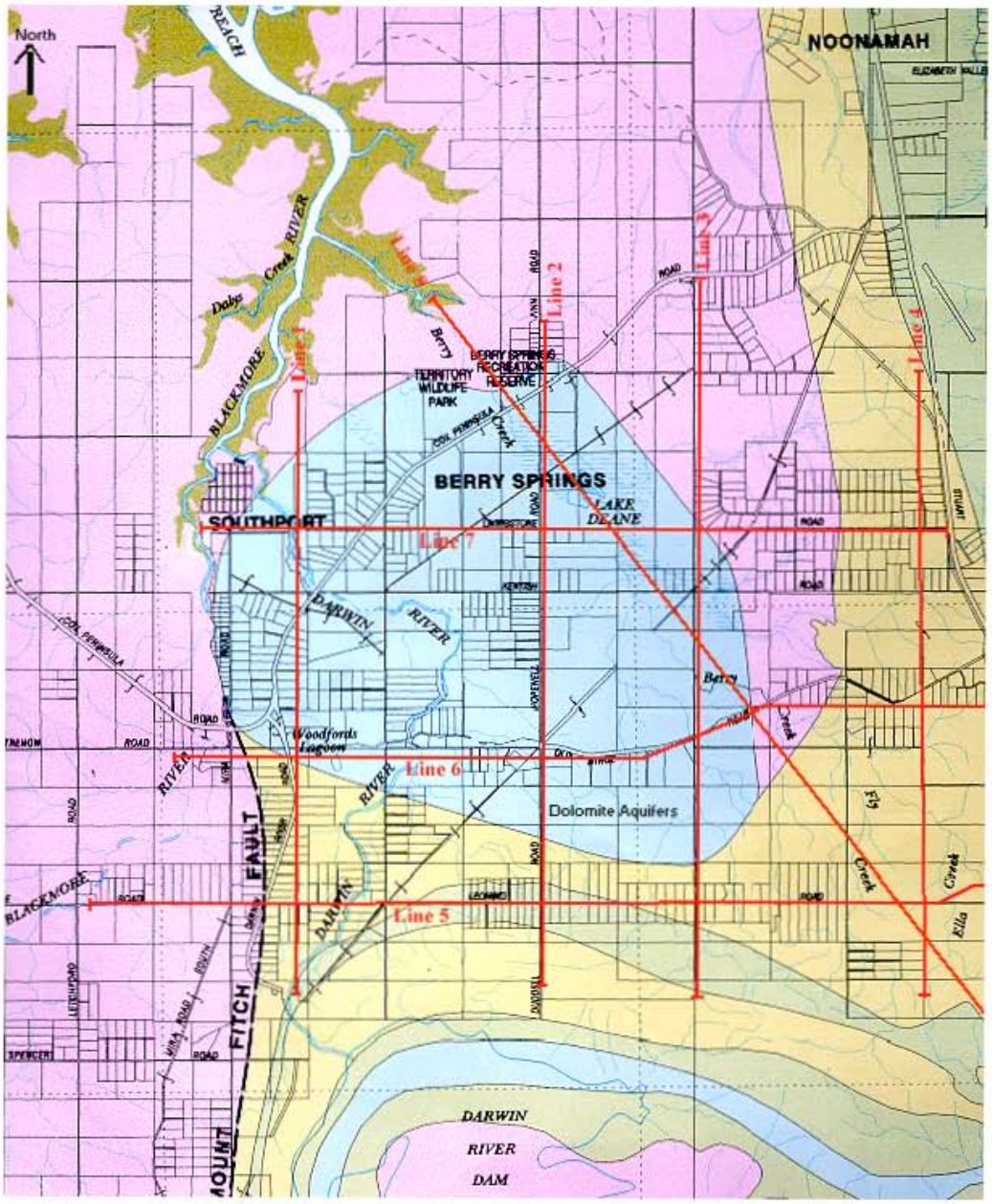
HYDROGEOLOGY OF DARWIN
Explanatory Notes
1:250 000 Scale Map



Northern Territory Government
Department of Infrastructure, Planning and Environment

Front Cover:
Part of Hydrogeological Map of the Darwin sheet in1:250 000 scale

Back Cover:
Marrakai (Corraborree Park– Leening Tree Lagoon) Area

Northern Territory of Australia
Dept of Infrastructure, Planning and Environment

HYDROGEOLOGICAL MAP OF DARWIN

Explanatory Notes 1:250 000 Scale Map

M. N. Verma

BATHURST ISLAND SC 52-15	**MELVILLE ISLAND SC 52-16**	**COBOURG PENINSULA SC 53-13**
FOG BAY SD 52-3	**DARWIN SD 52-4**	**ALLIGATOR RIVER SD 53-1**
CAPE SCOTT SD 52-7	**PINE CREEK SD 52-8**	**MOUNT EVELYN SD 53-5**

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SUMMARY:

The aim of this project was to investigate and establish the hydrogeology to produce a hydrogeology map as guidance to the groundwater supply potential for its use in different types of industry in this region. The area lies at the northern tip of the the Northern Territory.

The hydrogeology map of the Darwin sheet in 1:250 000 scale is the first hydrogeology map of the Darwin Sheet and one the numerous maps produced by the Natural Resources (then the Water Resources) of the Northern Territory Government.

This map has the special purpose of locating the groundwater supplies in the Darwin region, where rapid developments are taking place. Demand for groundwater is regularly increasing as development is expanding to new areas.

Geologically, the area lies in *the Pine Creek Geosyncline* in which the geology is very complex due to its nature of origin. Often geology changes within metres so does the groundwater prospect. Rocks were intensely folded, faulted, uplifted and subsided during 1,800 Ma orogeny.

Use of groundwater in this region varies from area to area. However, one of the major users is domestic in three major populated areas namely Darwin, Palmerston and rural areas.

However, 20% of piped water supply for Darwin, Palmerston and individual bores in rural area.

The horticultural industry is another major user which produces mango, banana, market vegetables, nurseries (flowers, orchid, etc). Other minor users include pastoral industry, aquaculture, reacreational parks, tourist places, small mines, schools, remote commercial users, defence forces, etc.

Major aquifers in this area are within carbonate (mostly dolomite), fractured and weathered rocks. This aquifer type covers about 40% of the map sheet area.

Medium aquifers are in the fractured and weathered non-carbonate rocks with an average sustainable yield ranging from 0.5 to 5.0 L/s. This aquifer type covers about 20% of the map sheet area.

Minor aquifers occur in non-carbonate stratified rocks and intrusive and it covers about 40% of the map sheet area.

Groundwater quality is generally potable except areas close to the sea and flood plains where saline water intrusion is common. Saline water is commonly used in the aquaculture industries for breeding fish, prawn, etc.

INTRODUCTION:

The Australian Map Grid (AMG) co-ordinates for the area is – 663306 to 825459 Easting and 8560946 to 8673001 Northing or, (12^0 00' to 13^0 00' Latitude and 130^0 30' to 132^0 00' Longitude). See Location Map (Figure 1).

The Darwin (1:250 000 scale sheet) area is the most populous (87,636) area in the Northern Territory. The total population of the Northern Territory was 197,600 as at June 2001.

Most the area is accessible by bitumen or gravel road. A major international airport is at Darwin, the capital of the Northern Territory. There is a newly built sea port facility at the East Arm, which will be connected to railway when railway line is built to connect to Alice Springs within two to three years.

