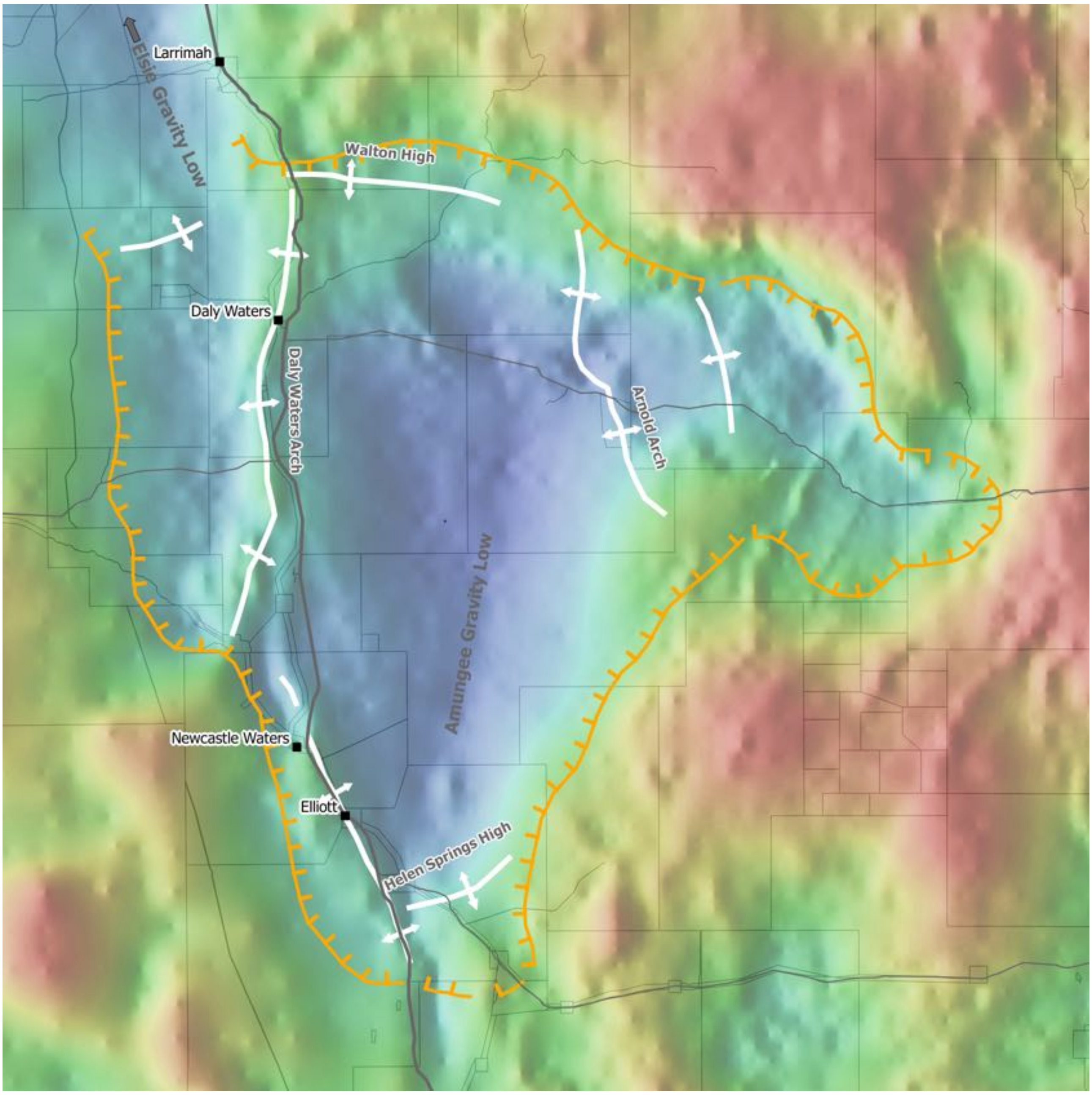
Beetaloo Basin Hydrogeological Assessment



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Executive Summary

The Beetaloo Basin is located in the Northern Territory approximately 180 km south-east of Katherine, the nearest regional centre. The region is sparsely inhabited with an estimated population less than 1000 and the only significant settlements occur along the Stuart Highway at Elliot and Daly Waters. Pastoral leasehold accounts for over 90% of landuse within the basin with the remaining tenure including Aboriginal Land Trusts and freehold, Crown Land and small conservation reserves. The study area occurs over three bioregions: the Stuart Plateau Bioregion, the Mitchell Grass Bioregion and the Gulf Falls and Uplands Bioregion. The area has a semi-arid climate with average rainfall ranging from 665 mm in the north of the basin to 518 mm in the south. Rainfall is linked to the north Australian monsoon and falls almost exclusively between December and March. The topography of the basin is dominated by the flat-lying Sturt Plateau and the Barkly Tablelands in the south. Surface drainage is limited in these areas and water ways only flow briefly in response to heavy rainfall. Lake Woods, a large ephemeral lake in the south of the study area, is the most notable drainage feature. To the north-east of the basin a more substantial surface water system drains towards the Gulf of Carpentaria.

