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GROUNDWATER ABSTRACTION IN THE ROPER REGION - NORTHERN TERRITORY

Developing the North – groundwater and agriculture

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ABSTRACT

An assessment of the sustainability of water resources in the Roper region's Tindall Limestone Aquifer (TLA) was undertaken in 2016 using neoteric data, to ascertain a balance between maintaining the integrity of the natural environment, while maximising the potential of the available water resources for future economic development. The TLA is one of the Northern Territory's best-quality, highest-yielding groundwater resources (Department of Land Resource Management, 2016). The current Northern Territory Government is committed to continuing the water allocation planning to ensure on-going management of resources in the region (Northern Territory Government – Draft Water Allocation Plan, 2011).

In many Australian regions, water is allocated for various forms of use, these allocations are based on current and historic information (including past and present rainfall patterns) relating to the availability of water in the area. This information is the basis on which water extraction licences are granted and subsequent abstraction from ground and surface sources occurs. When determining the capacity of an aquifer, comprehensive bore data are essential. These bore data are obtained from existing bores, or by drilling new test holes, which provides recovery, yield, depth, and drawdown information. This is valuable when assessing both the capacity of an individual bore, and the availability of water in the area. Collation of data from numerous bore sites combined with other data on the Roper region will assist in determining the capacity for water allocations, and developing a water plan to ensure its sustainability.

Water Allocation Planning for the TLA Mataranka began in 2008, with no WAP yet declared: to date, 19 groundwater licences appear on the Groundwater Extraction Licence register for Tindall aquifer (Mataranka) of which, 12 licences were granted for agriculture (for up to a ten-year period) (Department of Land Resource Management, 2016). Water licences give the Northern Territory Government a mechanism with which to reduce water allocations as a result of reduced annual aquifer recharge. Historical records for the Roper region TLA and existing areas of interest (AoI) are sparse. This study used new data to examine the water resources of the TLA in the Roper River region and recommends: undertaking further analysis using these new data; increasing the number of automatic gauging stations; and expanding site exploratory work to increase resource reliability for future water planning and allocations.

INTRODUCTION

This section covers the literature relating to previous research in the area of interest (AoI) and sets them in their environmental and geological contexts.

1.1. Existing Studies

When assessing the sustainability of water resources in the Roper region Tindall Limestone Aquifer (TLA), it is essential to strike a balance between maintaining the integrity of the natural environment and ecosystem, while maximising the full potential of the available water resource. The TLA is one of the Northern Territory's best quality, highest-yielding, groundwater resources (Department of Land Resource Management, 2016). The current Northern Territory Government is committed to continuing its water allocation planning to ensure on-going management of resources in the region (Northern Territory Government – Draft Water Allocation Plan, 2011).

It is essential that legislation such as the Northern Territory Water Act regulations and planning reflect local environment and community use to mitigate wastage, and inappropriate use of water. It is important for water resources to be allocated among competing demands so as to meet socio-economic and cultural aspirations, minimise pollution, support ecosystems, and sustain industry, including producing food, protein, and energy. In many Australian regions, water is allocated for various end-uses; these allocations are based on current and historical information (including past and present rainfall patterns) relating to the availability of water in that particular area. This information is the basis on which water extraction licences are granted and subsequently water is abstracted from either aquifers (groundwater supplies), or from nearby rivers, creeks, or streams. When determining the capacity of an aquifer, comprehensive bore data are essential. These bore data are obtained from existing bores, or by drilling new test holes, which provides recovery, yield, depth, and drawdown information for the particular site. This is valuable information when assessing and determining both the capacity of an individual bore, and the availability of water in the area. Collation of data from numerous bore sites combined with other existing scientific information for the Roper region will assist in determining the capacity for water allocations, and developing WAPs to ensure a sustainable environment.

Many areas in Australia have highly-controlled water monitoring and allocations regulated through both state and federal legislation. Currently, in the Northern Territory, water planning is in its infancy as a result of the limited amount of raw data available, and the need to use data based on desktop studies and computer simulations. Water Allocation Planning for the TLA Mataranka commenced in 2008, with no WAP yet declared: to date, 19 groundwater licences appear on the Groundwater Extraction Licence register for Tindall aquifer Mataranka of which the 12 licences granted for agriculture (for up to a ten-year period in accordance with the Water Act) have been applied for and granted (Department of Land Resource Management, 2016). Water licences give the Northern Territory Government an independent equitable mechanism with which to reduce water allocations as a result of reduced annual aquifer recharge (i.e., after a poor wet season). The introduction of this system in conjunction with numerical modelling assists in managing water resources equitably, safeguarding the aquifer against over-abstraction of water in drier years, and allowing maximum water availability for the environment when circumstances require it.

Historical records of the Roper region TLA, and existing area of interest (AoI) are sparse: to date the most current, comprehensive modelling report on the Roper River Catchment is the water study conducted by Knapton in 2009 (commissioned by the Department of Natural Resources, Environment, the Arts and Sports).

Knapton had previously made ambitious attempts to model the entire Cambrian limestone aquifer (including the TLA), based on projected data in view of the actual data paucity.

The typical nature of karstic aquifers (Cambrian limestone aquifer system, which includes the TLA) encompasses chemical weathering which produces secondary porosity and permeability in the carbonates (Knapton, 2009).

The weathering zone in carbonate aquifers results in more permeable, and possibly cavernous strata, for up to a maximum depth of 100 to 150 m below the surface. As a result of limited historical bore data in the region (data availability over the last one to nine years) there has been limited knowledge of groundwater levels, quantity, and quality of the resource, resulting in theoretical estimates based on computer modelling projections: MIKE powered by DHI and Global Water Research Coalition's one-dimensional MIKE11 component of the MIKEFLOOD model (Knapton, 2009). TLA modelling undertaken to date is capable of providing a WAP guide, however it should not be used as a WAP tool until a better data set becomes available;capable of providing increased confidence in the modelling outcomes (Department of Land Resource Management, 2011). The associated data provided by the monitoring bores that were classed suitable in the Mataranka area were highlighted as inadequate and unable to constrain the modelling projection; this was shown through the inclusion and use of the standing water level (SWL) of two boreholes (RN028082 and RN029013) south of Larrimah which are located outside the Tindall aquifer Mataranka WAP area (Department of Land Resource Management, 2011). However, recent, extensive, bore-drilling in the region has allowed a more accurate assessment of the availability and suitability of the regional resource. This study examines the water resources of the TLA in the Roper River region.

1.2. The AoI and its Hydrogeological Context

Figures 1 to 6 show the location of the AoI, the underlying geological conditions, currently available rainfall gauging stations, general directions of groundwater flow, the Daly Basin aquifers around the AoI (marked as Elsey Station), and the estimated daily aquifer recharge, respectively.

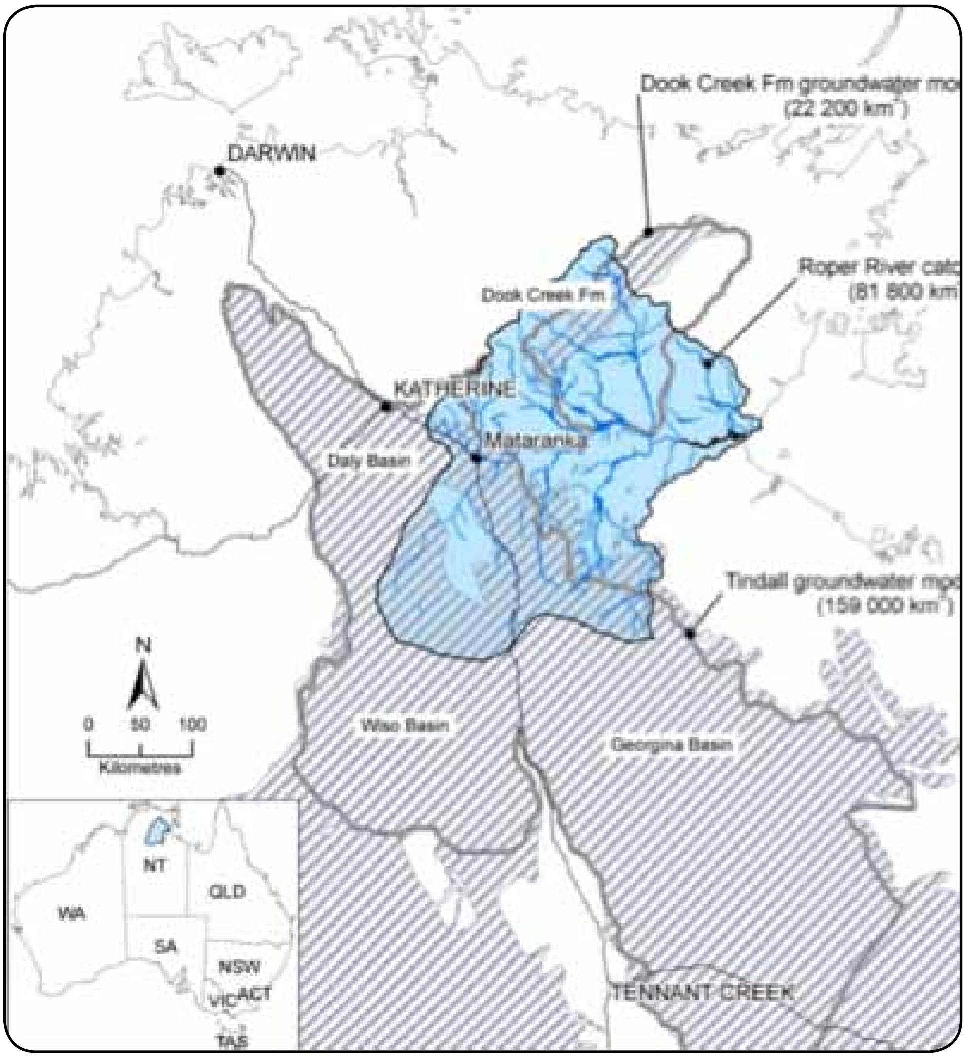


Figure 1. Location of the Roper River catchment with respect to the major groundwater basins (Knapton, 2009)