In the absence of an established detailed hydrogeology map, the area was sub-divided into (13) major regions where most developments were planned. This provided a convenient way to carry out detailed hydrogeological investigation in each region over number of years as the development demanded. They are in alphabetical order as follow:

Acacia Gap
Berry Springs - Noonamah
Cox Peninsula
Darwin Urban
Darwin Rural (Howard Springs-Humpty Doo)
Finniss River
Knuckey Lagoons-Holmes Jungle Nature Park
Lambells Lagoon & Lambells Lagoon South
Marrakai - Leaning Tree Lagoon - Woolner
Middle Point
Palmerston
Rum Jungle
Sunday Creek Area in Humty Doo Region

Finniss River and south of the Darwin River Dam areas are not investigated in detail, yet. However, Groundwater potential is very low and so is population in this region.

Data were gathered from - a) various hydrogeological investigations over last 30 years or so, b) day to day hydrogeological advices to public and different government organisations, c) from the private drillings and NTGS maps, to produce this map.

The map has been compiled in house with the Microstation CAD software on Geocentric Dataum of Australia (GDA94), conforms to the colour scheme and principles of the UNESCO International Legend for hydrogeological maps. The project included the compilation and production of both the map and a data base (*Hydsys*) containing information on 7,155 bores up to 15 March 2002.

Previous groundwater investigations carried out in this area by the Natural Resources (then the Water Resources) Division are listed below:
Darwin Rural Area (1969 & 1979*); Cox Peninsula* (1980); *Lambells Lagoon* (1981); *Palmerston* (1981); *Lambells Lagoon South* (1994); *Middle Point* (1995); *Berry Springs-Noonamah* (1997); *Darwin Urban Hydrogeology* (1998); *Leaning Tree Lagoon* (1998); *Acacia Gap* (1999) & Marrakai - Woolner (2000).

Since last twenty years demand for groundwater has increased nearly four fold. Because many regions have been developing rapidly - viz. 17 Mile (Virginia Road), Palmerston, Berry Springs - Noonamah, Lambells Lagoon and Darwin Rural area. Therefore, need for a hydrogeology map of the Darwin region became necessary to provide hydrogeological advice. The map preparation commenced in 1997. Though, it may be said that map preparation started back in early 70s when McMinns borefield was established. A groundwater Investigation was carried out by Consultant Coffee & Partners to assess groundwater availability in the McMinns – Benham area and a report (1980) was produced. While in-house a major investigation had commenced in 1979, which resulted in a detail hydrogeological map of the Darwin Rural area (Verma, 1979).

Most of data came from individual private drillers as well as the government investigations. To prepare this map, it was essential to divide the whole area into small horticultural regions based on anticipated groundwater potentials combined with the water demand for a particular region. Each individual area had its own groundwater characteristic due to complexity of geology. Therefore, individual areas were mapped separately. Finally, all the information were gathered and put together to produce this map in a scale of 1:250 000.

2. GEOGRAPHIC SETTINGS

2.1 Climate

The climate is monsoonal with a hot and humid wet season from October to April and a pleasant dry season from May to September. A humid atmosphere carried in by northwesterly to westerly winds characterizes the hot wet season while a southerly wind brings cooler atmosphere and characterizes the dry season.

The mean annual rainfall ranges from about 1691 mm. Most of the rain falls between November and April. See Table 1.

Temperature ranges from 20 to 34° C during the wet season and from 14 to 32° C during the dry season.

Average evapotranspiration averages about 2000 mm per year.

Table 1 Monthly Mean Rainfall at the Darwin Airport since 1946

Month	Rainfall (mm)	Wet days
January	431.0	25.6
February	343.0	24.0
March	314.0	18.6
April	95.4	10.8
May	20.9	2.7
June	1.3	0.2
July	0.9	0.5
August	6.1	1.0
September	16.4	3.0
October	73.9	10.2
November	143.0	16.7
December	249.0	21.4
Total	1412.4	134.8

Source: *Hydsys* Data Base, DIPE, NT Gov.

However, the annual mean rainfall in the most northern part (viz. at the Darwin Airport) is 1691 mm since 1946. Discrepancy between the total mean monthly (1412.434 mm) and mean annual (1691 mm) is due to factors controlling the statistic calculation. The highest rainfall ever recorded was 2,759 mm in 1998 at the Darwin Airport.

In the most southerly part (at the East Finniss River at White's Overburden, Rum Jungle, Batchelor), the mean annual rainfall since 1984 is 1450 mm.

Hence, there is an average drop of 241 mm in the mean annual rainfall from north to south.

2.2 Physiography

Physiographically the Darwin sheet may be divided broadly into five (5) geomorphic units as follows:

1 *Coastal and Estuarine Plains* – They are foreshores, low lying coastal floodplains. Contains estuarine sediments, saline and calcic mud, clay and silt up to 7 m above sea level. Creeks and rivers are tidal up to 60 km inland. Vegetation is mainly *melaleuca leucodendron*.

2 *Alluvial Plains* – They occur inland and are flat with gentle gradient and gradational from coastal plains. Flood plains, incised channels and levee banks adjacent to rivers and major creeks. Deep sandy or silty soil. Open grasslands and scattered trees.

3 *Northern Plains* – It is in northern half of the Darwin with moderate to low relief; flat to undulating loamy, sandy or gravelly, sandy and lateritic soils underlain by Tertiary, Cretaceous and Proterozoic sediments. Open forests with *pandanus, melaluca, grevillea, acacia, eucalypts, calytrix* and clumps of rainforests. A remnant of Koolpinyah surface.

4 *Dissected Foothills* - Southern part of Darwin; up to 50 m above sea level with skeleton, gravelly, dissected detrital lateritic soils and Lower Proterozoic rocks. Lateritised benches of Cretaceous rocks. Stunted woodland, mixed scrub, palm forests and low hills.

5 *Dissected Uplands* - Southern part of Darwin, up to 200 m above sea level with shallow, gravelly, rocky skeleton soils and Lower Proterozoic rocks. *Eucalyptus* and mixed woodlands. Form prominent strike ridges and boulder-strewn hills.

Physiographic map shown in Figure 2. Refer Pietsch, et al, 1988) for details.

There are 11 major Catchment within this sheet and are shown in green on the Hydrogeological Map of Darwin 1:250 000 scale.

Land Use

Major land users in this area are shown below in order of its use and commercial importance:

1. *Horticulture* – (numerous small vegetable and fruit growing areas, and nurseries). Agriculture and horticulture industries have surpassed mining and other industries in this region. Most of the crops grown are tropical fruits like mango, banana, water melons, rock melons, jack fruit, paw paw (popo), four corners, etc. and many tropical vegetables like pumpkin, egg plants, ochra and many more. Successful developments have been increasing the water demand since last 20 years.

2. *Tourism* – (Places and Parks)
Unique tropical picturesque floodplains and wetlands combined with crocodile infested rivers have created a large tourist market in this region. It has grown up many folds, particularly due to wildlife like crocodile and buffalo, which can be viewed from the comfort of a boat. A small part of the *Kakadu National Park* lies on the eastern boundary within the Darwin sheet. Few other small nature parks in this area are also very popular as tourist destinations. Vast wetland can be viewed from top of a tower building known as "*window on the wetland*". Most of the coastlines are usually not available to the general public because they are either part of the Aboriginal Reserve cattle station or restricted government land.

3. *Mining* – (Numerous small leases)
There are numerous small abandoned mines of tin, gold, copper, uranium, iron, etc. and road materials like granite and gravel all over the area. Uranium and copper used to be mined at Rum Jungle till 1969. Road materials are still being mined. An explanatory note –(Ahmad, 1993) provides a detail of mines and deposits in the Darwin 1:250 000 scale map sheet.

4. *Aquaculture* – (Barramundi & Prawn breeding farms).
Aquaculture industry is also growing slowly but steadily. Breeding farms for barramundi fish and prawn are setup when groundwater with required salinity is available viz. Middle Point Barramundi Farm. At present there are only two or three farms.

