Appendix Y- Summary of CloudGMS Groundwater Modelling Study Singleton Station (CloudGMS, 2017).

1. Groundwater modeling

FAFM engaged CloudGMS in 2017 to develop a suitable groundwater model to facilitate the local, site-specific bore field planning and assess the regional impacts on groundwater levels in the aquifer systems of the Western Davenport region due to groundwater extraction at Singleton Station.

Scope

The objective of the Singleton groundwater model was to provide a basis for evaluating:

- the local impacts of various pumping geometries for bore field planning to;
  - optimise bore spacing for good yield and minimum interference between bores (managing overall drawdown and pumping efficiency);
  - indicate likely bore depths, including pumping from different aquifers; and
  - examine drawdowns over different time periods – e.g. 5 yrs, 15 yrs, and 30 yrs
  - examine water table recovery once pumping ceases
- the regional impacts of the proposed pumping to demonstrate:
  - impacts to groundwater levels that will occur at groundwater dependent vegetation (GDV) sites identified by the DENR;
  - the impacts on adjacent users.

Modeling approach

The existing groundwater flow model of the Western Davenport Plains (WDP) aquifer system used by DENR for water resource assessment purposes was constructed by CloudGMS using the MIKESHE platform. The model was designed to examine regional catchment scale processes / water balances and was not designed to examine in detail the local pumping effects related to parameters such as small-scale changes to bore field geometry.

To provide a suitable platform to examine the local-scale performance and the regional impacts of the proposed Singleton Station bore field, a regional scale FEFLOW groundwater flow model with local refinement around the proposed pumping bores at Singleton Station has been developed. The Singleton FEFLOW groundwater model was developed in accordance with the Australian Groundwater Modelling Guidelines (Barnett et. al., 2012).

The main advantage of FEFLOW is its capacity to incorporate local refinement where detail is required whilst also enabling coarse mesh where detail is not required. Using this approach, the groundwater model will have the capability to inform bore field geometry and operational practices, by estimating the effects of different extraction regimes within the modeled aquifer area. It will also be capable of examining regional impacts on existing groundwater users and also examine cumulative impacts associated with existing and proposed future users.

The FEFLOW model geometry, layering and material properties are consistent with the existing WDP MIKESHE model (CloudGMS, 2017). The FEFLOW model has been benchmarked against the WDP MIKESHE using a notional development scenario at Singleton (SC4). SC4 considered stock and domestic use, current full entitlements and new applications (including developments on Singleton Station and Neutral Junction) cumulative impacts to the WDP groundwater system associated with existing and proposed future users.

Figure 1 below shows the existing observation sites which were used in the groundwater modelling.