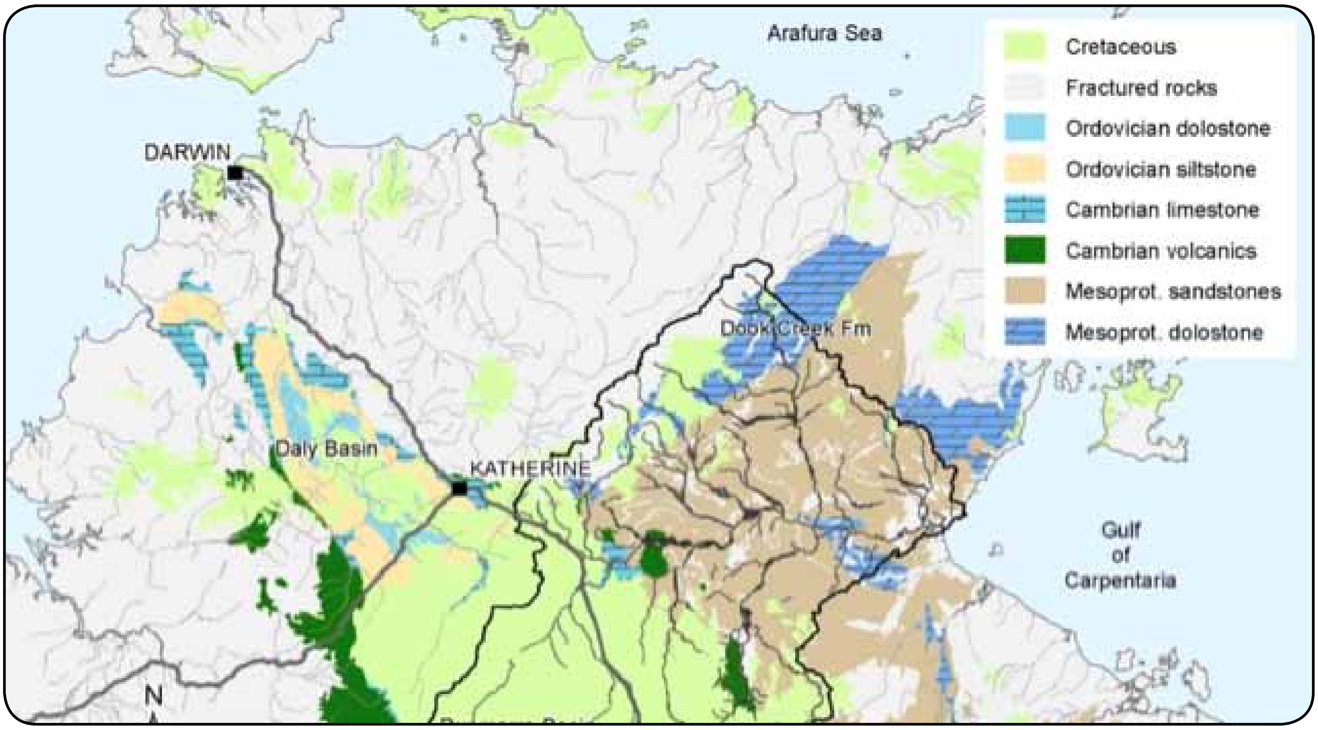


Figure 2. Regional geology of the AoI and its surroundings, approx. 15° S, 133° E (Knapton, 2009).

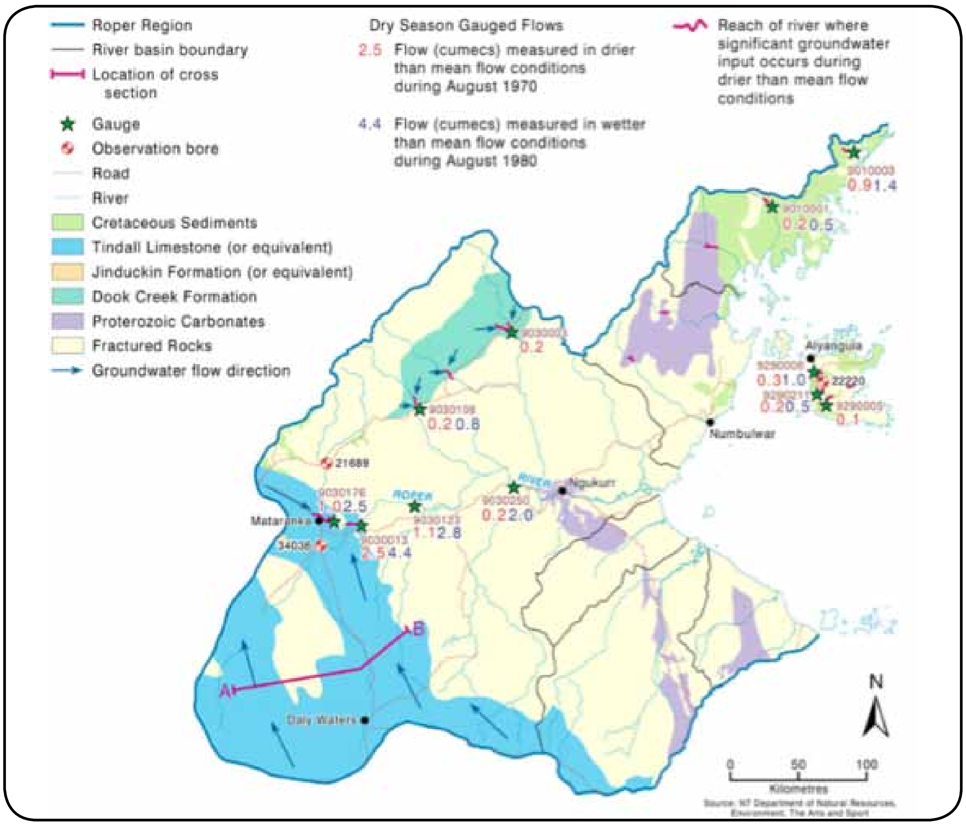


Figure 3. Roper region: automatic rainfall gauging stations (CSIRO, 2009)

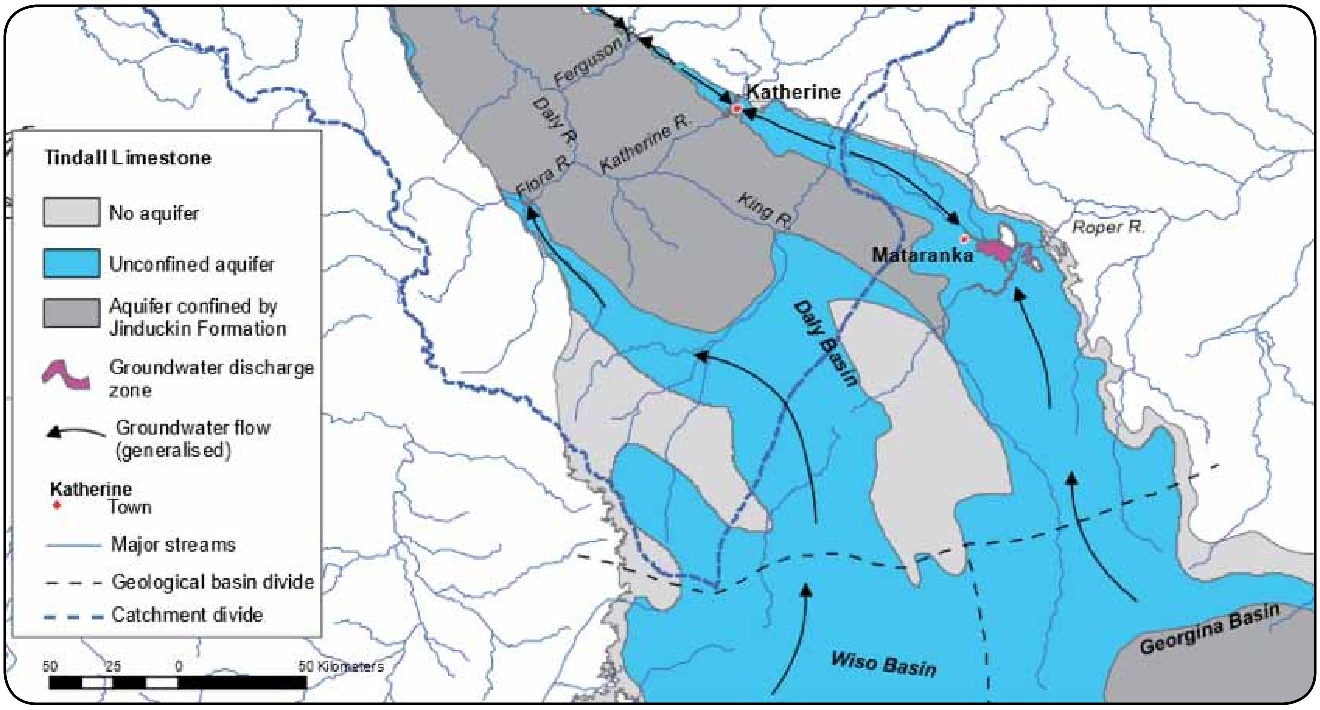


Figure 4. Tindall aquifer and general ground water flow directions therein (DLRM, 2016)