5. *Pastoral* leases – (mainly cattle)
There are only four moderate cattle stations in this area, because dry, flat and grassland areas are limited, which are suitable for cattle. These cattle stations are *Koolpinyah*, *Marrakai*, *Mount Bundey* and *Woolner*. Pastoral industry

in Marrakai area is declining due to its sub-division (*Leaning Tree Lagoon*) for the market garden.

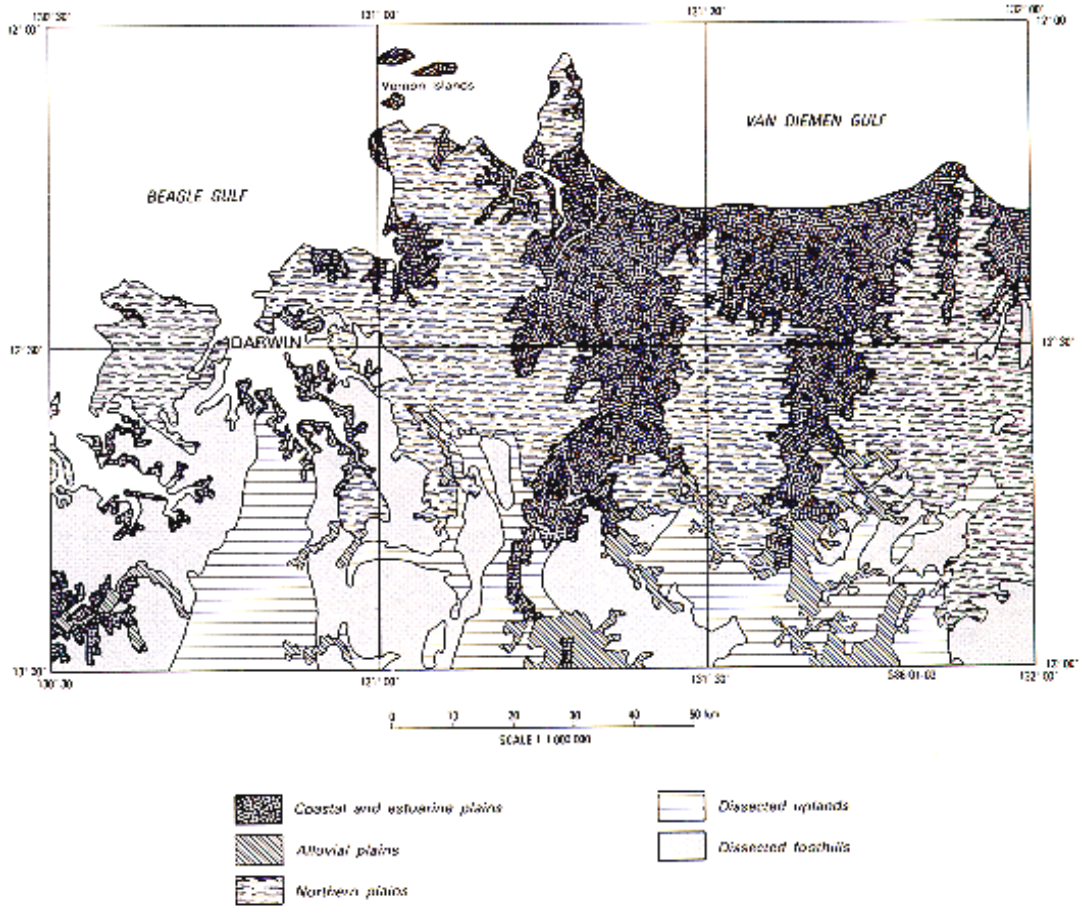
6. Aboriginal lands – (native land reserves)
There are numerous reserves for aboriginal people in which access is by permit only.

7. Australian Defence Force- (facilities).
There are many Defence Forces establishments within Darwin sheet. Origin of Darwin city goes back to the Defence Forces. To facilitate defence personals this place was established, which grew to a city.

2.3 Surface Water
There are ten major Catchment areas in this region, see the Hydrogeological Map.

There are four major rivers in this area - *Adelaide River*, *Mary River*, *Wildman River* and part of *Finniss River*. Both the Adelaide and Mary Rivers form two separate large floodplains on the flat area close to the coast. These floodplains have become popular tourist attractions.

There are numerous stream-gauging stations,



Geomorphic Units of Darwin Figure 2

Source: NTGS, Geology Map of Darwin, 1:250 000, 1988

which are maintained by the Department of Infrastructure, Planning and Environment (DIPE). The Bureau of Meteorology maintains rainfall-gauging stations and few pluviometers being maintained by the DIPE. Details can be obtained from the NT Streamflow Catalogue, 1980-1983, PAWA, 1983.

3. GEOLOGY
The geology Map of Darwin, sheet SD 52-4 in 1:250 000 scale was produced by Bureau of Mineral Resources (BMR) and the NTGS (Northern Territory Geological Survey) in 1988. The Pine Creek Geosyncline dominates the area in which rocks are uplifted, subsided, folded, faulted and eroded. Geologically, it is a

very complex area. A minor basin was found in this area named as "Berry Springs Basin" (Verma, 1994).

Rocks in this area belong to Archaean, Proterozoic and Cretaceous age. Cainozoic sediments cover most of the surface area except hills.

Archaean rocks are the oldest and are limited to small areas and occur mostly as dome. They are the *Woolner Granite* (*Awg*), *Dirty Water Metamorphics* (*APd)* and the *Rum Jungle Complex* (*Ar*). Uranium and copper were found on the periphery of the Rum Jungle Complex granite.

The *Lower Proterozoic* rocks cover most of the area. They are described in the stratigraphy section. Numerous pegmatite and dolerite dykes and sills have been intersected in bores. Few metals like tin, bismuth, gold, antimony, etc. have been mined in pegmatite. Outcrops of the Lower Proterozoic rocks are not many as the Lower Cretaceous sediments cover most of it.

The *Middle Proterozoic* rocks occur in very small areas with very limited outcrop.

There are Jurassic rocks (*Petrel Formation*, *JKp*) but they occur in a very small region.

The *Lower Cretaceous* (*K*) rocks are flat lying and not affected by any orogeny. They are light coloured stratified rocks and occur in most of the area except hills. Its thickness has been found up to 60 m, but it could be higher. Details of Cretaceous rocks can be seen in the BMR Bulletin 73 (Ref. Skwarko, 1966). Top layer of Cretaceous is generally laterite with thickness around 5 m.

Cainozoic sediments cover most of the surface area particularly the lower elevation. Average thickness of these sediments is about 3 m.

3.1 Stratigraphy and Structure

Stratigraphy of the area is shown in Table 2.

Archaean (*Ar*) rocks are the oldest rocks and they are granite, biotite schist, amphibolite, gneiss, migmatite and other intrusive igneous rocks.

Archaean and other granite intrusive have formed domes at places and have influenced the geologic structures through out the area including the Berry Springs Basin.

Proterozoic age (*P*) rocks occur widely, which are parts of the *Pine Creek Geosyncline*. These rocks were repeatedly subsided and uplifted within the geosyncline, which resulted in tight folding and faulting. However, only one small basin has been found on this map sheet which is named as the *Berry Springs Basin* resulting from both the geological structural effect and the deposition on the northern slope of the Archaean granite dome. Due to a long non-deposition period from 1800 to 225 Ma, surface weathering produced karst topography on carbonate surfaces. This process produced new layers from eroded carbonate rocks, which were later covered by the Cretaceous sediments producing right environment for the aquifers.

There are numerous major geologic structures, which are clearly visible on air photos and satellite images. *Giant Reef Fault* and *Tom Turner's Fault* are the longest ones in the area and are clearly visible. These faults are believed to be good conduit for movement of minerals and metals dissolved from granite and deposits. For example the Tom Turner's Fault runs through Litchfield Complex where groundwater could dissolve and pick up elements like radium^{226} from granite. radium^{226} has been intersected in a bore (RN 21572) in Cox Peninsula with a value ten times the limit.