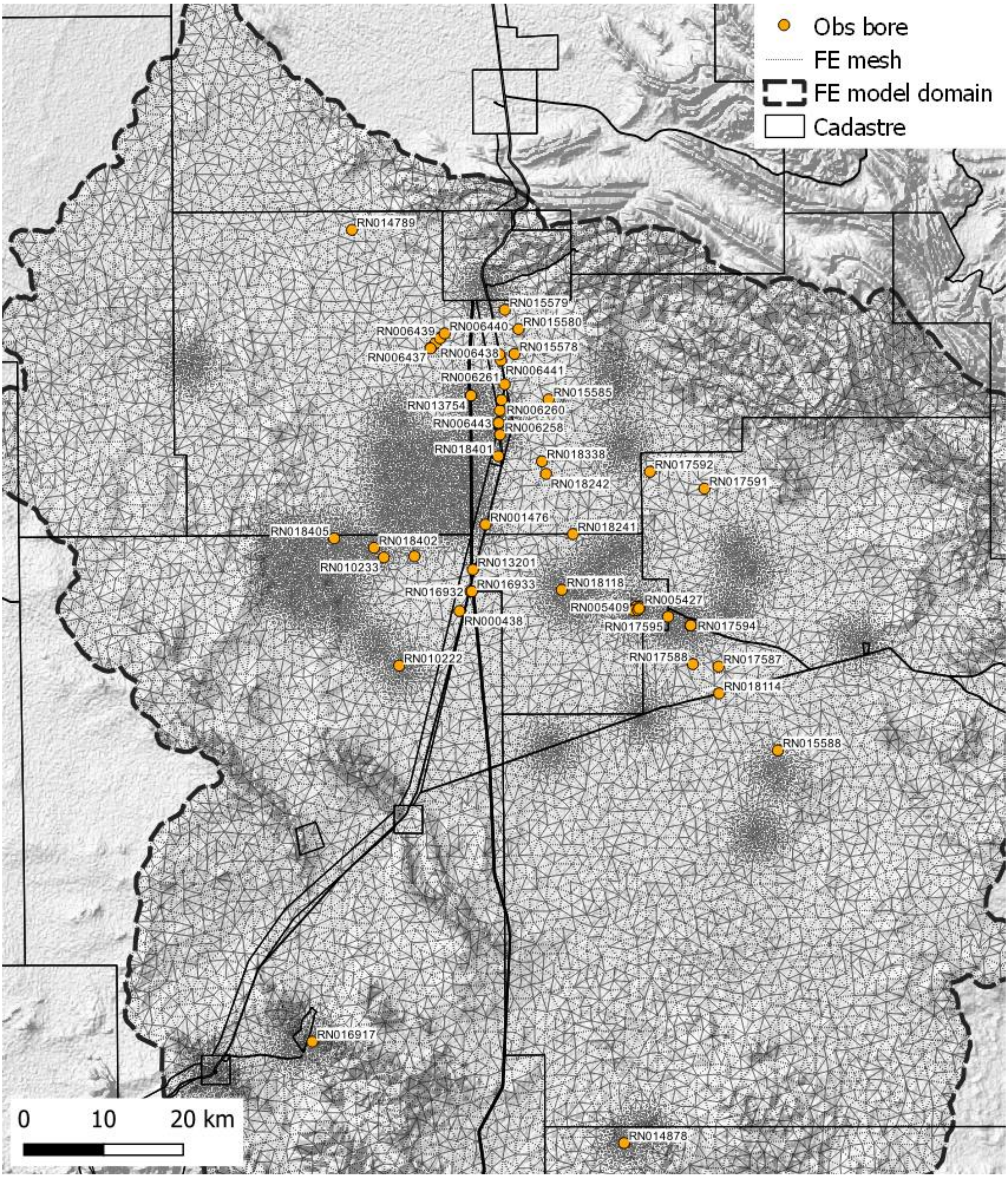

Figure 1 *Observation sites used in the groundwater flow model*

Figure 2 below shows a cut-away section of the groundwater flow model showing the layer geometry and inset of the proposed bore field showing the layering representing the Cenozoic, the 10 metre thick weathered Cambrian sediments and Arrinthrunga Fm.