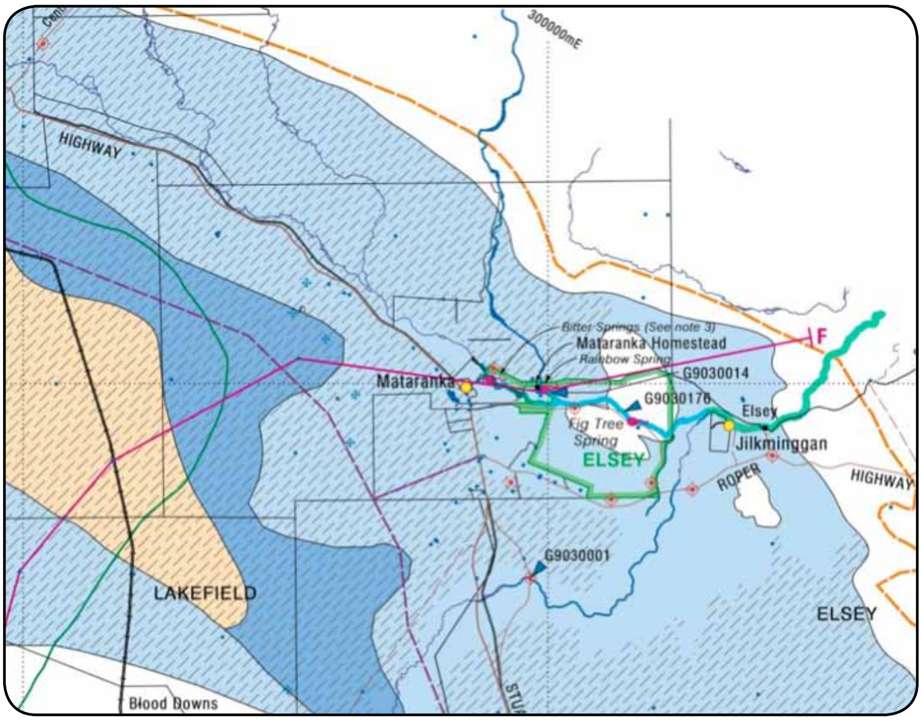
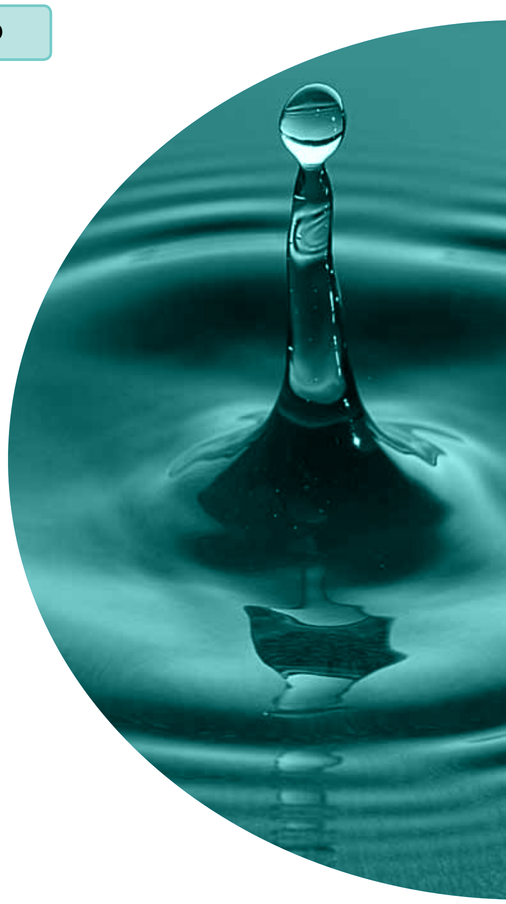


Figure 5. Daly Basin aquifers, Mataranka and the Elsey Station AoI (Tickell 2007)



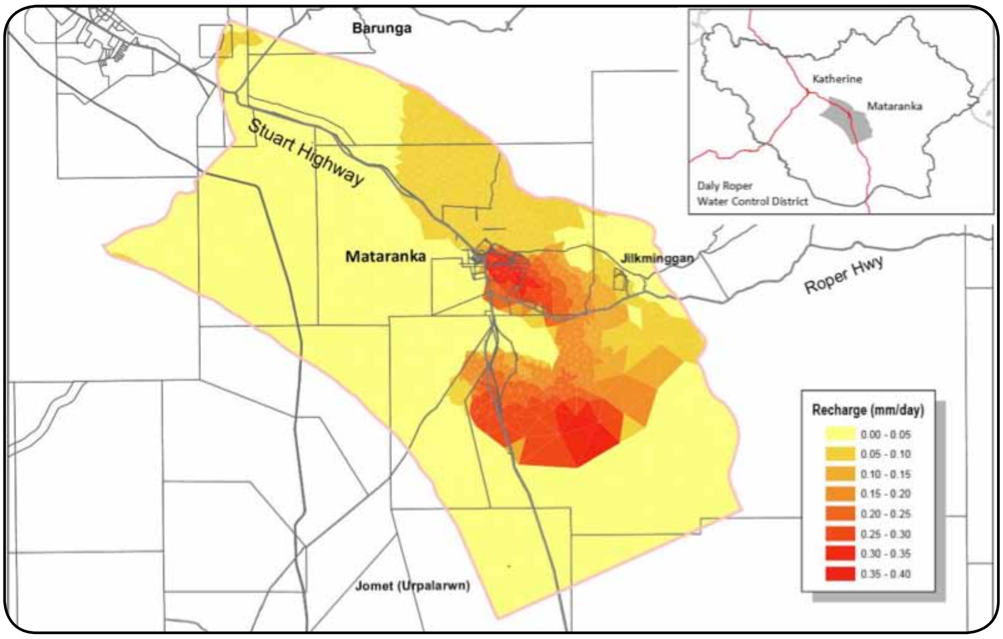


Figure 6. Average aquifer recharge rate in the AoI (NTG, 2017)

depression storage, infiltration into the soil surface; interflow (lateral flow) through surface soil strata, and groundwater flow to streams (Ladson, 2008). The rainfall data used in this study were obtained from Bureau of Meteorology (BoM) gauging stations. Missing rainfall data were estimated by correlation between rainfall data, and remotely-sensed outgoing long-wave radiation (OLR) and temperature data. These rainfall data were used as a basis for further correlation of the SWL in bores and the effect on aquifer recharge.

1.3. Tindall Aquifer (Mataranka): Scope of Study

In this study an analysis of the efficacy of neoteric data (new approaches to existing methods of data collection) in existing modelling projections of sustainable water availability in the overlying areas of the Tindall aquifer has been conducted. Existing data used in this analysis covered: precipitation, permeability of the soils and rocks in the surrounding areas, interaction of aquifers, movement of groundwater, and the topography of the AoI. These factors all directly affect the annual recharge capacity of the Tindall aquifer. A brief outline of each of these elements is provided; with the ways in which the previously unanalysed neoteric aspects of such data have been applied.

1.3.1. Precipitation

Wet season rainfall is dissipated in many forms when recharging this aquifer: as direct stream precipitation, channel and lake flows, interception by vegetation,

1.3.2. Permeability

In the case of karstic rock formations such as the limestone (predominant in the Tindall aquifer), the permeability affects aquifer recharge.

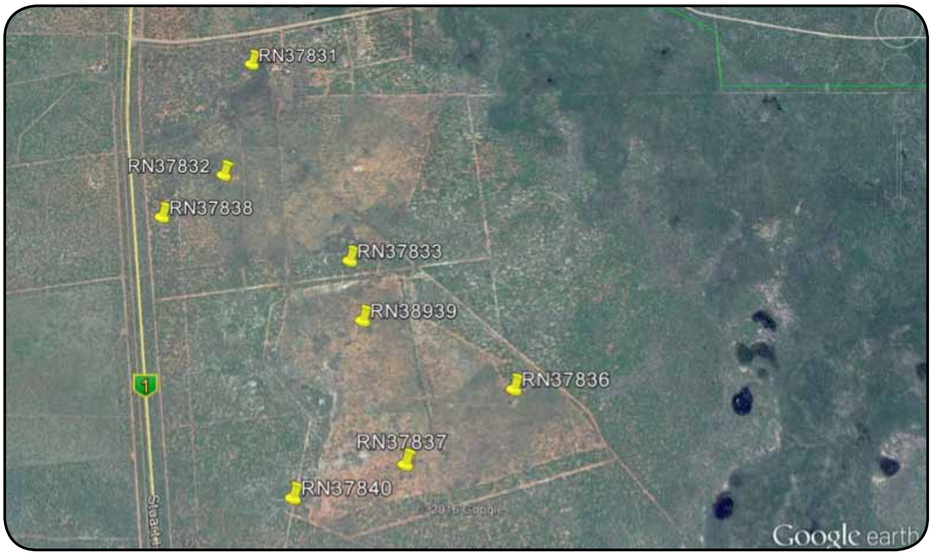


Figure 7. Borehole locations

(Google Earth Ver. 6.2.2.6613. Roper Region, Australia, 14° 01´ S, 133° 16´ E, eye altitude 5.80 km, 1 April, 2016)

In this study, the coefficients of permeability, and stratification of geologic media in each borehole (Fig. 7) will be identified with rock chip recovery data used to estimate the coefficient of permeability at 1 m vertical intervals. These permeability estimates were used as the lower limit for the projected coefficients of permeability used in subsequent modelling; however, no upper limits to the permeability were assigned to allow for the underground nature of the rock fractures and cavities in the AoI.

1.3.3. Groundwater Movement

There are two mechanisms driving groundwater movement in the TLA: natural gravity-driven flow and flow arising from aquifer recharge (point sources, stream bed seepage, diffuse areas and sink holes), and discharge areas (through springs, rivers, and bores). Previous groundwater flow directions (Fig. 4) and bore drawdown and yield are important factors that affect the flow regime in the AoI. The rate at which the bore drawdown occurs and recovers is critical to determining the potential capacity of the groundwater resource in the TLA. The drawdown data assist in determining the capacity of the aquifer, water recharge thereof, and flow therein, to provide sustainable limits to abstraction in both the immediate area and the entire Cambrian aquifer system (including the Tindall, Oolloo, and Jinduckin aquifers). Bore yield data form the basis of this analysis and will provide the foundation for the proposed abstraction recommendations.

1.3.4. Interaction of Aquifers and Sinkholes

Water movement into aquifers is dependent on the permeability of the aquifer, and the permeability of its materials, and groundwater may move more than several metres per day (depending on strata properties). Particularly in the karstic Tindall aquifer, permeable materials such as the limestone foundations contain interconnected cracks and spaces that are both regular enough and large enough to allow water to move freely. If large areas of the underground limestone weather as a result of the action of groundwater, these cavities can become caves (with many interconnected chambers) or caverns, and consequently, if the roof of one of these caves or caverns collapses, this results in the development of a sink hole which affects the rate of recharge of the aquifer. Due to the irregularity of sinkhole conditions and sizes, their effect on aquifer recharge was not analysed in this study; however, sinkholes do play an integral role in aquifer recharge, and their importance should not be overlooked (there have been 52 recorded sinkholes in the Roper region and Tindall aquifer).

1.4. Summary

The top of the TLA was selected as a common datum, the elevation (relevant to datum) of each borehole was determined to compare depths to the SWL in each borehole. The changes in SWL follow variations in the rock strata, and furthermore, act as an aid to the identification of the main geological formations and their likely permeability.

Figure 8. Aerial views of the AoI: taken from 14° 58´ S, 133° 12´ E (c.15 km from Mataranka)

In addition to visual on-site inspection and an aerial survey (Fig. 8) the borehole SWL data can confirm wetland and swamp areas.

As seen in Fig. 8, the prominent vegetation types are typical of open paperbark and eucalypt woodland with palms (typically Livistona rigida). A once thriving environment (as evinced by the size, and age, of the trees therein) has become waterlogged, resulting in a loss of tree, and vegetative, cover.

The aim of research was to evaluate the sustainable availability of water from the TLA (Mataranka) by analysing available data in relation to water recharge and groundwater movement. New additional information in relation to the TLA, including yearly aquifer recharge and yield, enables an independent assessment of the capacity for sustainable water abstraction and justifies future water allocations in the Mataranka region.