As the area lies in the Pine Creek Geosyncline region, most of the rocks are folded and faulted. Therefore, fractures are abundant everywhere. These geologic structures have been extensively exploited reliably for the groundwater, which are discussed in the hydrogeology section.

Table 2 Stratigraphy of the Darwin 1:250 000 Hydrogeology Map Sheet

Era/Age	Group Name	Formation & Lithology
Cainozoic (*C*)		
	Quaternary (Q)	*Qca* - Mud; silt, clay; *Qaf* - Clay; mud; silt; *Qcr* -Sand; shelly sand; coralline sand; Q*a* - Gravel; sand; silt; Qcl- Sand; silt; clay
	Tertiary (Cz)	*Czs* - Unconsolidated sand, ferruginous and clayey, sandy and gravelly soils: commonly containing limonite pisolites
		Cz - Sandy and gravelly soils
		Czl - Pisolitic and mottled laterite: in situ and reworked remnants of standard laterite profile
Cretaceous (*K*)		
Lower		*Bathusrt Island Formation* (*Klm*) - Kaolinitic silicified claystone, siltstone & sandstone; basal conglomerate: radiolaria rich claystone
Jurassic (*J*)		
		Petrel Formation (*JKp*) Conglomerate, conglomeratic sandstone, unconsolidated quartzose sandstone, breccia
Proterozoic (*P*)		
		Carbonate Layer (*Psd*) This may be equated to the Hinde Dolomite of the Tolmer Group
Middle	Tolmer (*Pt*)	*Hinde Dolomite (Pth)* – Dolomite, dolomitic arenite, calcareous siltstone, chertified ooid
		Depot Creek Formation (*Ptd*) Pink quartzite and quartz sandstone, commonly ripple marked
		Buckshee Breccias (*Pyb*) Ferruginous quartzite breccia occurs in a very small area in the berry Springs region
Middle	Granites (*Pg*)	
	Mount Bundey Granite	(*Pgu*) Biotite granite; minor adamellite
	Goyder Syenite	(*Pgd*) Syenite
	Two Sisters Granite	(*Pgts*)Granite; adamellite; granodiorite
	Zamu Dolerite	(*Pdz*) Altered quartz dolerite; gabbro and amphibolite
Lower	*Well Tree Metamorphics*	(*Pwt*) Quartz-felspar-biotite gneiss, commonly containing garnet and sillimanite; quarzitic gneiss; quartzite, minor quartz-felspar-muscovite gneiss
		Sweets Member (*Pws*) Marble, in places graphitic; para-amphibolite; cal-silicate gneiss; quartz-felspar-biotite gneiss
	Fog Bay Metamorphics (*Pc*)	Biotite gneiss; amphibolite; minor quartzite
	Finniss River (*Pf*)	
		Burrell Creek Formation (*Pfb*) Shale, siltstone, phyllite, in places colour banded; fine to very coarse sandstone, Conglomerate, quartz-mica-schist and gneiss
	South Alligator (*Ps*)	
		Mount Bonnie Formation (*Pso*) Laminated reddish brown shale and siltstone with minor laminated black chert bands, minor pyritic banded iron formation; argillite
		Gerrowie Tuff (*Psg*) Laminated grey, brown and red silicified siltstone; argillite; tuffaceous chert
		Koolpin Formation (*Psk*) Ferruginous and graphitic siltstone and shale with chert bands; silicified dolomitic lenses
		Ella Creek Volcanics (*Pse*) Massive goethitic ironstone; quartzite, black shale; chert breccia with oolites; ferruginous siltstone
	Mount Partridge (Pp)	
		Wildman Siltstone (*Ppw*)- Laminated colour-banded shale (pyritic & carbonaceous at depth); silty shale; siltstone; minor silicified dolomite; quartz sandstone; fine quartzite
		Acacia Gap Quartzite Member (*Ppa*)- Quartzite, pyritic; sandstone; interbedded shale & phyllite
		Whites Formation (Ppi)- Calcareous & carbonaceous pyritic argillite; dololutite; dolarenite; quartzite; calcareous para-amphibolite
		Coomalie Dolomite (*Ppc*) & *Koolpinyah Dolomite* (*Ppk*) – Silicified dolomite; magnesite, marble;
		Crater Formation (*Ppr*) – Haematite boulder conglomerate; cross-bedded pebbly arkose; quartzite; sandstone and shale
		Mundogie Sandstone (*Ppm*) – Sandstone; quartzite; arkose; graded bedding; cross bedding
	Namoona (Pn)	
		Celia Dolomite (*Pnl*) Stromatolitic magnesite and dolomitic marble; commonly silicified at surface
		Beestons Formation (*Pnb*) Quartz conglomerate and grit; arkose; quartz sandstone
Archaean (*A*)		
	Rum Jungle Complex (*Ar*)	Leucocratic granite; granite gneiss; schist & gneiss; banded iron formation
	Woolner Granite (*Awg*)	Granite
	Dirty Water Metamorphics (*Apd)*	Chlorite-quartz-calcite schist; gneiss; meta-arkose and quartzite; amphibolite
	Waterhouse Complex (*Aw*)	Granite; gneiss; amphibolite; migmatite

Source: Geology Map of Darwin, 1:250 000 Scale, Sheet SD 52-4, BMR & NTGS, 1988 & Discussions with NTGS, 2000 and various regional hydrogeology maps produced by M. N. Verma since 1979.

4. HYDROGEOLOGY

The complex geology and structure of the Pine Creek Geosyncline has created a similarly complex hydrogeologic environment in which aquifer characteristics show extreme variation according to lithology, tectonic history, weathering and a lesser degree to the recharge conditions. The hydrogeological environment of aquifers may be divided into two broad sections: a) *calcareous fractured and weathered rocks* and b) *non-calcareous fractured and weathered* and *intrusive rocks*.

4.1 Carbonate Fractured and Weathered Rock

Major Aquifers

Carbonate rocks are calcareous siltstone, dolomite, silicified dolomite, dololutite, dolarenite, magnesite and marble. Carbonate aquifer covers about 40% of the map sheet area. The most productive carbonate aquifers are in *Koolpinyah Dolomite Formation* (*Ppk*), *Coomalie Dolomite Formation* (*Ppc*) and *Dolomite* Layer (*Psd*).

Sustainable yield in these aquifers are > 5.0 L/s but yield up to 40.0 L/s has been found. However, high contents of fine sand and/or clay, which are found quite often may reduce the yield to nil.

These aquifers are found promising only if they are overlain by a reasonably thick layer of the *Bathurst Island Formation* (*Klm*) of the Lower Cretaceous age. Aquifers are usually found at the unconformity with overlying *Lower Cretaceous* sediments (1 to 20 m thick). Higher the thickness of the Lower Cretaceous sediment, higher the yield (Verma, 1979). The aquifer at the unconformity contains un-assorted boulder, conglomerate and pebble of the Lower Proterozoic carbonates; and also sandstone boulder and basal conglomerate, clay, silt and sand of the Lower Cretaceous age. This zone was named "*McMinns Hydrostratigraphic Unit*" by Verma (1979) due to its lithological characteristic, the layer contains rocks from two different ages.

Origin of this aquifer is attributed to a long non-deposition period from 1800 to 225 Ma. During this period the erosion of carbonate surface created *karstic* topography in which dolomite boulders, conglomerates and pebbles were filled in the lower parts of karsts and in weathered surfaces. Then on the top of this surface the Lower Cretaceous sediments were deposited during 225 to 65 Ma period. It created a permeable layer containing both the Lower Proterozoic and Lower Cretaceous sediments. However, fine sand and/or clay in this zone also occur, which might be impermeable. See details in the report 8/1980, "*hydrogeology of the Darwin Rural Area*".

