Tindall Limestone drilling, 2011

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Cover photo: Sampling drill cuttings at RN37413, photo S. Tickell
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**Executive Summary**

Investigation drilling was done during September 2011 adjacent to the Katherine River where it crosses the Tindall Limestone. At the same time a series of stream gaugings were made along the same section of the river.

The drilling identified a consistent stratigraphy within the formation, comprising three thick limestone packages separated by two thinner shale intervals. The limestone units were mapped across the area using gamma logs. Their distribution immediately beneath the river was also determined. The lowermost limestone appears to be faulted against basalt on the margin of the Daly Basin and does not subcrop beneath the river. The middle limestone directly underlies the river upstream of the old rail bridge and the uppermost one directly underlies the river downstream of there.

The Katherine River is currently a gaining stream fed by groundwater discharge from the Tindall aquifer. Stream gauging indicated a total discharge of 3 cumecs distributed unevenly along the river. The largest inputs occur at the upper section of the Tindall Limestone, at or near its contact with the overlying Jinduckin Formation. Lesser inputs occur from the basal part of the uppermost limestone and the top and middle sections of the middle limestone.

At the first site drilled two monitoring bores were constructed, one in the uppermost limestone and one in the middle limestone. Water levels were 0.16m higher in the shallow bore than in the deeper one. At that site each limestone hosts a separate aquifer with the intervening shale forming a barrier to groundwater movement.

Unlike the upper and middle limestones the lowermost one is not directly connected to the river. It also hosts a major aquifer and its discharge to the river must occur through overlying units. It is postulated that karstic collapses associated with sinkholes and caves have breached the shale barriers sufficiently to allow groundwater to move between aquifers, especially in the upper 30m where weathering is more intense.

1 **Introduction**

1.1 **Aims**

The Water Resources Division of NRETAS carried out an investigation of the Tindall aquifer in the vicinity of the Katherine River. The work aimed to find out if the Tindall Limestone is a single aquifer or if it is made up of several aquifers separated by interbedded low permeability shale layers. If this is the case then it was hoped to locate which sections of the river bed are underlain by which aquifer. The answers to these questions will improve the computer model which is used to make decisions about water allocation in the Katherine region.

1.2 **Methods**

A transect of four investigation boreholes was drilled into the Tindall Limestone at Katherine (Figure 1). It runs in a north east to south west direction perpendicular to the regional strike of the Tindall Limestone and parallel to the Katherine River. The
holes were sited on either Crown land or on land controlled by the Katherine Town Council.

Gamma logs were run in each borehole with the aim of correlating marker beds between holes. The bores were intended to be drilled to sufficient depth to intersect at least one marker bed. Difficulties with poor circulation and poor hole stability limited RN37413’s gamma log record to 64m which was insufficient to get a good match with other logs.

A down-hole optical scanner was run in an existing monitoring bore RN22286. The hole is cased to 19m and is presently open to 162m, exposing a large section of the formation. Gamma and calliper logs were run at the same time. This hole was used as a reference section to compare to gamma logs from the other holes. The work was done by Borehole Wireline Pty. Ltd.

Water samples were airlifted from each of the bores following their construction. They were analysed for major ions only (Table 1).

As part of this study the hydrographic section of NRETAS conducted a series of eight stream gaugings at strategic locations in the Katherine River during September 2011. Katherine Hot Spring and Northbank Spring were also gauged and flows were visually estimated for Springvale Spring, Tindall Creek at the Victoria Highway and Leight Creek at Eumangalan Rd. Tindall Creek at Uralia Rd. and Maude Ck at the Gorge Rd. were dry at the time. The purpose of the gauging was to better define where groundwater inflows to the river occur.

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Table 1 Chemical analyses of groundwaters

Tindall Limestone drilling, 2011
1.3 Geology

The Tindall Limestone is of the order of 160m thick at Katherine and comprises packages of limestone up to 45m thick separated by intervals of interbedded shale, siltstone and limestone up to 10m thick. Individual shaley units are laterally extensive and are usually easy to recognise on gamma logs as they have distinctive high gamma signatures. The formation dips at less than one degree basinwards to the south west.