2. RESULTS

Neoteric, and correlation-derived, data are presented as follows: rainfall, borehole stratigraphy and yield, and water quality.

2.1. Rainfall

To obtain a better understanding of recharge in the TLA, an analysis of the annual rainfall (on an NT water year basis: 1 October to 30 September) has been conducted. The rainfall data used in this analysis have been obtained from the BoM database for those gauging stations shown in Fig. 9.

Table 1 summarises information pertinent to the rainfall gauging undertaken in the AoI with omissions in each dataset for the gauging stations of interest ranging from 9.1 % to 63.6 %. These inevitable omissions give rise to error when analysing annual rainfall records. Additionally, there is a total maximum rainfall recording error of c. ± 10% for manually recorded rainfall gauges due to gauge location, evaporation losses, and the loss to accumulation of water on the internal walls of the rain gauge. For the purposes of this analysis this maximum error bound was deemed negligible because annual rainfall only accounts for c. 8 % (Knapton, 2009) of the annual recharge in the TLA.

Figure 9. Rainfall gauges in the AoI (green plot boundary)

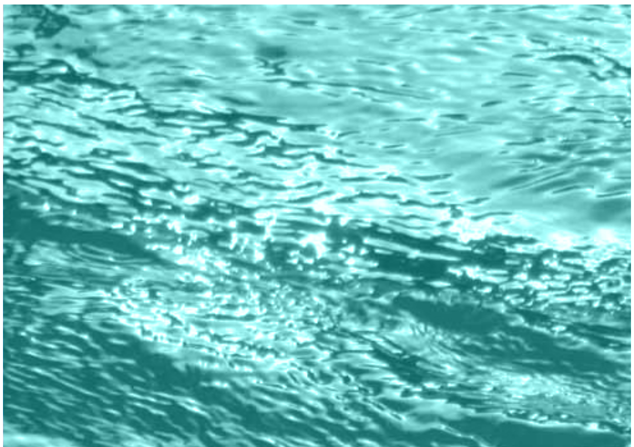
(Google Earth Ver. 6.2.2.6613. Roper Region, Australia, 14° 01´ S, 133° 15´ E, eye altitude 207.85 km, 1 April, 2016)

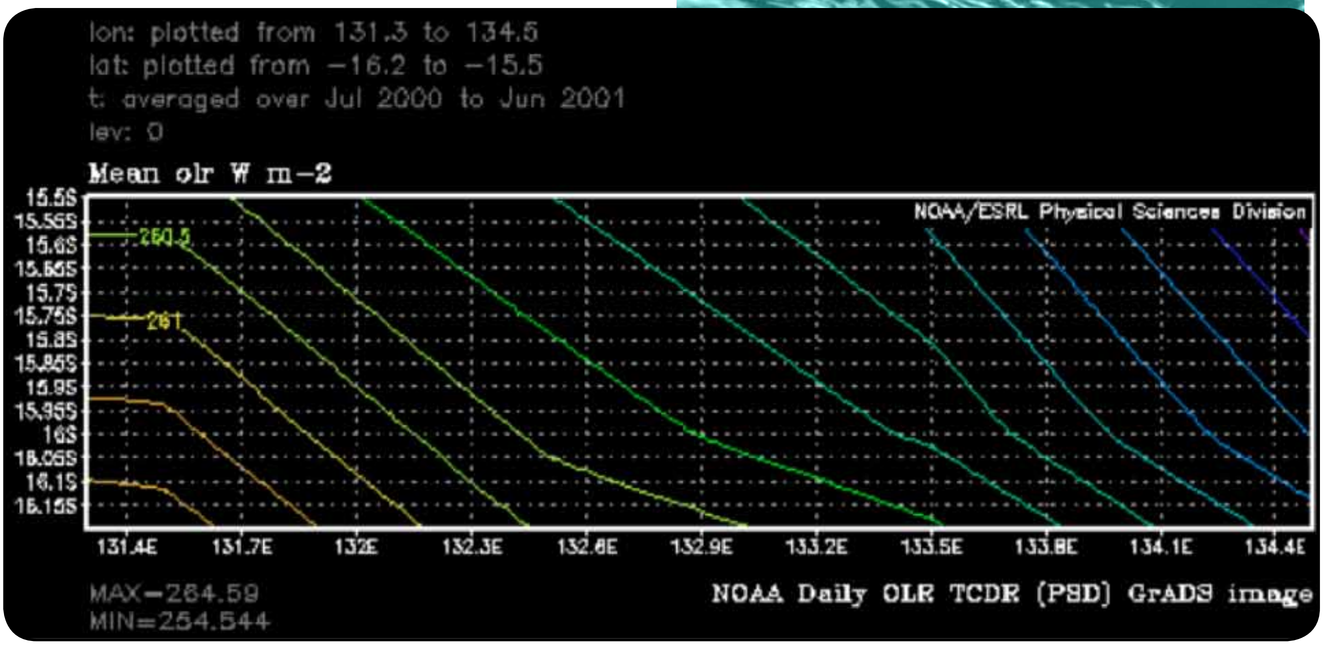
Table 1. Rainfall gauging stations in the AoI

Description	Gauge number	Record started	Elevation (m AHD)	Status	Gauge type	Missing data (%)	Latitude (°S)	Longitude (°E)
Mataranka Homestead	14610	1873	107	Open	Manual	21.2	14.46	132.26
Elsey	14623	1884	107	Closed	Manual	63.6	14.96	133.33
Larrimah	14612	1952	180	Open	Manual	9.1	15.57	133.21
Katherine Council	14902	1873	107	Open	Manual	57.6	14.46	132.26
Tindal RAAF	14932	1969	134	Open	Automatic	18.2	14.52	132.38
Gorrie Station	14638	1988	175	Open	Manual	12.1	15.53	132.65

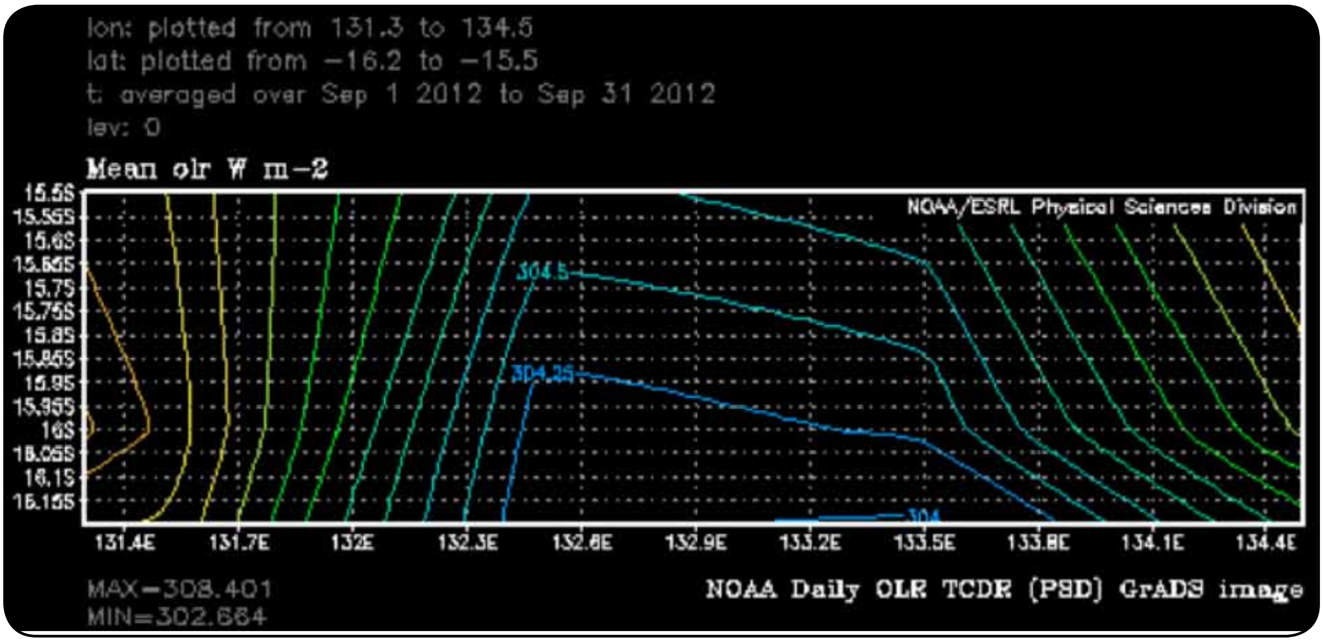
The missing rainfall data were projected by taking an average of the predicted rainfall data, based on the correlations obtained between the outgoing long-wave radiation (OLR, see Fig. 10) and mean minimum temperature with rainfall (Table 2).

A linear correlation between rainfall and OLR over the AoI was used to estimate rainfall when, and where, there were gaps in the BoM datasets.





(a) Roper region (July 2000 – June 2001, mean OLR (W m^{-2})



(b) Roper region (Sep. 2012, mean OLR (W m[-2])

Figure 10. Outgoing longwave radiation: Roper region (NOAA, 2016)