Major aquifers in the Berry Springs-Noonamah, Palmerston and Holmes Jungle areas are in the *Dolomite Layer* (*Psd*) of the Middle Proterozoic age. This dolomite was previously referred as *Middle Protozoic Dolomite* (*Psd*) and younger than the Burrell Creek Formation (Pfb) in the *Interim Report* (Verma, 1994). Later it was placed as a top layer (*Psd*) of the Koolpin Formation (Psk) of the South Alligator Group (Ps) as *Unclassified Dolomite* (1996) in the *Berry Springs Hydrogeology Map* (Verma, 1998) due to lack of data to support it as Middle Proterozoic. Later after a discussion with the Northern Territory Geological Survey (NTGS) geologist (Ahamd, pers. Com.), it is now named as the Dolomite Layer (*Psd*) which equates to the *Hinde Dolomite Formation (Pth)*. This is refereed as Dolomite (dlm) in recently published map "Rum Jungle Mineral Field" by Lally, NTGS, 2002. There is a proposal by the NTGS to investigate this dolomite in near future. This dolomite may equate to the *Hinde Dolomite Formation* (*Pth*) of the *Tolmer Group* (Pt) also. Although it should be noted that the Tolmer Group is gently dipping while this dolomite has steep dip (bore 33031). The same dolomite also occurs in a very small basin like patch in the *Sunday Creek region*. This dolomite still has to be proved by drilling.

It was observed in bore RN28856 that the Dolomite Layer (*Psd*) aquifer has fewer amounts of conglomerates and boulders and it does not appear to be undergone through extensive geosynclinal tectonic orogeny process as in case of the Koolpinyah and Coomalie Dolomite Formations. This suggests that this Dolomite Layer may belong to younger age than the Lower Proterozoic. The Lower Cretaceous sediments of the Bathusrt Island Formation (klm) overlie all the carbonate aquifers but the lithology at the unconformity is slightly different from the Koolpinyah or Coomalie Dolomite aquifers to the Dolomite Layer (Psd) aquifers due to reasons mentioned above.

In Berry Springs, sustainable yield up to 40.0 L/s has been obtained at an average depth of about 40.0 m below the ground level. However, aquifer depth has been struck up to 199.0 m below ground level in bore (RN33031) due to secondary structures like solution cavities. Aquifers were found in the

joints, fractures and interconnected solution cavities of dolomite containing quartz and magnesite crystals, which signifies a typical solution cavity.

Transmmissivity ranges up to 1500 m^2/day. Average thickness of the Koolpinyah and Coomalie Dolomite aquifers ranges from 1 to 20 m depending on the thickness of the overlying layer (Cretaceous sediments) refer Verma, 1979. The average depth of the aquifer varies from 20 to 70 m below ground level.

These carbonate aquifers are highly exploited all over rural areas. During 1970s, about 50% of Darwin water supply was obtained from *McMinns Borefield* in Humpty Doo area. Then the standing water level (SWL) of the region was found declined to an alarming level. Therefore, it was reduced to about 10% of the Darwin water supply. Groundwater from McMinns bores is also used to raise pH of the water supplied from the Darwin River Dam. There is a proposal to have another borefield in the carbonates around Berry Springs region to augment Darwin water supply.

Significant developments like tourism, parks and small market gardens are totally dependent on carbonate aquifers in all the rural area. Major plantations have also been developed in these aquifers, viz Cashew Farm in Wildman River Station (AGC Rep, 1987).

4.2 Fractured and Weathered (non-carbonate) Rock Aquifers

Medium Aquifers

This aquifer covers about 20% of the map sheet area and mostly in Proterozoic non-carbonate rocks.

Yields in well-developed fractures and faults could be considerably high. Therefore, it is always desirable to have a bore site in these aquifers selected by a hydrogeologist.

In few cases, in highly weathered rocks along major fractured environment, aquifers may become impermeable due to formation of clayey materials. Hence, in such cases bore should be sited a little away from the main fracture or fault to keep away from clay in the bore or drill deeper into fresh rock if aquifer extends deeper.

Details of yield range are shown in the Hydrogeology Map of Darwin (attachment). Average sustainable yield in *Medium aquifers* range from 0.5 to 5.0 L/s depending on extent of fractures and weathering. Yield up to 10.0 L/s has been obtained at places due to major geological structures. Transmmissivity varies widely and so it can't be generalised or averaged due to factor like fractures. However the transmmissivity could go as high as 800 m^2/day. It should be noted that the sustainable yield is usually 20 to 30% of the airlifted yield. Sustainable yield in the medium aquifers are in the formations shown below:

Yield L/s	**Formation**
Medium Aquifers	
0.5- 5.0	*Koolpin Formation* (*Psk*)
	Whites Formation (Ppi)
	Crater Formation (*Ppr*)
	Namoona Group (*Pn*)

4.3 Minor Aquifers

Minor aquifers occur in about 40% of the map sheet area Average yield in these aquifers is less than 0.5 L/s and occur in both the stratified formations and in igneous rocks as shown below:

Stratified rocks -
Burrell Creek Formation (*Pfb*)
Igneous rocks –
Mount Bundey Granite (*Pgu*),
Goyder Granite (*Pgts*),
Zamu Dolerite (*Pdz*),
Well Tree Metamorphics (Pwt),
Sweets Member (Pws),
Rum Jungle Complex (*Ar*),
Woolner Granite (*Awg*),
Dirty Water Metamorphics (*Apd*),

The *Bathurst Island Formation* (*Klm*) of the Cretaceous age is not classified as aquifer because it is a recharging layer and no production bore in this formation is provided anymore. Due to water level fluctuation, bore in this formation often becomes dry during the Dry season as most of the old bores drilled in this formation are shallow. Thickness of this formation varies from nil to 50m depending on the topography.

Usually aquifers are fully recharged annually by dependable tropical seasonal rainfall during Wet Season. Seasonal variation of the standing water level is about 10.0 m.

However, fractured and weathered rock aquifers are classified as local, because they are usually confined to small areal extent.

5. GROUNDWATER QUALITY

Groundwater quality varies throughout the area depending on geographical location, distance from recharge source and coastline, and the aquifer lithology. However, in general three types of groundwater exist –
a) *Fresh carbonate water*, b) *Fresh non-carbonate water*, mostly inland and c) *Saline* mostly along the coastline and within the floodplain.

Water quality is discussed below and major ions and cations are shown in Table 4.

5.1 Fresh Carbonate Water

Fresh carbonate water is alkaline and usually hard occurring in dolomite aquifers. Total Dissolved Solid (*TDS*) value is <1,000 mg/L. *pH* value ranges from 7.0 to 9.0. Bicarbonate (HCO_3) averages about 200 mg/L. Hardness ($CaCO_3$) value averages 150 mg/L. The water quality is shown in the Table 4.

There is a slight variation of water quality from Coomalie (Ppc) and Koolpinyah (Ppk) Dolomite to Dolomite Layer (Psd) aquifers.

TDS is lower in Psd than the Ppc & Ppk dolomite (see Table 5). Contents of calcium and magnesium are higher in Ppc & Ppk than that of Psd. Hardness ($CaCO_3$) averages about 150 mg/L in carbonate aquifers. Chloride, Sodium and sulphate are usually low in fresh water. Water quality variations in different carbonate waters are shown in Table 5.

Sunday Creek Dolomite is not drilled yet, however, the water quality is anticipated to be similar to *Psd* carbonate water. The water analyses of water from the Sunday Creek has been found to be carbonate (see Table 5). This creek water appeared to come from the sinkhole nearby. It should be noted that the chemical parameters shown here are averaged values only.