The Tindall Limestone is the basal formation of the Daly River Group. In the vicinity of Katherine it unconformably overlies basalt of the Antrim Plateau Volcanics and less commonly sandstone of the Jindare Formation (Kruse et al. 1994). It is conformably overlain by the Jinduckin Formation, also part of the Daly River Group. There is evidence for a period of subaerial exposure of the top of the Tindall Limestone prior to the deposition of the Jinduckin Formation (Kruse et al. 1994).

A narrow strip of alluvium is associated with the Katherine River. Alluvial deposits do not extend far beyond the levee banks of the river and the usually only extend slightly deeper than river bed level. Few exposures of Tindall Limestone occur in the river or on the adjacent floodplain, indicating a consistent but probably thin covering of alluvium. It consists of silty and clayey sand and sand.

Figure 1 Locality map
2 Observations

Graphic logs of the four new bores and of RN22286 are shown in Appendix 1. These include the bore construction, gamma log, water intersections, descriptions of cuttings and stratigraphic interpretations. The descriptions of cuttings are by the geologist for all but RN22286 which was taken from the driller’s log. The boreholes are yet to be levelled to AHD but RN37410 and RN37411 were levelled relative to each other using a water filled hose pipe. The top of casing in RN37410 is 0.046m lower than that of RN37411. On the 19th of September 2011 the water level in RN37411 was 0.164m below that in RN37410. Water levels were measured again on the 19th of October 2011 and the difference was 0.015m.

A brief description of the drilling and logging at each site follows below:

2.1 RN37410
This was sited just below the contact with the Jinduckin Formation and so penetrates the uppermost section of the Tindall Limestone. Gray cracking clay soil is present down to 1.8m, passing abruptly into grayish crystalline limestone. Between 69 and 72m calcareous shale is interbedded in the limestone. Calcareous light blue gray shale occurs between 72 and 75m and below that the strata is again limestone with traces of shale to the total depth of 85.6m. Aquifers were struck at several levels both above and below the shale bed. The hole was gamma logged and then constructed in order to monitor water levels in the limestone beneath the shale between 72 to 75m. Eighty metres of 156mm diameter steel casing was cemented into the hole between 69 and 80.1m. The cement inside the casing was drilled out and the zone below the casing left uncased and sealed off from the limestone above 72m.

2.2 RN37411
Located 8m north east of RN37410 this bore was drilled to 55.6m in order to monitor the limestone above the shale struck at 72m in RN37410. It was constructed with 100mm PVC slotted from 43 to 49m.

2.3 RN37412
This is the north eastern-most site, located off Emungalan Rd, adjacent to the Telegraph Line monument. It was drilled to a total depth of 84.8m. Cainozoic deposits extend down to 15m. The upper six metres comprises sandy alluvium. That is underlain by a chalky limestone that contains quartz sand and pebbles, probably a travertine. A buried soil developed on the Tindall Limestone extends from 15 to 18m and it consists of orange brown clay. The Tindall Limestone extends from 18 to 72m. It is light gray finely crystalline limestone down to 57m and chocolate brown siltstone below that depth. A gray, pyritic, fine to medium grained sandstone encountered from 72 to 78m belongs to the Jindare Formation. That in turn overlies basalt of the Antrim Plateau Volcanics.

No shale was seen in the cuttings of the Tindall Limestone, so the hole was constructed with 100mm PVC, slotted opposite one of the main water intersections from 43 to 49m. The hole was unstable so a gamma log was only run after the bore was constructed. A shaley interval was apparent at around 26m on the gamma log.
2.4 RN37413
This bore was sited approximately in the centre of the traverse, 900m north east of the Stuart Highway bridge over the Katherine River. Alluvial clayey sand was encountered to 8m before the hole passed into Tindall Limestone. The limestone proved to be very cavernous and difficult to drill. Circulation was partially lost and caving of loose material from above led to cuttings being contaminated. The hole remained in Tindall Limestone to the total depth of 86.6m. Shales were encountered at 36 and 42m and red brown siltstone was struck at 72m. Due to the caving it was impossible to pick the bottom of the shale and siltstone intervals. Again the hole was too unstable to run a gamma log in the open hole and it could only be logged after it was constructed. 100mm PVC was run to 64.7m and slotted from 53 to 59m.