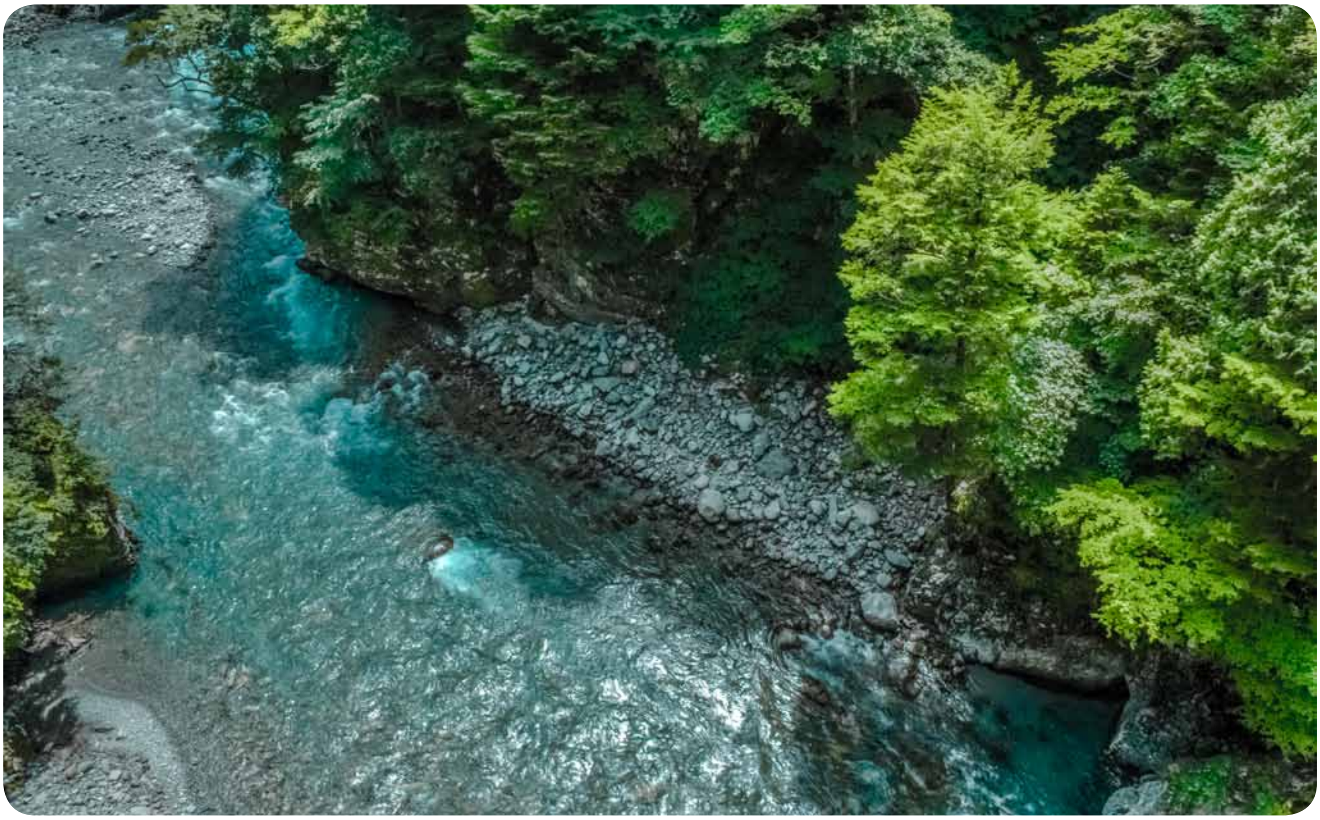


Table 2. Estimated annual average rainfall data

Description	Years with missing data	OLR-based rainfall (mm)	Temperature-based rainfall (mm)	Estimated average annual rainfall (mm)
Mataranka Homestead (14610)	1985-86	970	626	798
	1986-87	943	879	911
	1987-88	871	626	749
	1992-93	929	599	764
	1997-98	955	888	922
Elsey (14623)	1983-84	998	1010	1000
	1984-85	967	1020	992
	1985-86	970	865	918
	1987-88	871	637	754
	1988-89	979	1010	993
	1989-90	853	822	838
	1998-99	1060	841	949
	1999-00	1090	1340	1220
	2000-01	1100	852	976
	2002-03	868	1380	1120
	2004-05	926	549	737
	2005-06	1110	1700	1400
	2006-07	925	920	923
	2007-08	958	1090	1030
	2008-09	1020	775	899
	2009-10	950	915	933
	2010-11	1210	1010	1110
	2011-12	1010	1010	1110
	2012-13	-	1010	1110
	2013-14	-	1010	1110
	2014-15	-	1010	1110
Larrimah (14612)	2004-05	926	697	812
	2011-12	1010	775	892
	2012-13	-	709	709
Katherine Council (14902)	1984-85	967	720	844
	1985-86	970	972	971
	1986-87	943	943	943
	1991-92	893	767	838
	1992-93	929	983	956
	1997-98	955	872	914
	1998-99	1060	1240	1150
	1999-00	1140	1160	1130
	2000-01	1100	1240	1170
	2002-03	868	993	930
	2003-04	1030	1320	1180
	2004-05	926	729	827
	2005-06	1110	1280	1190
	2006-07	925	665	795
	2007-08	958	1120	1040
	2009-10	950	898	924
	2010-11	1210	1640	1420
	2013-14	-	1100	1100
	2014-15	-	883	883
Tindall RAAF (14932)	1988-89	979	919	949
	1989-90	853	1240	1050
	1990-91	960	1240	1050
	1991-92	909	1240	1050
	1992-93	929	1240	1050
	1993-94	926	1240	1050
Gorrie Station (14638)	1983-84	998	1010	1000
	1984-85	967	1010	987
	1992-93	929	689	809
	2007-08	958	594	776

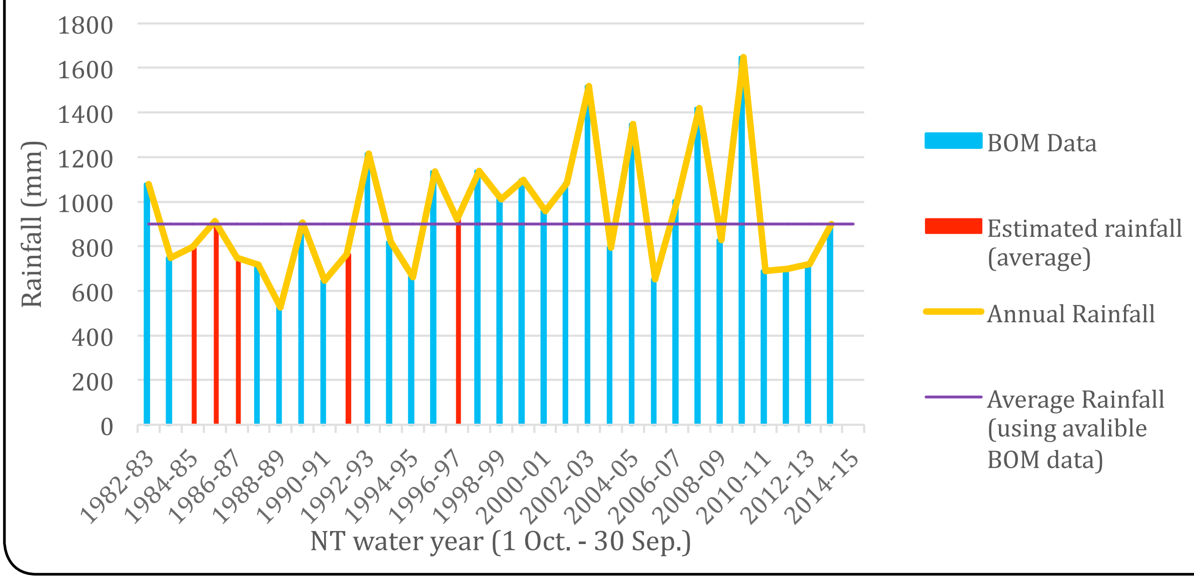


Figure 11. Mataranka Homestead rainfall data with omissions estimated.

The estimates in Table 2 represent the average predicted rainfall at each location for those years with missing rainfall data. Using the average rainfall from both the rainfall-OLR correlation and the mean minimum temperature-rainfall correlation enabled a potentially more accurate projected rainfall estimate. Figure 11 shows typical existing (BoM, Mataranka Homestead, gauge no. 14610) and estimated data (mean average of OLR-correlated, and daily minimum temperature-correlated rainfall) from 1983 to 2015, this being the closest site to the AoI.

2.2. Borehole Data

The effect of rainfall on borehole SWL, the site investigation, and permeability predictions from sparse data are now discussed. Each of the boreholes was located on Stylo Station within the AoI, which is approximately 5 km from Mataranka (as measured from the station homestead, Fig. 7). Table 3 summarises the key borehole data (note that no drill testing was conducted on rainfall days). All boreholes were advanced by air-lifting.

Table 3. Borehole test data

Registration no.	Yield (l s^{-1})	Completion SWL (m below GL)	Drill depth (m)	Duration (h)	Completed	SWL (m AHD)	Latitude	Longitude
37831	121.6	8.06	90.6	24	24 Jan. 2016	128.94	-14.942	133.081
37832	> 30	16.79	90.8	2	8 Sep. 2015	132.21	-14.950	133.081
37833	130.3	12.24	95.0	24	8 Feb. 2016	140.76	-14.956	133.089
37836	> 50	18.45	114	4	9 Sep. 2015	121.55	-14.964	133.100
37837	> 50	23.02	121	3	9 Sep. 2015	139.98	-14.967	133.093
37838	115.0	19.47	103	24	11 Feb. 2016	135.53	-14.953	133.076
37839	105.2	20.92	102	4	2 Apr. 2016	138.08	-14.962	133.088
37840	27.80	28.12	95.8	5	20 Oct. 2015	134.88	-14.971	133.086

Figure 12. Borehole 37831 - (a) Discharge during yield test - (b) Rock chip recovery

2.2.1. Site Investigation

On-site investigations where conducted to obtain the data required for this analysis, and to offer an alternative to relying entirely on projected data. Figure 12 shows a typical borehole drilling operation (Borehole Registration No. 37831) and the associated rock chip recovery.

Figure 13 shows no clear correlation between SWL and rainfall for the various locations across the Roper region; however local knowledge suggested a correlation in the Mataranka region. It is thought that no correlation was found in this analysis due to the lack of consideration of the following: rainfall variability and rainfall location with respect to the SWL across the catchment area, strata thickness and permeability, and the location of rainfall with respect to the surface cretaceous clay acting as a relatively impermeable cap to the TLA.

In a secondary attempt to determine this relationship, the number of days since rainfall was plotted against borehole SWL (Figure 14).

Although there was no clear relationship between rainfall frequency and a higher SWL (i.e., water found closer to ground level), a weak correlation was obtained for the cluster ringed in Figure 14. As a result of the sparsity of data and the inability to take into consideration the areal extent over which rainfall occurred, data projections were the best means of analysis available.