Table 4 A Typical Water Quality of Different Aquifers

Aquifer Name	pH	TDS	EC	Ca	Mg	Na	Cl	SO_4	SiO_2	F	HCO_3	Hardness ($CaCO_3$)
		<---------- mg/L ----------										---------->
Major	7.0–9.0	400	400	40	45	2	5	8	15	1	250	150
Medium	6.4- 7.0	120	260	5	4	5	8	10	15	1	30	70
Minor	5.4- 6.4	100	160	2	2	2	2	15	15	0.1	10	10

Table 5 Comparison of Groundwater from Different Carbonate Aquifers

Aquifer Name/Area	pH	TDS	EC	Ca	Mg	Na	Cl	SO_4	SiO_2	F	HCO_3	Hardness	Remarks
		<---------- mg/L ----------									($CaCO_3$)	---------->	
Ppk/Ppc	7.0–9.0	200-500	300-600	30-40	30-45	5	10	10	15	1	200-500	~ 150	
Psd	6.4–8.9	200-400	200-500	20-35	8-15	3	6	3	4	1	105-400	~ 150	
Sunday Creek	7.7	321	579	62	36	6	8	13	17	0.3	373	303	CreekWater

5.2 Fresh Non-Carbonate Water

Non-carbonate water is acidic close to rain water and occurs in all non-carbonate rocks. pH has a wider range from 6.4 to 7.0. TDS is usually lower (200 – 500 mg/L) than carbonate water. Contents of Ca & Mg are lower in this water than carbonate water.

Groundwater in the Bathurst Island Formation of the Cretaceous age is recent and acidic because it is directly recharged by the rainwater. Water in other minor aquifers (see chapter 4.3) viz. Burrell Creek Formation is less acidic than the Cretaceous water, because the water travels for considerable time to react and dissolve minerals from the host rocks.

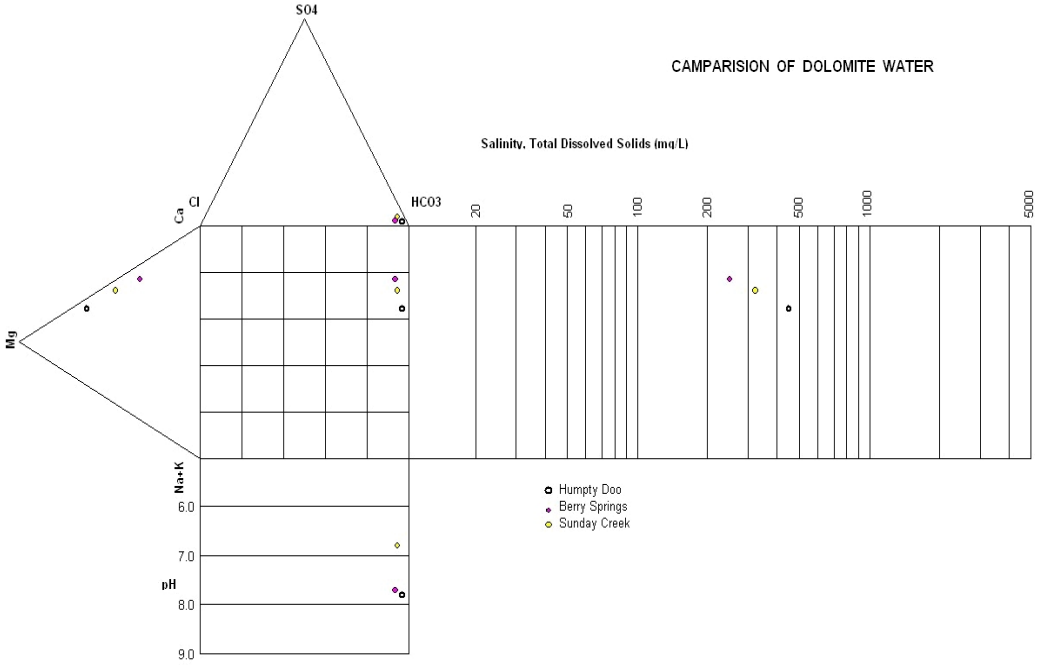
Water quality from granites and intrusive areas is generally acidic and may contain heavy metals or radioactive minerals like radium^{226} as in Cox Peninsula. See Reference (Ahmad, 1973). There are few reports of arsenic in groundwater from area west of the Darwin River Dam in bore (RN 2561), which is thought to come from pegmatite within Burrell Creek Formation. In Humpty Doo region *arsenic* (1.0 µg/L), *selenium* (<1.0 µg/L) and high content of *Iron* (73.0 mg/L) were found in a bore (RN 30059), which may be associated with the arsenopyrite found in siltstone with quartz-vein or pegmatite (?). A very small traces of *gold* (0.3 µg/L) and *bismuth* (3.0 µg/L) were found in bore RN27479.

5.3 Saline Water

TDS value of more than 1,000 mg/L is considered to be saline for human consumption. Salinity however sometime ranges up to 60,000 mg/L, which is more than sea water level. They occur normally along the coast and the intertidal drainage and Quaternary clay, and within the flood plains.

The salinity gradient has been observed in bores in the Middle Point region. Salinity increases towards the floodplain from higher inland ground. Salinity is confined to lower elevations obviously.

Saline groundwater is being used successfully in the aquaculture industry. Due to higher and continuous pumping of bores in the Middle Point region, saline water intrusion has been noticed during the Dry Season.



Durov Diagram showing the average Water Quality of different dolomite aquifers

6.0 PROSPECTIVE AREAS for Various Industries – Horticulture, Aquaculture, Tourism, etc.

In Darwin Rural area developments (mainly horticultural) had been going on for many years. Now, there are at least twelve (12) distinct regions where developments are taking place at a rapid pace. They are described briefly below:

Acacia

Situated about 50 km south south east from Darwin city around Acacia Creek. This area is developing as a horticultural region to grow tropical fruits like mango, banana, popo, etc. and recently vegetables are being tried. Water supply is totally from carbonate aquifers. This region was investigated in 1999 and a report NR2000/004 by Tickell, is available.

Transmmissivity value varies up to 700 m^2/day.

Berry Springs - Noonamah

It about 4 km north west from Acacia Gap area and about 50 km south from Darwin. It is now a major horticulture centre for growing mango, banana, jackfruit, rambutan, mangosteen, carambola (five star), and some tropical vegetables. No manufacturing industry is permitted in this region in order to protect the groundwater. Tourism is very popular in this area because of a *Wildlife Park*, a big *Orchid farm* and picnic spot at a *nature park.* There is an artificial lake (Barden's Lake) where skiing, boating and other water activities are available. Also, there is dam (Darwin River Dam), which is another popular picnic spot. All the water requirements for this region are provided from groundwater. Transmmissivity value varies from 500 to 1,500 m^2/day.

Investigation for another *borefield* is being planned in this area to augment the main water supply. Therefore a detail hydrology study of this region would be required. A major hydrogeological investigation was carried out during 1993/94, report 30/1994 by Verma is available.

Cox Peninsula

This area is to the west of Darwin across the sea. The quick access is by ferry from Darwin city and by road it is 100 km. Goundwater prospect is very low, so the population has not grown here since last 30 years or so. Domestic water is obtained by pumping from a small man-made pool into which water is collected from natural seepage from under the laterite. This seepage slows down during end of the Dry season causing water scarcity. There is only one motel at Mandorah to cater for tourists and this is the only industry here due to lack of water. There is an aborigine community settlement and few residential houses along the northern beach. There is a receiver station near Delisavale and a transmitter station at Charles Point for relaying and broadcasting news to overseas north in different Asian languages. A detailed hydrogeological investigation was carried out, a report 8/1982 by Verma is available.

Darwin Urban

This area includes mainly urban residents. Water supply is from the *Darwin River Dam* (south of Berry Springs). However, 10% of this supply is supplemented by groundwater from *McMinns Borefield* (Darwin Rural Area). Groundwater provides much needed calcium from carbonate aquifer as well as keeps .