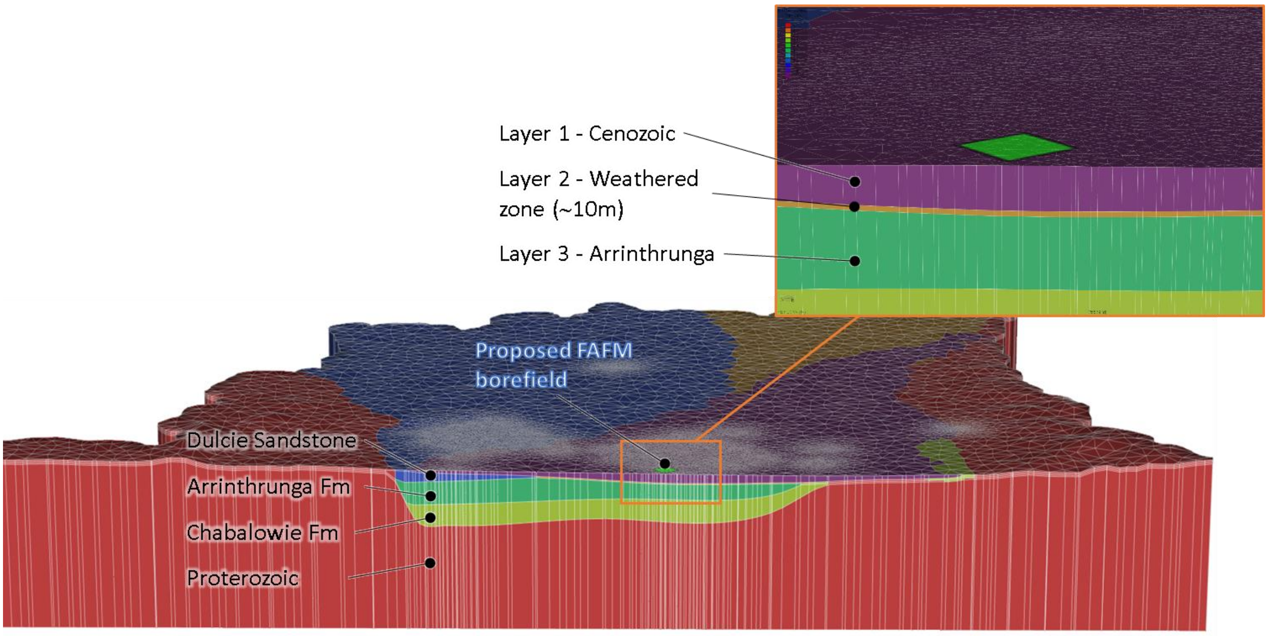

Figure 2 *Cut-away section of the groundwater flow model showing aquifer geometry*

1.1 Bore field geometries

CloudGMS then modelled a range of different scenarios, representing different bore field configurations, moving from a single bore field located in the south east corner, bordering the train line (SC4), to separate bore fields in the southern part of the property. The basis for the chosen bore field SC 28 shown in Figure 3, is described in Section 1.2 of this report.

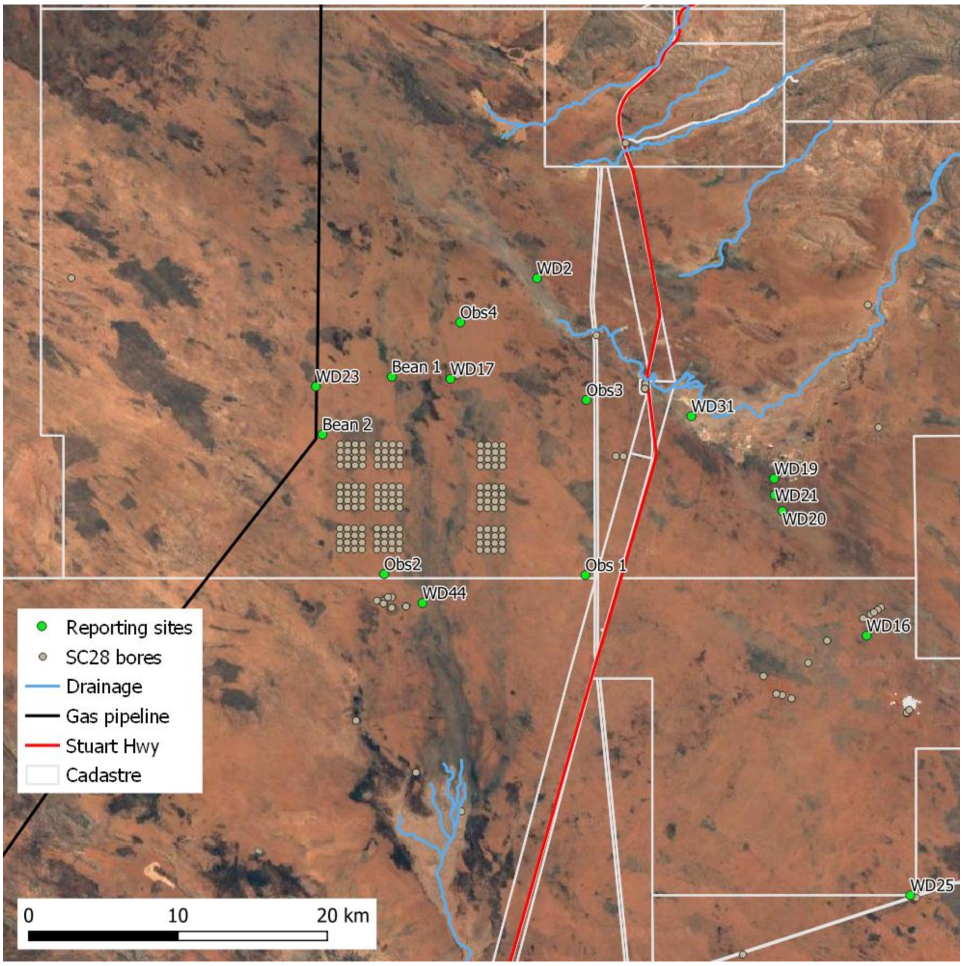

Figure 3 *Geometry of chosen bore field SC28.*

1.2 Aquifer properties, water quality and bore yield

Aquifer Properties

The characteristics of the aquifers which underlay Singleton have been obtained from:

– Land and Water Resources of the Western Davenport Plains General Summary Report (Ride G 2007);
– Assessment of Groundwater Resources in the Western Davenport Plains Water Control District (Hydro Tasmania Consulting 2009);
– Water Allocation Plan – Western Davenport Water Control District 2011-2021; and
– Water Allocation Plan – Western Davenport Water Control District 2018-2021.

As noted above, there are three hydrogeological distinct environments within the District and Singleton overlies two of them. However the Central Plains Management Zone is relevant to this project and groundwater pumping will take place from aquifers underlying this zone.

Singleton Station is located above two large regional aquifers which underlie the central sandplains of the District and trend north west to south east. These regional aquifers comprise:

– Cainozoic aquifers – calcrete, sand and sandstones, silt and clay, Quaternary gravel. Shallow, multiple, semi confined aquifers occur across much of the area.
– Cambrian sedimentary aquifers – Arrinthrunga and Chabalowie Formations comprising limestone, minor sandstone, dolostone and dolomitic sandstone. Deep, semi confined, fractured and weathered, some intergranular porosity, regional extent.

Groundwater flow through the basin is generally from south-east to north-west. There are no known major aquitards within the basin and ground water is assumed to flow between aquifers.

The large regional bedrock aquifers are recharged locally by rainfall runoff from the Davenport Range whilst the shallower aquifers receive recharge directly from incident rainfall and seepage through watercourses such as Taylor Creek run-out. The shallow Cainozoic aquifers appear to be generally in hydraulic contact with the deeper Cambrian aquifers. A significant groundwater level response occurs after high rainfall events and is followed by a slower decline in water levels. Indications are that high rainfall recharge events are infrequent, typically occurring every 35 years. A summary of some pertinent characteristics is given below:

– According to the current WAP, the total aquifer storage in the Central Plains zone is estimated at 138,314,200 ML.
– Thickness of Cainozoic aquifers generally ranges between 5 and 65 m although can be up to 100m. Deeper Cambrian aquifers are estimated to be an average of 150 m in thickness ranging between 20 m at the foot of the Davenport Ranges and 300 m in the south west;
– Water is likely to be encountered on average at 10 m to 30 m below the ground surface and the typical water table under Singleton is between 8m and 20m below the surface;
– Groundwater levels can increase by up to 12 m following major rainfall events but are otherwise in steady decline between recharge events;

Additional aquifer parameters were obtained from the MIKESHE model (CloudGMS, 2017) for the purpose of groundwater flow modelling. These parameters are presented in Table 1 below.

Table 1 Saturated zone hydraulic parameters

Name	Zone	Kh	Kv	Sy	Ss
		(m/d)	(m/d)		
Cenozoic	1	1.83E+00	4.70E-01	4.00E-02	1.00E-04
Dulcie / Lake Sup	2	8.23E-01	8.23E-02	4.00E-02	1.00E-05
Arrinthrunga Fm	3	7.47E-01	7.47E-02	4.00E-02	1.00E-05
Chabalowie Fm	4	1.85E+00	1.85E-01	4.00E-02	5.00E-06
Basement	5	1.00E-02	1.00E-02	1.00E-02	1.00E-06

Water Quality

Salinity Levels

The level of salinity in irrigation water is measured in total dissolved salts (TDS) or electrical conductivity (EC) where TDS (mg/L) = 0.68 x electrical conductivity (μS/cm). High levels of soluble salts can induce physiological drought in the plant. Plant roots may have an adequate water supply but are unable to absorb the water due to osmotic pressure.

The Australian Water Quality Guidelines for Fresh & Marine Waters (ANZECC 1992), are shown in Table 6-3. Central Australia is characterised by higher aquifer salinity levels than more northern regions, however the Western Davenport Region is generally lower compared to other areas in Central Australia as illustrated in Figure 4.