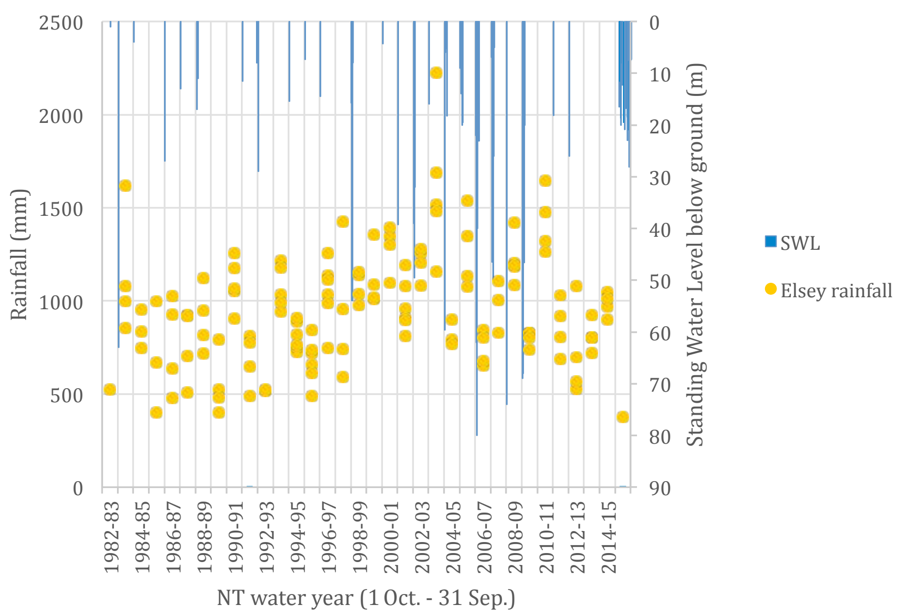


Figure 13. The effect of rainfall on SWL at locations across the Roper region (1982-2015)

2.2.2. Permeability Estimates

Information from boreholes 37831 to 37833, and 37836 to 37839 enabled estimates of permeability and stratification depths of geologic media to be made. The soil or rock with the lowest permeability for each of the geological strata was selected as the defining property for each of the strata, as water flows through the path of least resistance. The following permeability estimates (Table 4) have been assigned in accordance with published values for the relevant geologic media (Knappett & Craig, 2004; Blyth & de Freitas, 1984).

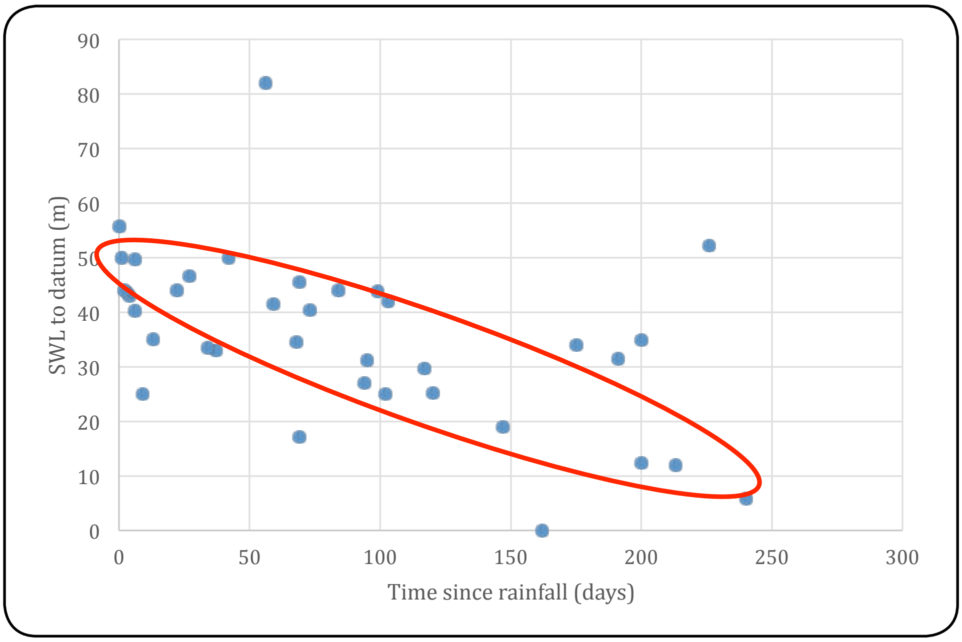


Figure 14. Relationship between SWL and Mataranka Homestead rainfall

The permeability estimates (Table 4) are values assigned as a lower bound thereto: as the most impervious geological components for each layer have been selected for the assessment, these values are, given the sparse data, the most realistic coefficients available with which assess the sustainability of abstraction from the TLA.

These lower bound values should not decrease if the geological medium remains unchanged: it was deemed unrealistic to identify an upper bound to the likely permeability as the founding cretaceous limestone is renowned for its fractures and cavities.

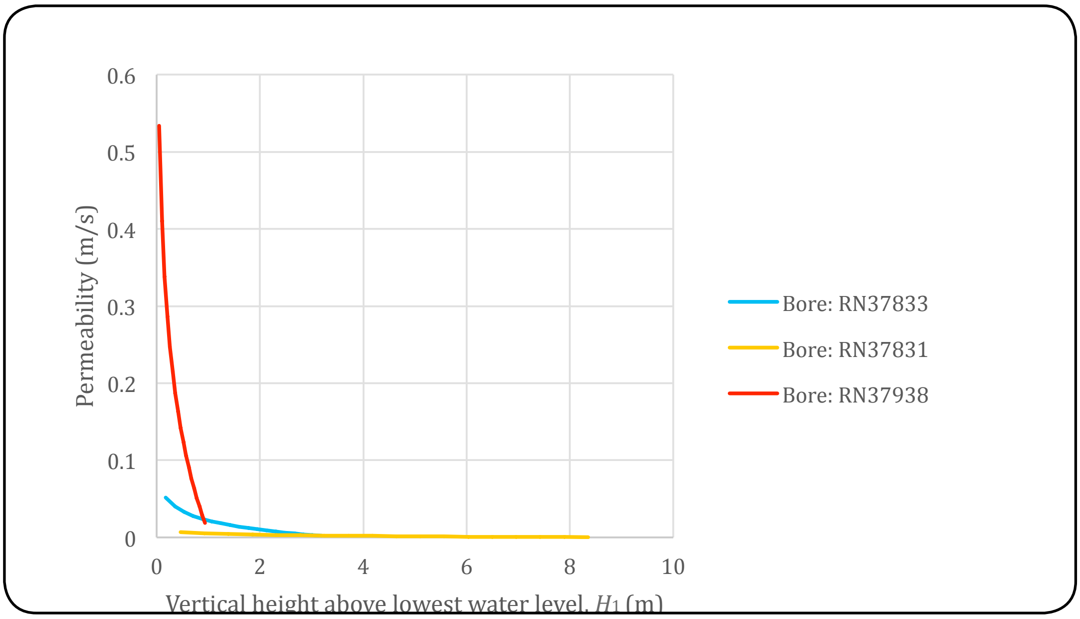


Figure 15. Vertical soil permeability around those bores subjected to yield testing.

The coefficients of permeability and stratification depths of the observed geologic media for the boreholes subjected to yield testing are shown in Figure 15.

As shown in Figure 15 a large variation in the estimated coefficients of permeability was identified between each of the borehole locations, all of which lay within a circle with a radius of c. 2 km.

Table 4. Estimated coefficients of permeability

Borehole registration no. (Yield (l s^{-1}))	Soil or rock types	Strata depth (m)	Estimated permeability (m s^{-1})
37831 (121.6)	Sandy topsoil	0 – 3	1×10^{-3}
	Laterite	3 – 8	1×10^{-5}
	Clay	8 – 18	1×10^{-9}
	Brown/grey limestone with clay and sand bands	18 – 37	1×10^{-7}
	White/grey limestone	37 – 50	1×10^{-9}
	Brown siltstone	50 – 54	1×10^{-10}
	White/grey limestone	54 – 57	1×10^{-9}
	Grey limestone	57 – 63	1×10^{-9}
	Dark grey limestone	63 – 88	1×10^{-9}
	Pink limestone	88 – 91	1×10^{-9}
37832 (> 30)	Topsoil	0 – 3	1×10^{-4}
	Clay	3 – 9	1×10^{-9}
	Sand	9 – 12	1×10^{-5}
	Sandstone	12 – 13	1×10^{-9}
	Clay	13 – 18	1×10^{-9}
	White/grey limestone with sand bands	18 – 30	1×10^{-7}
	Grey limestone	30 – 35	1×10^{-9}
	Grey/blue limestone	35 – 42	1×10^{-9}
	Blue limestone	42 – 45	1×10^{-9}
	Blue limestone with yellow clay stone	45 – 51	1×10^{-10}
	Blue/grey limestone with sand	51 – 60	1×10^{-6}
	Brown siltstone	60 – 68	1×10^{-10}
	Grey limestone	68 – 78	1×10^{-9}
	Dark grey limestone	78 – 83	1×10^{-9}
	Basalt	83 – 108	1×10^{-10}
37833 (130.3)	Topsoil	0 – 3	1×10^{-4}
	Brown clay	3 – 7	1×10^{-9}
	White clay	7 – 10	1×10^{-9}
	Red/purple clay	10 – 14	1×10^{-9}
	White limestone with banded siltstone/sandstone	14 – 45	1×10^{-8}
	White/grey limestone with broken bands/cavities	45 – 78	1×10^{0}
	Dark blue limestone	78 – 89	1×10^{-9}
	Red basalt/limestone with dark grey bands	89 – 97	1×10^{-9}
37836 (> 50)	Topsoil	0 – 3	1×10^{-4}
	Sandy clay	3 – 12	1×10^{-5}
	Red clay	12 – 19	1×10^{-9}
	Weathered limestone	19 – 42	1×10^{-6}
	White/grey limestone	42 – 68	1×10^{-9}
	Grey limestone	68 – 88	1×10^{-9}
	Pink/grey limestone	88 – 114	1×10^{-9}
37837 (> 50)	Sandy topsoil	0 – 9	1×10^{-4}
	Red clay	9 – 12	1×10^{-9}
	Brown/yellow clay	12 – 15	1×10^{-9}
	Brown clay	15 – 36	1×10^{-9}
	Weathered limestone clay/sand bands	36 – 60	1×10^{-6}
	White/grey limestone	60 – 93	1×10^{-9}
	Grey limestone	93 – 102	1×10^{-9}
	Black limestone	102 – 110	1×10^{-9}
	Red/pink limestone	110 – 121	1×10^{9}
37838 (115.0)	Sandy topsoil	0 – 6	1×10^{-3}
	Sandy clay	6 – 12	1×10^{-6}
	Sand	12 – 18	1×10^{-5}
	Clay	18 – 24	1×10^{-8}
	Weathered limestone	24 – 45	1×10^{-6}
	White/grey limestone	45 – 72	1×10^{-9}
	Grey limestone	72 – 86	1×10^{-9}
	Black limestone/basalt	86 – 97	1×10^{-9}
37839 (105.2)	Sandy topsoil	0 – 4	1×10^{-3}
	Sandy clay	4 – 21	1×10^{-7}
	Weathered limestone	21 – 41	1×10^{-6}
	White/grey limestone with yellow bands/siltstone	41 – 87	1×10^{-8}
	Grey/dark grey siltstone	87 – 103	1×10^{-10}