2.5 RN22286
Down-hole logs, including an optical scan, gamma and calliper were run on the 24th of November 2011. A selection of the optical images is shown in Figure 2. The locations of these images are shown in Figure 2j in relation to the gamma log.

The section is predominantly limestone, both massive and bedded. Several main lithologies are present, including finely colour banded limestone with abundant bedding parallel stylolites (Figure 2a), limestone with broad colour banding and few stylolites (Figure 2b), laminated limestone with traces of stromatolites (Figure 2d) and mottled limestone (Figure 2f). The latter contains abundant dark mottles that are largely parallel to bedding and range from isolated patches to continuous thin layers. The mottled limestone and the limestone with broad colour bands grade into each other.

Two thin shale intervals occur at 36.4 to 40.3m (Figure 2c) and 95.6 to 99.8m (Figure 2e). The latter is more finely bedded than the former. A major shaley unit occurs from 128.5 to the bottom of the hole at 153.9m (Figure 2g). It is a chocolate brown colour with some sections showing abundant cream stringy mottling, often parallel to bedding.

2.6 Water quality
All of the water samples analysed (Table 1) are typical of groundwaters from limestone aquifers in the Top End. Calcium and magnesium are the main cations and bicarbonate is the dominant anion. They are alkaline (ph 8.1 to 8.4), have high hardness (221 to 351mg/l) and a total dissolved solids content in the range 300 to 390mg/l.
Figure 2 Down-hole optical images and gamma log from RN22286.
3 Discussion

3.1 Geology
The shale/siltstone beds seen on the down-hole optical image of RN22286 are generally recognisable across the Katherine area, especially on gamma logs. They have distinctive signatures which are traceable from borehole to borehole. On the basis of gamma logs, the Tindall Limestone can be subdivided into three limestone packages separated by thinner shales. The limestones are informally referred to here as Limestones B, C and D, with B being the oldest (Figure 2j). Correlations between gamma logs of RN37410 and RN37412 are good, however an incomplete gamma log and poor sample recovery in RN37413 made for poor correlations with that borehole. The red brown siltstone encountered in RN37413 at a depth of 72m is a distinctive marker bed and is considered to be the same as that struck at 126.1m in RN22286 and at 57m in RN37412. Surrounding boreholes with gamma logs were also used to assist with the interpretation shown on cross-section A-B (Figure 3).

The Tindall Limestone can be seen to dip to the south west at a low angle. Between RN37412 and RN37410 the average dip is about 0.5 degrees. Another important observation is that the Tindall Limestone is likely faulted against the Antrim Plateau Volcanics (and or the Jindare Formation) to the north eastern end of the section.

All existing borehole gamma logs were interpreted in terms of the limestone units B, C and D (Appendix 2). The depth to the base of the shallowest limestone unit in each hole was noted and an interpretive map showing the distribution of the three limestone units at ground level was made (Figure 1). The oldest unit, Limestone B occurs at ground level only to the east of Katherine, several kilometres from the Katherine River. Limestone C comes to the surface to the northeast of the Stuart Highway, while Limestone D is at the surface on the opposite side of the highway.

The river bed lies some 20m below the level of the surrounding countryside so the contact between Limestones C and D in the river bed must lie downstream of its position in relation to that on the adjoining higher ground. Taking the dip of the beds into account, the contact immediately below the river bed must lie at about 1km downstream of the old rail bridge.

3.2 Groundwater discharge
A series of stream gauging were done along the Katherine River (Figure 4). They are summarised in Figure 5 as a profile of stream flow vs distance downstream from Ironwood gauging station. The projected sub-stream bed geology is superimposed on the profile. The flows progressively increase downstream as the river gains water from springs and seepage through the river bed. Eighteen springs have been located along the river banks during previous surveys (Tickell, 2007)(Figure 6). These are listed in Table 2. Most have relatively small flows of a few litres per second or less. The exceptions are Katherine Hot Spring, Northbank and Springvale Springs which had flows of 0.44, 0.07 and 0.05 cumecs respectively at the time of the current survey. The total observable spring flow, including Leight and Tindal Creeks is less than 0.5 cumecs. The great majority of the groundwater accessions to the river must occur unseen through the river bed.