Darwin Rural (Howard Springs-Humpty Doo)

It is about 20 km southeast of Darwin, where first time tropical vegetables and fruits were grown. Water supply comes mostly from bores though water-mains run through this region. It become the first popular rural residential and primary producing area. Howard Springs in this region is a very popular picnic spot where perennial Spring (*Howard Springs*) exists in carbonate rocks.

A borefield (*McMinns Borefield*) was established in this region which supplied groundwater for the Darwin City's nearly 50% water supply. However, it caused lowering of the regional standing water level during 1970s. Therefore, the supply was reduced from 50 to about 10% of the total water supply.

Most of local water supply requirements in this region comes from carbonate aquifers. A detailed hydrogeological investigation can be seen in Report 8/1980, Verma. There was another report Coffey & Partners, 1982. Transmmissivity values in these carbonate aquifers vary from about 500 to 2,800 m^2/day.

Finniss River

This region lies south west corner of the map. Groundwater potential is poor. However, this area is developing into a rural dwelling region west of the Berry Springs and Darwin River Dam.

There is a small cattle station in this region. Aquaculture could be the right industry to establish here because there is a potential for saline water along Finniss River.

Knuckey Lagoons-Holmes Jungle Nature Park

This area is located on the suburban outskirts of the Darwin city and therefore, this region is also known as backyard savannah. There is a perennial spring *(Palm Creek Spring)* in the *Holmes Jungle Nature Park* in which small *savanna* exists. Any additional pumping or drilling of bore is not recommended in order to protect the park and the spring. Major users of the groundwater are *nurseries*, *turf farm* and *crocodile park*. See Hydrogeology report 43/2001, Verma. Transmmissivity value is same as Palmerston aquifers and varies from about 200 to 2,600 m^2/day.

Lambells Lagoon & Lambells Lagoon South

This region is totally dependant on the groundwater where banana and mango are grown and it has become a major growing centre.

This region is about 60 km east south east of Darwin and it is well established itself as horticultural centre where popo, banana and mango are grown and some vegetables. Northern Territory Government encouraged public to buy land at a low price to be used for horticulture only.

There are Groundwater Resource investigation Reports 5/1988, Jolly & YinFoo; Report 58/1995D and YinFoo & Verma, 1995. Transmmissivity value is about up to 3,000 m^2/day in carbonate aquifers.

Marrakai - Leaning Tree Lagoon - Woolner

This area is on the eastern boundary of the map. There are cattle stations, national parks including part of the world famous *Kakadu national Park*, camping, boating and fishing parks. Cashew farming was established in 1980s, which didn't succeed, but it may again be started.

Recently, areas around *Leaning Tree Lagoon* have been sub-divided where tropical fruits and vegetables are grown. It is in a developing stage. Like other areas around here, they

totally depend on groundwater. Therefore, an investigation was carried out (Verma, 1998). Now, this area may develop fast as the groundwater potential has been established. Transmmissivity value is anticipated to be same as Lambells Lagoon area, up to 3,000 m^2/day in carbonate aquifers.

Middle Point

It is immediately east of the Lambells Lagoon and surrounded by flood plains in which saline water intrusion is common. Therefore, only a limited development is possible in fresh water in this region. Rice farming was experimented unsuccessfully during 1950s. Mainly mango, popo and banana are grown and totally dependant on groundwater. Barramundi farm has been set up to use the saline water existence. This area is famous for tourism. There is a *Lookout Tower* to watch panoramic view of the *wetland*. B*oating* in the Adelaide River is rewarding where crocodiles can be seen jumping out of the river. *Fishing* is another big attraction here.

A detailed groundwater investigation was carried out during 1997/98. Report 03/1998D, Verma. An hydrology investigation was carried out by consultant (Aquaterra)- report Project No. 065, Document 027-b, May 1999.

Palmerston

This is a satellite city with population about 20,000. Major aquifer in this region occurs in carbonate rocks (Carbonate Layer) same as Berry Springs. A groundwater resource investigation was carried out in 1987, Report 15/1988, Power & YinFoo.

Transmmissivity value varies up to 2,600 m^2/day.

Rum Jungle

Rum Jungle is situated at the southern tip of the map and south of the Darwin River Dam. Uranium and copper were mined in this region, which closed down in 1969. Rehabilitation of the Rum Jungle mine was carried out during 1980s when many monitoring bores were drilled. This is a restricted area. Mining of magnesia in this region may start soon, which would require groundwater.

Production bores for the Batchelor township are in the Coomalie Dolomite.

Sunday Creek (Humpty Doo Region)

This area has not been drilled yet to prove the rock type (Carbonate Layer), which is believed to be similar to dolomite of Berry Springs - Noonamah, Palmerston and Knuckey Lagoons-Holmes Jungle Nature Park areas. Seepage water from this area (sinkhole) into the creek has been sampled and analysed, which indicated it carbonate water. A detail investigation of this carbonate rock is anticipated soon. There is a quarry in this region for road construction material.

The Darwin 1:250 000 map sheet area is becoming more important than ever. The Alice Springs to Darwin (1,400 km) *Railway* line construction has commenced in 2001 and anticipated to be completed by year 2004. Another major proposed development in this region is a *petroleum refinery*, which may be built within 5 years time.

SUMMARY OF GROUNDWATER RESOURCES

The hydrogeology map of the Darwin Sheet in 1:250 000 scale is the first hydrogeology map for the Darwin sheet in 1:250 000 scale and one of numerous maps produced by the Natural Resources (previously known as the Water Resources) of the Northern Territory Government. This map has been prepared to help locate the groundwater supplies in the Darwin region.

Geologically, the area lies in *the Pine Creek Geosyncline,* which had gone under intense folding, faulting, subsidence, uplifting and then erosion during orogeny in the Lower Proterozoic period (1800 Ma). Therefore, the geology is very complex and it changes within metres so does the groundwater prospect.

About 10% of the the water supply to Darwin and Palmerston cities comes from the groundwater from the *McMinns Borefield* situated in the Darwin Rural Area. An investigation is proposed to locate a new borefield for augementation to the main water supply in future.

Major aquifers are within Proterozoic carbonate (dolomite) fractured and weathered rocks with an average sustainable yield more than 5.0 L/s. This aquifer covers about 40% of the map sheet area.

Medium aquifers are in Koolpin Formation (Psk), Whites Formation (Ppi), Crater Formation (Ppr), Namoona Group (Pn) of the Lower Proterozoic age with an average sustainable yield ranging from 0.5 to 5.0 L/s. This aquifer covers about 20% of the map sheet area and mostly in Proterozoic non-carbonate rocks. Yields in well-developed fractures and faults could be considerably high. Therefore, it is always desirable to have a bore site in this type aquifer selected by a hydrogeologist.

Minor aquifers occur over the rest (40%) of the area in stratified non-carbonate and intrusive rocks. They cover a large area on the western side in the Burrell Creek Formation and small areas of Archaean and Proterozoic granites and dolerite intrusives. This aquifer may have an average sustainable yield ranging up to 0.5 L/s. Fractures in Burrell Creek Formation may enhance the yield.

General groundwater quality is potable except those close to the sea and in the flood plain where saline water intrusions are common.

Use of groundwater in this region varies from one to another area. Major areas are listed in the chapter 6.0. Fresh water is with TDS ≤1000 mg/L.

Major users of fresh water are primary producers in the rural areas growing tropical fruits like mango, banana, jackfruit, rambutan, citrus, carambola (five star), etc, market vegetables, nurseries (flowers, orchid, etc), tropical cut flowers, cattle feeds, etc.

Other minor users are pastoral industry, reacreational and national parks, tourist places, small mines, schools, remote commercial users, defence forces, etc.

Use of saline water (TDS >1,000 mg/L) has been taken up recently in the aquaculture industry successfully for breeding fish, prawn, etc. (viz Middle Point Barramundi Farm).