As an alternative method to predicting the coefficients of permeability for the corresponding geological strata and depths, Equation 1 was used (see Figure 16) to predict a family of curves from which estimated permeability k could be taken from borehole yield q as found during pumping-out tests:

$$k = \frac{q \ln\left(\frac{r_2}{r_1}\right)}{\pi\left(h_2^2 - h_1^2\right)}$$

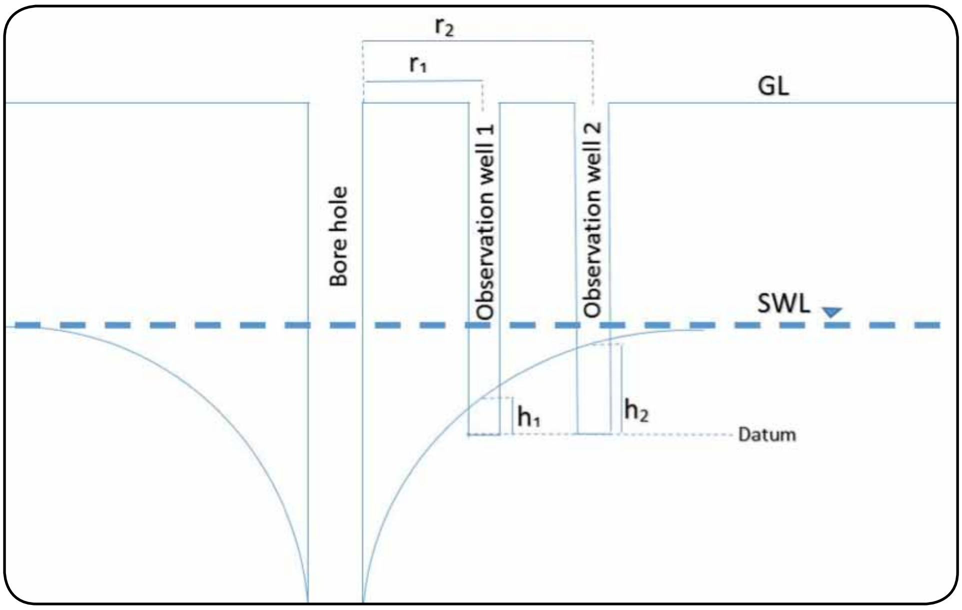


Figure 16. In situ pumping-out test used to determine the permeability

Figure 17 shows one of the predicted permeability curve families (borehole RN37831), in addition to the lower permeability limits for each borehole as previously discussed.

Using the 80:20 rule of thumb under which 80 % of groundwater is left to the environment and 20 % is therefore available for abstraction, the observed short-term yields from the boreholes, and the estimated permeabilities in the AoI, allows some understanding of the surrounding environment and its geological variability. Insufficient information was available for a meaningful groundwater flow model to be implemented: such is the nature of the problem in this relatively remote location. Suffice to say the borehole yield and water quality (see below) can be used to outline possible agricultural uses to which the land in the AoI may be put.

2.3. Water Quality

The alkalinity of 150 mg $CaCO_3$/L reflects the nature of the cretaceous limestone strata. The cretaceous limestone is rich in calcium carbonate which is gradually released under the influence of the carbonic acid in the recharging rainfall. Weathering, and therefore the release of calcium carbonate, is a slow process that occurs due to the infiltration of the rainfall recharge, however as little as approximately 8 % (Knapton, 2009) of the total aquifer recharge results from precipitation which implies a piecemeal nature to the deterioration of the limestone.

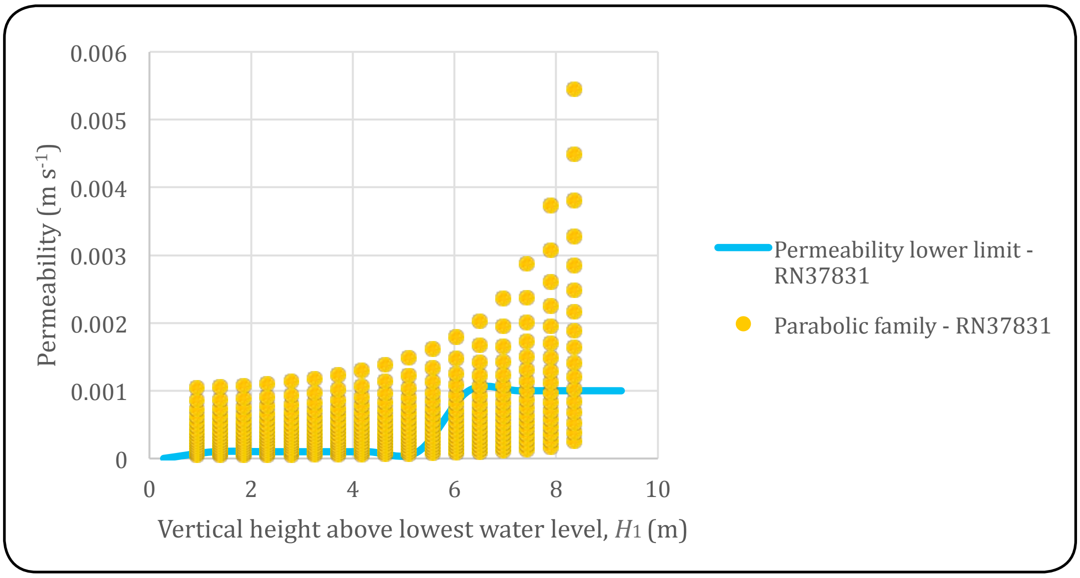


Figure 17. Estimated variation in permeability with depth (borehole 37831)

Table 5. Water quality data

Parameter	Value	Unit	Determination limit	Method reference	Analyte description
Alkalinity	150	mg $CaCO_3$/L	20	2320B	Alkalinity as mg $CaCO_3$/L
CO_3	< 10	mg/L	10	2320B	Carbonate
HCO_3	180	mg/L	10	2320B	Bicarbonate
OH	< 1	mg/L	1	2320B	Hydroxide
pH	7.16		2	4500-H+	Water pH
EC	1430	mS/cm	1.8	2510B/WCL06	Electrical conductivity
F	0.33	mg/L	0.1	WCL-03	Fluoride
Ca	122	mg/L	0.01	3120B	Calcium
K	16	mg/L	0.04	3120B	Potassium
Mg	48.6	mg/L	0.01	3120B	Magnesium
Na	124	mg/L	0.08	3120B	Sodium
Si as SiO_2	36.6	mg/L	0.043	3120B	Si as silica
S as SO_4	90	mg/L	0.12	3120B	S as sulphate
Total hardness	504	mg $CaCO_3$/L	1	3120B	Calculated from Ca & Mg
Total Fe	0.016	mg/L	0.01	3120B	Total iron
TDS 180	868	mg/L	1	WCL05	Total dissolved solids dried at 180 °C
Cl	143.6	mg/L	2	4500-Cl-D	Chloride
CL as NaCl	240	mg/L	3.3	4500-Cl-D	Cl as NaCl
NO_3	2.4	mg/L	0.1	WCL17	Nitrate by colorimetric flow analyser

Incidentally, Mataranka Township's water supply from the TLA meets Australian Drinking Water Guidelines (ADWG), and this same standard may be assumed (in the absence of evidence to the contrary) in the AoI.

3. FUTURE ECONOMIC DEVELOPMENT IN NORTHERN AUSTRALIA AND THE AOI

Research has identified the intensification of agricultural production in Northern Australia as providing some of the best opportunities for future economic development. This will require confidence in the availability of resources, an understanding of the risks involved and that products can be cost-effective and grown sustainably. Effective, efficient water management, from both a regulatory perspective, combined with end-user efficiencies, is an essential element in providing and embracing these opportunities for future development. A study conducted by the Northern Territory Government has revealed a range of potential horticultural crops suitable for cultivation given the data available from the AoI: this analysis was solely based on environmental conditions, soil types, and properties, with no financial consideration given. The AoI was rated as being of medium-high agricultural capability (Dasari, 1998). As of November, 2011 an analysis conducted by the National Water Commission concluded that only 5 % of the 20 % available water in the region was allocated (this is based on 80:20 rule guidelines, used in the Northern Territory where there is no declared WAP) (NTG, 2017). Although, as of October, 2016, there has been an increase in the amount of water allocated in the TLA, the increase in actual consumption has been minimal. As water consumption increases so does the amount of available data which enables an increase in accuracy of the assessment of the quality and quantity of water in the TLA. Additional data obtained from recent development in the Mataranka area highlights the abundance of water available for abstraction from the TLA.

This new information highlights the need to update model input data as it becomes available.

Table 6 shows the average water use for various horticultural, and agricultural, purposes and the estimated rturn (excluding consideration of expenses) per annum. Given that the agricultural sector plays a key role in the economic development of a region, an increase in agricultural output and productivity can contribute to the overall economic development of Northern Australia. It is imperative, when planning future agricultural development, that water resources are allocated efficiently and equitably and are used to achieve socially, environmentally and economically-efficient outcomes. Agriculture can also contribute positively to the hydrological cycle, for example through aquifer recharge and water purification.

Recognition of the complexity and diversity of water resource management is important: policies addressing water management need to reflect variability across different water basins due to varying climate, terrain, and land use. Future water planning needs to reflect these variations and become more decentralised to improve food security and efficient water use. Mechanisms such as water trading, incentives to improve water-use efficiency, and increased water monitoring, assist in lowering the cost and increasing the benefits to agricultural users of water. These mechanisms which can be driven by policy and water management plans, should encourage farmers to implement improvements in water productivity and the uptake of more efficient technologies such as drip irrigation.

To ensure a sustainable use of water in the TLA, it is essential to balance the needs of consumptive water users across the region with environmental needs and requirements. In the NT where WAPs have not been widely adopted (WAP areas only account for 160,005 km2, or 11.3 %, of the area of the NT), the 80:20 rule (80 % of the aquifer water left to the environment: 20 % abstracted) is generally adopted. The future challenge will be to ensure water resources used for agriculture are allocated among competing demands so as to: sustain the agricultural industry; produce more food; be energy efficient; minimise pollution; support ecosystems, and meet social and cultural aspirations. Future agricultural development in the AoI will require that more data be available to guide better policy-making, an improved knowledge of the connection between groundwater and surface water, to improve the accuracy of the sustainable amount of water available in the aquifer for development, and modelling to encourage future development with granted water allocations based on the 80:20 guidelines until water WAPs are formalised in undeclared areas.