No rain or runoff occurred during that period that the gaugings were done, so the water added to the river is all groundwater sourced from the Tindall aquifer. The total
increase between Ironwood and Springvale (downstream of Tindal Ck.) is 3 cumecs. Note that no account has been taken here of losses due to evapotranspiration or pumping out of the river. Evapotranspiration has previously been estimated to be of the order .004 cumecs/kilometre of river (Tickell, 2002) which equates to 0.05 cumecs for the whole section. Pumpage is unknown and is assumed also to be minor in comparison to the groundwater accessions.

The increase in flow as the river crosses the Tindall Limestone is not gradual but occurs in a number of steps. Key sections along the river are now described:

- 0.1 cumecs between Ironwood and Knotts Crossing. Given that the accuracy of the gauging method can be up to 5% of the flow depending on local conditions, it is likely that there is no change in flow over this reach of the river. The underlying geology is basalt of the Antrim Plateau Volcanics in the upstream third and Limestone C in the remainder.

- 0.6 cumecs between Knotts Crossing and Leight Creek. Springs 2, 3, 4 and 5 (Figure 6) and associated river bed seepage in that vicinity are the likely source. These are underlain by the mid-section of Limestone C.

- 0.25 cumecs between Leight Creek and the old rail bridge. The river crosses the upper section of Limestone C in this reach. Only a few small springs are present.

- 0.75 cumecs between the old rail bridge and a point one kilometre downstream. Springs 7 to 10 (Figure 6) and associated river bed seepage in that vicinity are the likely source. These are underlain by the base of Limestone D.

- 1.05 cumecs between the previous point and the Low Level crossing. Of this only 0.49 cumecs comes from the Hot Spring and Northbank Spring and the remainder is sourced from river bed seepages in the vicinity of the two springs. These are located near the top of Limestone D. The Tindall Limestone/Jinduckin Formation contact is exposed in the Katherine Hot Spring. It is presumed that the river does not gain any water between the Hot Spring and the Low Level crossing because it flows over Jinduckin Formation in that reach.

- 0.45 cumecs between the low level crossing and Springvale Spring. Springs 14 to 17 and associated river bed seepage in that vicinity are the likely source. The springs are also in Limestone D, close to its contact with the Jinduckin Formation.

Limestone C accounts for only 0.75 cumecs of the discharge to the river. The remaining 2.25 cumecs is sourced from Limestone D. Of that amount, 1.5 cumecs discharges from the upper section of Limestone D and 0.75 cumecs discharges from its basal section.
3.3 Aquifers

At the first drill site RN37410 was constructed to monitor the upper section of Limestone C and RN37411 monitors the shallower aquifer at the site, the lower section of Limestone D. The water levels measured so far indicate different levels in the two aquifers, with the shallower one around 0.15m deeper than that of the deeper aquifer. This indicates that the shale between 72 and 75m in RN37410 is a barrier to groundwater flow and that the limestones above and below it can be considered to be separate aquifers. On a regional scale the aquifers are likely to be partially connected by the abundant sinkholes and caves which occur throughout the area (Karp, 2002). Vertical conduits between the limestone aquifers can form where the intervening shale layers are breeched by the collapse of underlying solution cavities. This is expected to be common in the upper 30m where large solution cavities are most common. At greater depths the degree of connection between the aquifers is likely to be less.

An important finding from the drilling is that the lowermost limestone, Limestone B, does not appear to subcrop below the Katherine River. It is known to be a major aquifer because the town production bores tap it and they are capable of individual yields of 90 L/sec. The borefield is situated 1.2km south east of Knotts Crossing. If discharge from that aquifer through the overlying Limestone C was occurring then greater accessions to the river upstream of the old rail bridge might be expected. Only 25% of the accessions can be attributed to Limestone C. A possible mechanism to account for this may be that in the vicinity of the river there is a component of horizontal groundwater movement in a downstream direction. This could allow the transfer of shallow groundwater between aquifers, eventually channelling the majority of it to the downstream limit of the aquifer to be discharged at points like the Katherine Hot Springs. Levelling of the new monitoring bores to AHD should help to resolve this problem.