Table 2 ***General guidelines for salinity of irrigation water (ANZECC 1992)***

TDS mg/L	Electrical conductivity (μS/cm)[1]	Salinity class
0-175	0–280	Low
175-500	280–800	Medium
500-1,500	800–2,300	High
1,500-3,500	2,300–5,500	Very high
>3,500	> 5,500	Extremely high

Table 3 below presents the TDS levels measured at a selection of registered groundwater bores (identified on Natural Resources Maps, Department of Environment and Natural Resources) distributed throughout Singleton. Water from most of the selected bores is rated as having "high" salinity levels as per the guidelines, although many of the samples would be suitable for a variety of horticulture.

Table 3 ***Typical Total Dissolved Solids (TDS) at site***

Registered bore number	Area	TDS (mg/l)	Salinity class
RN002046	Singleton	450	Medium
RN002050	Singleton	780	High
RN015582	Singleton	810	High
RN002051	Singleton	850	High
RN015583	Singleton	900	High
RN014519	Singleton	1070	High
RN002048	Singleton	1184	High
RN006437	Singleton	1240	High
RN002047	Singleton	2040	Very High
RN002049	Singleton	2690	Very High

In general, the freshest bore water of the Western Davenport region is encountered in the southeastern quadrant of Neutral Junction, the western and northern areas of Murray Downs and over much of Singleton. Across the Central Plains it is estimated that "the quality is better than 1,500 mg/l within an area of 4,000 km^2 and better than 1,000 mg/l within 2,000 km^2". Also, "In the deep aquifer, the salinity gradually increases with depth" (Ride G 2007).

More recently Geoscience Australia sampled groundwater at several sites on and near Singleton Station, with the hydrochemistry water quality values presented below in Table 4. It should be noted that, of the five bores sampled and tested:

– Bore RN019452 is screened at a depth of 230 m to 240 m which is more than 100 m deeper than any planned bore screening for irrigation at Singleton. Salinity is known to increase with depth.

[1] TDS (mg/L) = 0.68 x electrical conductivity (μS/cm)

– Bore RN019454 is at least 10 km north of the proposed bore field

These two bores have significantly higher TDS than the other sampled bores.

Bores RN019453 and RN019457 are located close to the proposed bore field and Bore RN019457 in particular is considered to best represent the water chemistry that can be expected from the Singleton bore field.

Table 4 Hydrochemistry values from water sampling by Geoscience Australia

RN		RN 019452	RN 019453	RN 019454	RN 019457	RN 019041
TDS	mg/L	2182	1095	1545	943	702
EC	uS/cm	3460	1631	2410	1464	1198
pH		6.99	7.09	7.23	7.49	7.21
Alkalinity HCO_3 equiv.	mg/L	294	252	336	207	194
Bromide	mg/L	3.46	1.15	1.68	1.02	0.71
Chloride	mg/L	856	260	416	220	149
Fluoride	mg/L	<1.00	0.76	1.67	0.92	1.54
Sulfate	mg/L	270	154	201	136	56
Silicon	mg/L	11	28.7	21.3	33.2	40.6
Calcium	mg/L	102	43	60	30	20
Magnesium	mg/L	102	36	66	29	32
Sodium	mg/L	380	212	254	208	126
Potassium	mg/L	99	52	113	32	39