Table 6. Crop water yield and estimated return per hectare

Product	Age at maturity	Water demand (ML ha^{-1} y^{-1})	Yield	Price (AUD per unit)	Return (AUD ha^{-1} y^{-1})	Comments
Avocado	Mature	9.6	15 t ha^{-1}y^{-1}	$12 – 24/tray	$45,000	c. 6 kg/tray 10.5 × 5 m spacing
Beef cattle	2 – 3 years	N/A	10 ha^{-1}y^{-1}	Ave.: $2.25/kg Steers: $4.29/kg	$7,200	Live weight prices Ave., 320 kg/head
Banana	Mature	19.6	Lady fingers (irrigated): 500 – 750 cartons ha^{-1}y^{-1}	$25/carton	$15,625	Lady fingers: c. 12 kg/carton
Cavalcade (hay)	Wet season crop (supplementary irrigation)	3.1	600 – 1000 kg ha^{-1}y^{-1}	$145.20 t^{-1}	$36,160	Jan. – May
Citrus	Mature (5+)	9	2500 – 3000 cartons ha^{-1}y^{-1}	$22.25/carton	$61,188	8 × 4 m spacing
Forage (sorghum/millet)	Dry season April sow	10.5	Sorghum (irrigated): 7 – 10 t ha^{-1}y^{-1} Sorghum (dry land): 2 – 6 t ha^{-1}y^{-1} Forage crops: 7 – 15 t ha^{-1}	Sorghum: $270 t^{-1} Forage crops: N/A	Sorghum: Irrigated $2,295 Dry land $1,080	4 months' hay-making
	May sow	10.7				5 months' hay-making
Lawn	Dry season	3.9 (0.5 ha)	N/A	N/A	N/A	Domestic
Luciana	1	2.1	N/A	N/A	N/A	No grazing
	2	4.1	Periodic heavy grazing			Grazed
	3	6.7				

Lucerne	Dry season	10.3	Irrigated: 2 – 2.5 t ha^{-1}/ cut (c. 7 – 8 cuts/y) Dry land: 1 – 2 t ha^{-1}/cut	A1: $8.50/bale B2: $6.50/bale C3: $4.00/bale	A1: $2,856 B2: $728 C3: $448	A1: c. 48 bales ha^{-1} B2/C3: c. 16 bales ha^{-1} 6 months' hay-making
Mahogany	1	1.3	N/A	N/A	N/A	4 × 2 m spacing
	2	2.6				
	3	2.8				
Maize	Apr. - Aug	5.8	8.3 t $ha^{-1}y^{-1}$	$191.90 ha^{-1}	$191.90	
Mangoes	1	0.3	5 – 6.5 t $ha^{-1}y^{-1}$	$3,000 t^{-1}	$17,250	10 × 5 m spacing
	2	0.9				
	3	2.0				
	4	3.1				
	5	4.8				
	6	7.4				
	Mature (7+)	8.6				
Melons	Mar. - May	2.9	Rockmelon: 1800 trays Honeydew: 2000 trays	Rockmelon: $14.65/tray Honeydew: $16.45/tray	Rockmelon: $26,370 Honeydew: $32,900	
	Apr. – June	2.9				
	May – July	3.0				
	June – Aug.	3.4				
	July – Sep.	3.8				
	Aug. – Oct.	4.5				
	Sep. – Nov.	3.8				
Nursery/ shade house	-	1.74 (0.1 ha)	N/A	N/A	N/A	
Onions	Apr. – Aug.	5.4	30 t $ha^{-1}y^{-1}$	$1,100 t^{-1}	$33,000	1.5 m beds 0.4 m wheel track
	May – Sep.	5.9				
Papaya	-	18.5	75 t $ha^{-1}y^{-1}$	N/A	N/A	3.5 × 1.5 m spacing
Peanuts	Mar. – Aug.	7.2	Irrigated: 5 – 7 t $ha^{-1}y^{-1}$ Dry land: 1.3 – 3.2 t $ha^{-1}y^{-1}$	$750 t^{-1} (in shell)	Irrigated: $4,500 Dry land: $1,650	
	Apr. – Sep.	7.5				
	May – Oct.	8.8				
	May – Nov.	10.1				
Potatoes	16 weeks	4.7	35 – 40 t $ha^{-1}y^{-1}$	$620 – 670 t^{-1} (unwashed)	$24,188	
	18 weeks	5.8				
	20 weeks	6.9				
Pumpkin	Apr. – July	4.8	18 t $ha^{-1}y^{-1}$	$382 t^{-1}	$6,876	
	May – Aug.	5.2				
	June – Sep.	5.8				
	July – Oct.	6.8				
	Aug. – Nov.	6.6				
Rhodes grass	Dry season	12.3	Mar. 9.9 t $ha^{-1}y^{-1}$	$85/bale (21 – 25 kg/bale)	$36,587 $19,196	7 months' hay-making
			June 5.42 t $ha^{-1}y^{-1}$			
Soy beans	May – Sep.	6.7	Irrigated: 2 – 4 t $ha^{-1}y^{-1}$ Dry land 1 – 2 t $ha^{-1}y^{-1}$	$600 t^{-1}	Irrigated: $1,800 Dry land: $900	
Squash	May – July	4.1	20.51 t $ha^{-1}y^{-1}$	$10,300 ha^{-1}	$10,300	1.8 m × 1.2 m spacing
	June – Aug.	4.4				
	July – Sep.	5				
	Aug. – Oct.	5.8				
	Sep. – Nov.	5.6				

4. SUMMARY

An assessment of the capacity and sustainability of the TLA has been attempted, through the use of the neoteric data and analysis herein. The testing of boreholes yielded up to 130 L s-1, exceeding all prior modelled yield projections (in the face of sparse data) in the Mataranka region. The difference between the practical measurements and the modelled projections (Karp, 2008) highlight the importance of in-depth, extended data sets: any groundwater model is only as reliable as its input data. The Cambrian Limestone Aquifer System comprises the Daly basin, Georgiana basin, and the Wiso basin, which converge over the Tindall aquifer. The flow between the Daly basin and the Georgina basin results in the unusual underground mixing of waters between basins in the surrounding Mataranka area.

These results indicate that further assessments need to be conducted to ensure that water resources are allocated equitably among competing demands, so as to: sustain the agricultural industry; produce more food; be energy efficient; minimise pollution; support ecosystems, and meet social and cultural aspirations. It is imperative to maintain the integrity of the natural environment and ecosystems in the region while maximising its economic development.

Assessments of the interpretation and a coupled understanding of the ground and surface water regimes in the TLA need to be the focus of future research. Ensuring efficient, effective water planning in the Top End of the NT depends upon the understanding of the TLA.

5. POLICY RECOMMENDATIONS

Additional research and analysis are recommended to obtain more evidence (from site investigations), which allows analysis to be based on data rather than numerical projections. Additional data collection in the AoI is essential to further understanding the groundwater systems and their interaction with the surrounding environment. Data collection in the form of borehole testing (investigating water quality, yield, and spatio-temporal variability), accredited Bureau of Meteorology weather stations, river gauging stations, and soil testing (investigating soil classification and material properties) would be beneficial in understanding the TLA and its interactions with the surrounding environment.

Further investigation of the annual recharge of the TLA, and its origins is essential, with a particular focus on recharge via sinkholes. Although it is known that sinkholes provide significant recharge, to date there is little knowledge regarding their role and effect on the aquifer.

It is also necessary that legislation evolves to reflect the desire for a sustainable environment, while ensuring maximised water usage, in its most lucrative form.

Extraction of water resources by consumptive users has the potential to play an important role in the economic development of the Mataranka region, so it is imperative that a balance between the environment and development is maintained.

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Charlie Fairfield, is a Chartered Engineer and holds the Power and Water Corporation Chair in Sustainable Engineering at Charles Darwin University. He is embedded within Power and Water's Water Services Division where he collaborates on research into projects ranging from asset management to irrigation and sewer design. He has worked as a consultant to the civil engineering industry for over 20 years, and also works on a variety of projects here, in Indonesia, and Timor-Leste. He is a member of the AWA and a Fellow of The Institution of Engineers Australia.

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REFERENCES

Australian Bureau of Statistics (2016) Agricultural Commodities, Australia (2014-15). Catalogue no. 7121.0, ABS, Canberra.

Blyth FGH & de Freitas MH (1984) A Geology for Engineers. 7th Edition, Arnold, London, pp. 12 & 218.

CSIRO (2009) Water in the Gulf of Carpentaria Drainage Division. A report to the Australian Government from the CSIRO Northern Australia Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, Australia, p. 18.

Dasari NR (1998) Potential horticultural crops for Mataranka area. Pers. Comm. Northern Territory Government, Department of Primary Industry & Fisheries, Berrimah Farm, 5 Aug. 1998.

DLRM (2011) Northern Territory Groundwater Stocktake. Technical Report 31/2011D, Northern Territory Government, Department of Land Resources Management, Palmerston. Available at: http://www.territorystories.nt.gov.au/bitstream/handle/10070/247395/Northern_Territory_Groundwater_Stocktake_WRD11031.pdf?sequence=1. Last accessed: 14 March, 2017.

DLRM (2016) Katherine Water Allocation Plan. Available at: https://landresources.nt.gov.au/water-resources/water-allocation-plans/katherine-water-allocation-plan. Northern Territory Government, Department of Land Resources Management, Palmerston. Last accessed: 14 March, 2017.

Karp D (2008) Surface and groundwater interaction in the Mataranka area. Technical Report No. 17/2008D, Water Resources Branch, Northern Territory Government, Department of Natural Resources, Environment & The Arts, Palmerston.

Knappett JA & Craig RF (2004) Craig's Soil Mechanics. 8th Edition, Spon Press, London, p. 41.

Knapton A (2009) Gulf Water Study: an Integrated Surface – Groundwater Model of the Roper River Catchment. Part C: FEFLOW Groundwater Model. Technical Report No. 31/2009D, Northern Territory Government, Department of Natural Resources, Environment, The Arts & Sport, Water Resources Branch, Palmerston.

Ladson A (2008) Hydrology: an Australian Introduction. Oxford University Press, Melbourne.

NOAA (2016) Earth System Research Laboratory ESRL: PSD: Visualize NOAA Daily OLR TCDR (PSD) Data. US Department of Commerce, National Oceanic & Atmospheric Administration, Boulder, Colorado. Available at: http://www.esrl.noaa.gov. Last accessed: 14 March, 2017.

NTG (2017) Water Allocation Plan for the Tindall Limestone Aquifer, Mataranka – Daly Waters. Northern Territory Government, Department of Environment and Natural Resources, Palmerston.

Tickell SJ (2007) Daly Basin Aquifers. Northern Territory Government, Department of Natural Resources, Environment, The Arts & Sport, Water Resources Branch, Palmerston.