The higher water levels recorded in the deeper aquifer are consistent with upward movement of groundwater and the river being a discharge feature. Water level recorders have been placed in both RN37410 and RN37411 and it is hoped that the data collected over the 2011/12 Wet season will shed light on the dynamics between the two aquifers, the river and recharge.

3.4 Recommendations for further work

- Level the new bores and the river bed closest to each bore to AHD. The bores can then be added to the existing monitoring bore network to improve knowledge of the groundwater flow pattern in the vicinity of the river. Logger data from RN37410 and RN37411 can also be compared to the river height /rainfall record from the old rail bridge gauging station (G8140001).

- Run down-hole flow meter logs on any existing uncased bores that span more than one limestone unit to determine if any inter-aquifer flow is occurring and if so in which direction. Two likely candidates for flow tests are RN22286, RN22390, RN22391, RN22392, RN22397, RN22394 and RN29430.
4 References


Figure 3 Gamma log cross-section A-B, see Figure 1 for the location of the section.

Figure 4 Stream gauging locations and flows.
Figure 5 Stream flow profile along the Katherine River.

Figure 6 Springs on the Katherine River, see Table 2 for descriptions.

Tindall Limestone drilling, 2011
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Table 2 Springs on the Katherine River
Bore Construction | Gamma Count | Graphic Log | Strata

- Soil: gray cracking clay, silty and Limestone, light gray, finely crystalline
- Limestone: light brown gray, fine to medium crystalline, some grains dissolved out leaving a slightly porus mass, hard
- Limestone: as above and a trace of soft cream clay
- Limestone: as per 12 to 15m
- Limestone: light gray to cream, fine to medium crystalline, hard
- Limestone: as above and limestone, medium crystalline, cream, brittle, slightly porus and shale, very calcareous, firm, light blue gray and light tan
- Shale: very calcareous, firm, light blue gray, minor limestone, cream
- Limestone: shaley, light tan, firm, minor limestone, dark gray, hard, minor shale, light blue gray

Tindall Limestone drilling, 2011
Bore Construction  Graphic Log  Strata

**Tindall Limestone drilling, 2011**

- **Bore Construction**
  - 100mm PVC
  - 199mm hole
  - 206mm steel
  - 255mm hole

- **Graphic Log**
  - Soil: gray cracking clay, silty and Limestone, light gray, finely crystalline
  - Limestone: light brown gray, fine to medium crystalline, some grains dissolved out leaving a slightly porous mass, hard
  - Limestone: as above and a trace of soft cream clay
  - Limestone: as per 12 to 15m

- **Strata**
  - **Tindall Limestone**
  - **slots**
  - **SWL 10 m**

**Planting Tickell 2005**
Bore Construction | Gamma Count | Graphic Log | Strata

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soil
red brown, silty sand, very fine, unconsolidated, at 3.6m limestone, white, earthy, very fine

limestone
white, finely crystalline to chalky, minor light pinkish brown ironstaining, abundant fine to coarse quartz embedded in the limestone and pebbles to 1cm of sub rounded quartz (soil calcare or travertine)

clay
orange brown, soft and pebbles as above

limestone
light orange brown, firm to hard, finely crystalline, abundant solution pits

no returns

limestone
light gray with abundant orange brown stains on fractures, abundant solution pits, hard, finely crystalline

limestone
as above and chert, black, brittle (trace reaction to hcl along cracks)

siltstone
chocolate brown, calcareous, firm, trace limestone as above, trace of pyrite (small clumps of fine crystals), minor sandstone, very fine, red brown, firm to soft

sandstone
light to medium gray, hard, pyritic in parts, crystalline calcite on some joints, fine to medium grained

basalt
black, hard, fine grained, altered with abundant dull green mineral (chlorite?), calcite veins common
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**Appendix 2 Depths to formation tops**