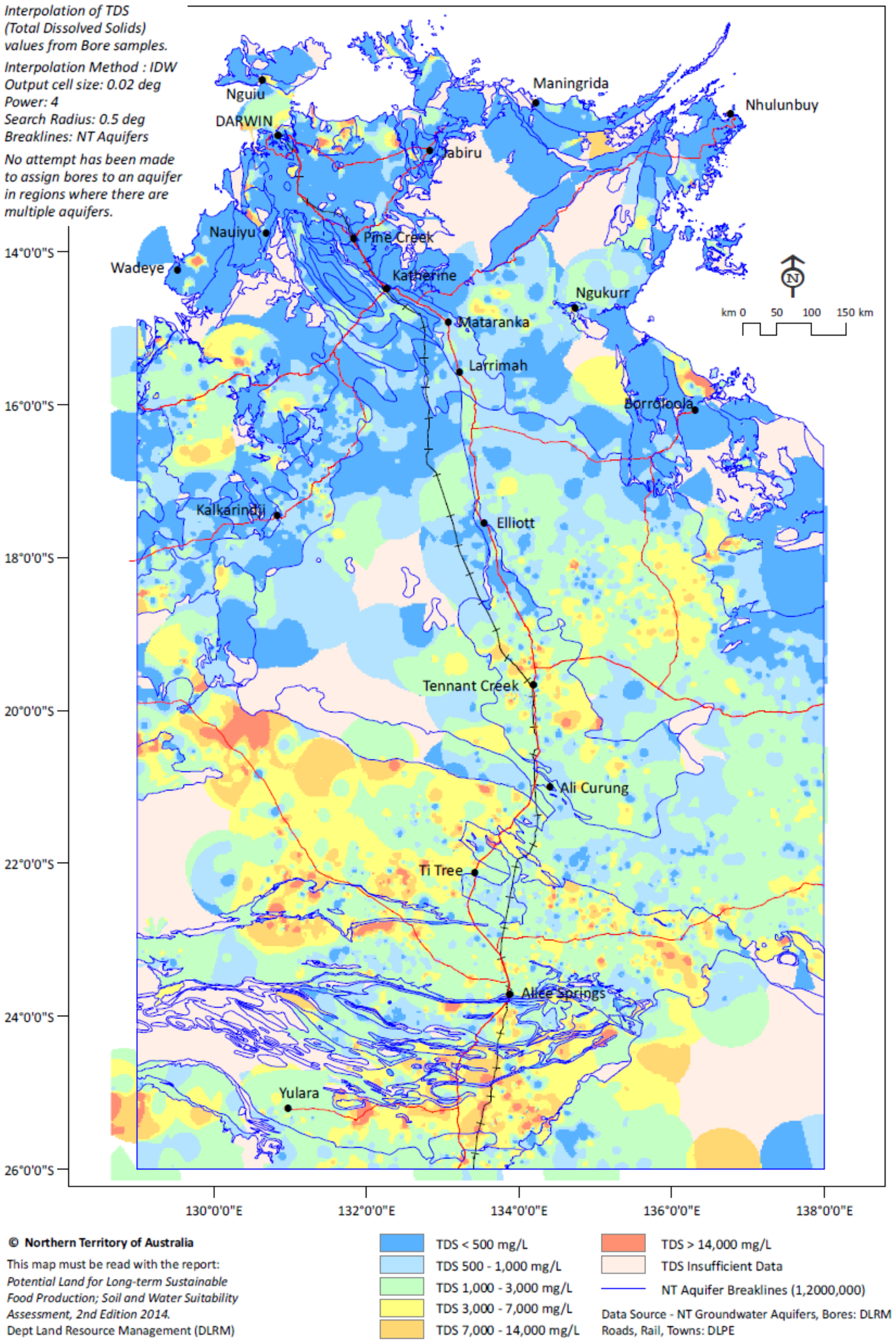

Figure 4 Aquifer salinity

Bore yields

The Singleton area contains 52 bores (of which 15 are classified as production bores with various water uses). None are classified as irrigation bores. There are irrigation bores on Neutral Junction Station which are producing fodder under pivot irrigators, and also near Ali Curung on a watermelon farm.

A summary of bore yield for different water uses is provided in Table 5 and is based on the records held by the Department of Environment and Natural Resources. It is understood that the reported borehole yields are based on test-pumping over relatively short time periods. Also, bore yields within the same aquifer have been found to be quite variable. Therefore, an interpretation of the reported yields as a continuous bore yield achievable across extensive areas of the study area carries significant uncertainty. Figure 5 illustrates the variability of bore yield across the area although some of this variability is due to different bore depths which access different aquifers.

Average bore yield of non-irrigation bores across the Neutral Junction, Murray Downs and Singleton areas is 2 to 3 l/s with a maximum bore yield of 20 l/s. These would mostly be stock bores and not constructed for large yields. There are clusters of higher yielding bores that have been drilled for the purposes of irrigation supply and have an average bore yield of 20 to 24 l/s with a maximum bore yield of up to 40 l/s.

Comparing the bore yield records with previously reported information it is concluded that shallow aquifers are likely to have highly variable bore yields of up to 10 l/s. The deep, high yielding, regional aquifers consisting of fractures and limited porous zones in limestone, conglomerate and sandstones are likely to yield upwards of 20 l/s. Whilst localised, low yielding, minor aquifers will have yields generally less than 1 l/s.