8.0 USE AND APPLICATION OF THE MAP

This 1:250 000 scale hydrogeological map can be used to :

- provide a basic understanding of the hydrogeology of the region
- Assist the planning of groundwater resource development and management
- Identify areas of groundwater resource potential to aid future development, particularly for horticultural and primary producers.
- Obtain hydrogeological data for application to land-use planning related to certain industry.
- Select areas for further investigation if needed for any particular purpose/industry

It is highly recommended that users who are not familiar with the principles of hydrogeology utilise the map in combination with this commentary and specialist groundwater guidance. For further details work refer to 1:100 000 hydrogeological maps available from the *Natural Resources Division* of the *Department of Infrastructure, Planning and Environment*, Darwin. Six (6) 1:100 000 scale hydrogeological maps were prepared by M. N. Verma (2002) and combined to prepare this 1:250 000 scale hydrogeological map.

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10 ACKNOWLEDGEMENTS

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Project team comprised:
P. B. Jolly - Project Co-ordinator
M. N. Verma – Project Manager
L. Fritz – Cartographer

Special thanks to the rural landowners and dwellers who always co-operated during this investigation. Thanks to all colleagues (both professional and technical) who worked at various stages of this project.

APPENDICES

APPENDIX A
MAP PREPARATION METHOD

10.0 Collection of Data

The data on which the map is based comprised:

- 1:100 000 scale six (6) geological map sheets – Darwin, Koolpinyah, Point Stuart, Bynoe, Noonamah and Mary River.
- 1:100 000 scale six (6) topographic map sheets – Darwin, Koolpinyah, Point Stuart, Bynoe, Noonamah and Mary River
- 1:250 000 Topographic map sheet of Darwin
- 1:250 000 Geology map sheet of Darwin
- Bore information from the records of Department of Infrastructure, Planning and Environment.
- Various hydrogeological and geological reports within this sheet area.
- Rainfall and evaporation data from the Bureau of Meteorology.
- Various Satellite imageries.

11.0 Data Processing

The basis of the hydrogeological map is six (6) geological maps in 1:100 000 scale and various projects carried out within this sheet over 30 years or so. Numerous hydrogeological data were derived from private bores.

12.0 Remote Sensing

Remote sensing was restricted to individual projects.

13.0 Map Preparation

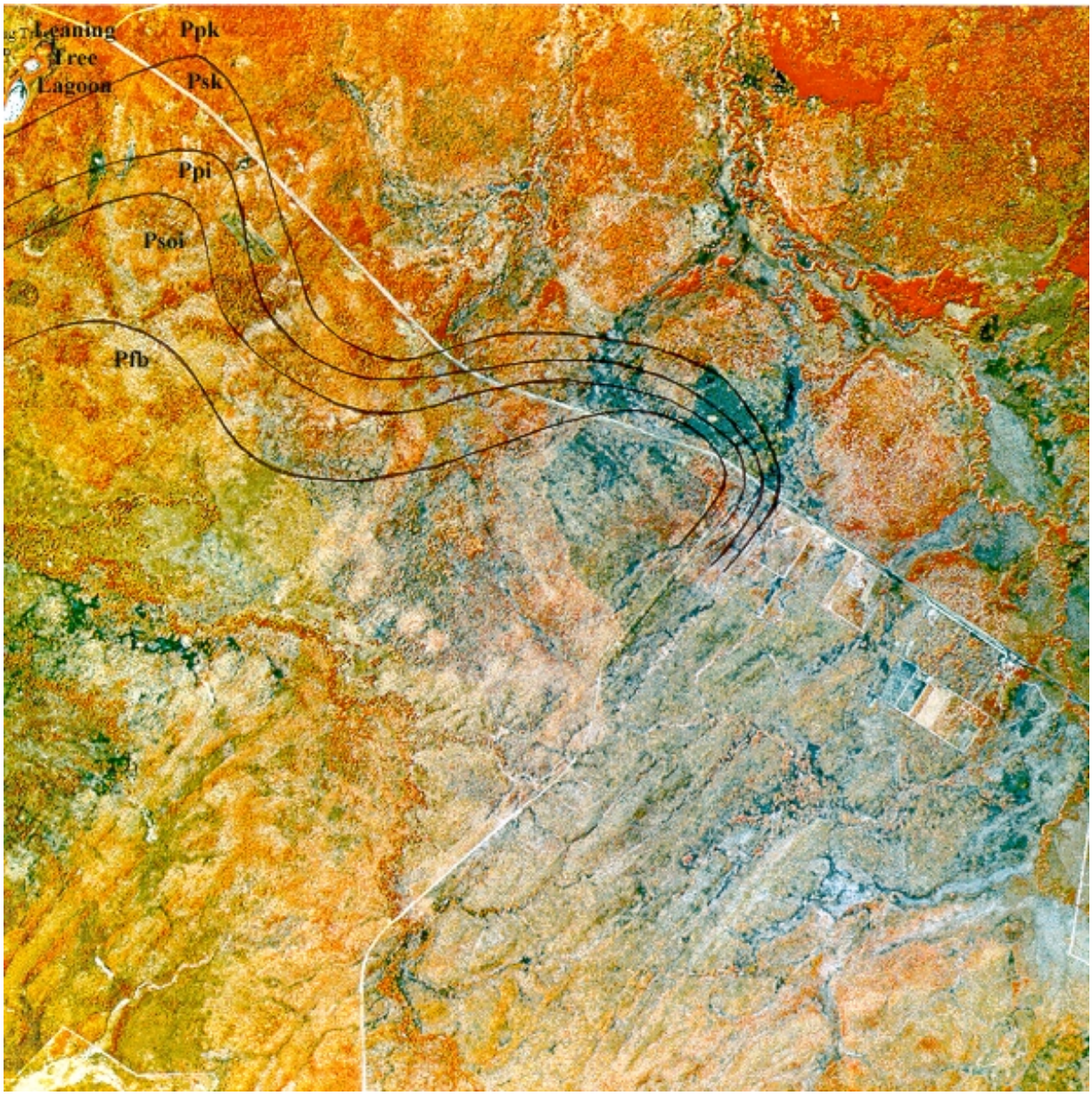
Microstation computer mapping application was used to produce the map. The map was produced on the Geocentric Horizontal Datum of Australia 1994 (GDA94) and the vertical datum is in metres, the Australian Height Datum (AHD).

APPENDIX B
BORE DATA BASE

The bore data base is held on the Computer network of the Department of Infrastructure, Planning and Environment (DIPE), which may be transferred for the use on PC-based word processing software. It may be viewed using "*Borescan*" program and "*Hydsys*" within the Department's network.

A record of a total of 7155 bores are available in the system as at 15 March 2002, which provides basic details:
RN – Registration number of the bore

Grid Reference - Australian Map Grid (AMG) full to the nearest to 10 m.
Bore Name – Name of the bore
Date Drilled – Month and year of the completion of drilling.
Construction Details – Simplified information giving dimensions of cased and "perforated" or open sections.
Depth Drilled – Depth below the natural surface to which bore was drilled , rather than base of the bore as completed.
Aquifer Depth – Depth at which a significant quantity of ware was intersected.
SWL (m) – Standing Water Level in metres below natural surface, usually from date when drilled unless shown otherwise.
Yield (L/s) – Usually airlifted yield, unless pumping test indicated.
Driller's Log – Driller's version of lithology of strata samples (Lithology Version).
Lithology – Interpreted geology (Stratigraphy Version) – Geologic formation symbol. Summary in main text.
Chemical Results – A summary of all chemical analysis results.
Remarks – Additional details as available on bores status, data on swl, availability of geophysical log and/or geological log, whether test pumped, etc.



Marrakai Area - Corraborree Park and Leening Tree Lagoon