The analysis in this report has assumed a pump rate of 15 l/sec.

The average completed depth of irrigation bores across all areas is between 80 and 90 m below ground surface and the average depth to water is in the order of 10 to 20 m.

Table 5 Summary of bore characteristics

Land Parcel	Number of bores		Yield (l/s)	Depth to water (mbgl)			Completed bore depth (mbgl)	
	Irrigation production bores	All other bores	Irrigation production bores	All other bores	Irrigation production bores	All other bores	Irrigation production bores	All other bores
Singleton (average yield)	15	37	15	5	10	7	77	37
Singleton (Maximum yield)	15	37	40	17	23	29	193	76

Note: Singleton station cluster assumed to be for purposes of irrigation

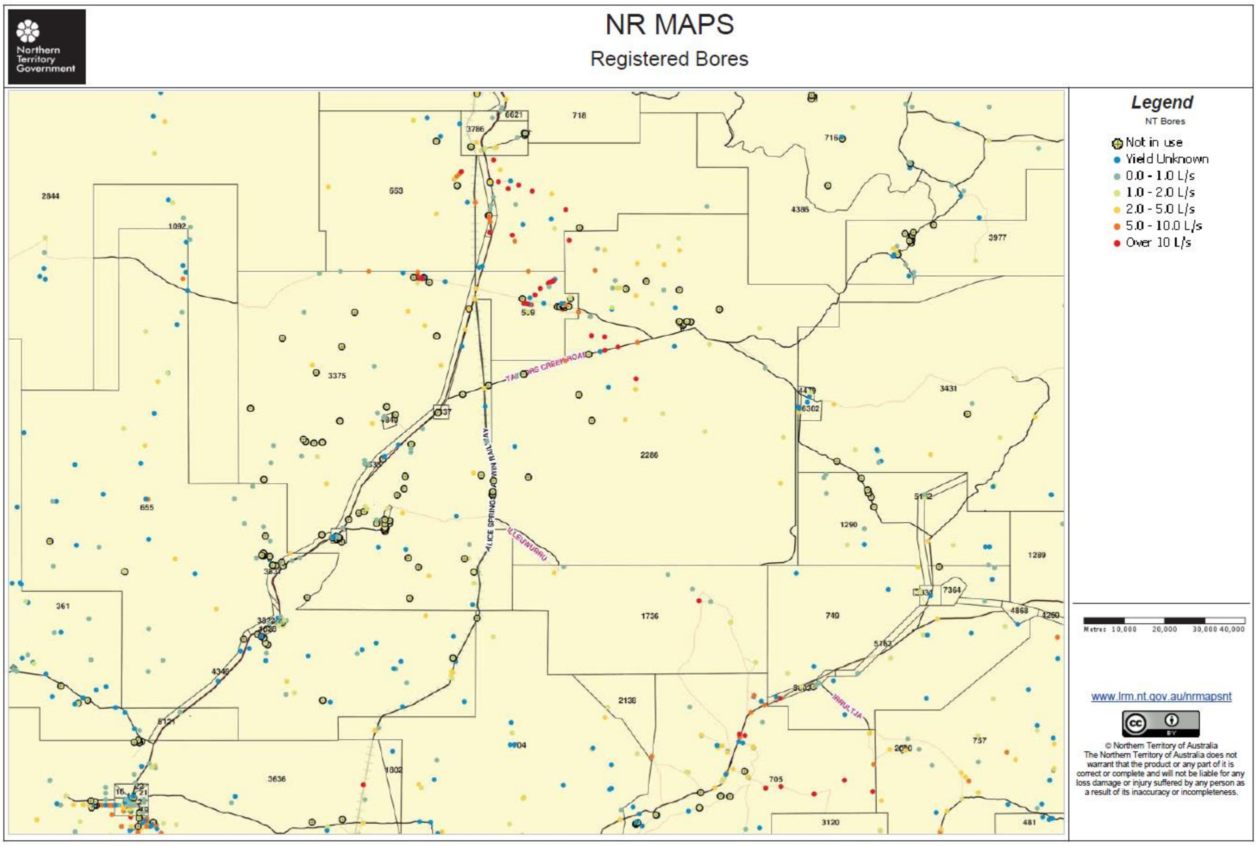

Figure 5 *Registered borehole locations (Department of Environment and Natural Resources, 2015*