The Beetaloo Basin comprises a thick sequence of flat-lying mudstone and sandstone formations (Roper Group) that were deposited between 1500 and 1430 million years ago (Ma) – see Table I. The Roper Group is estimated to reach of 5000 m in thickness in the centre of the basin and with the exception of the north and east margins occurs at an average depth of around 500 m. The Roper Group is overlain by the Georgina Basin (630 – 497 Ma), which includes widespread basalts and a thick limestone sequence that forms the Cambrian Limestone Aquifer (CLA), a significant water supply aquifer. The Georgina Basin is capped by Cretaceous mudstone and sandstone (145 – 66 Ma) and recent alluvial and laterite deposits.

Table I Summary of Beetaloo Basin Hydrostratigraphy

PROVINCE	PERIOD / AGE	FORMATION	AQUIFER STATUS	THICKNESS (m)	YIELD (l/s)	AVE. EC (µs/cm)
CARPENTARIA BASIN	CRETACEOUS 145 – 66 Ma	Undifferentiated	*Local Aquifer*	0 - 130	0.3 - 4	1800
GEORGINA BASIN	CAMBRIAN 497-630 Ma	Cambrian Limestone Aquifer (CLA) – Anthony Lagoon Beds	REGIONAL AQUIFER	0 – 200	1 - 10	1600
		Cambrian Limestone Aquifer (CLA) – Gum Ridge Formation	REGIONAL AQUIFER	0 – 300	0.3 - >20	1400
		Antrim Plateau Volcanics	REGIONAL AQUITARD *Local Aquifer*	0 – 440	0.3 - 5	900
		Bukalara Sandstone	*Local Aquifer*	0 – 75	0.3 - 5	1000
BEETALOO BASIN (ROPER GROUP)	NOT KNOWN	Hayfield Mudstone	REGIONAL AQUITARD *Local Aquifer*	0 – 450	-	32000
		Jamison Sandstone	*Local Aquifer*	0 – 150	-	138000
	MESO-PROTEROZOIC 1430-1500 Ma	Kyalla Formation	REGIONAL AQUITARD	0 – 800	-	-
		Moroak Sandstone	*Local Aquifer*	0 – 500	0.5 - 5	131000
		Velkerri Formation	REGIONAL AQUITARD	700 – 900	-	-
		Bessie Ck Sandstone	*Local Aquifer*	450	0.5 - 5	-

The CLA, comprising the Gum Ridge Formation and the Anthony Lagoon Beds, is an extensive regional aquifer system that forms the principal water resource in the Beetaloo Basin. Limestone in the CLA is commonly fractured and cavernous and regionally bore yields of up to 100 l/s have been recorded from this aquifer. Around 80% of water bores drilled in the basin screen the CLA, these bore supply water for the pastoral industry and communities including Elliot, Daly Waters, Larrimah and Newcastle Waters. Where the CLA is absent, has limited saturated thickness or is deep, local scale aquifers are targeted in Proterozoic fractured rock, Georgina Basin formations and the base of the overlying Cretaceous sequence. Groundwater resources in these aquifers are of limited extent and have a lower yield (< 5 l/s) relative to the CLA. Limited information exists on the hydrogeological characteristics of the Roper Group sequence as it occurs at depth within the Beetaloo Basin. Sandstone dominated formations may behave as aquifers, however, drilling results suggest these formations have limited permeability and will only form marginal, local scale aquifers. Groundwater in the Roper Group is highly saline and contrasts with the shallower, utilised aquifers in which groundwater is generally of drinking water quality.

The CLA contains a significant but largely undeveloped groundwater resource with the sustainable yield from the Georgina Basin estimated to be in the order of 100 000 ML/year (NALWTF, 2009). Existing groundwater use in the Beetaloo Basin is estimated at 6000 ML/year[1]. Unconventional gas exploration in the Beetaloo Basin is at a very early stage and the volume of water required to develop any potential resource is uncertain. However a first order estimate of the water required to develop potential gas resources on Origin tenements is 1000 ML/year over the development phase (Origin 2015, pers. comm). Combined, current groundwater extraction and projected demand for gas development in the Beetaloo Basin represents 7% of the estimated water resource available from the CLA in the Georgina Basin.

The regional groundwater flow direction in the CLA is north-west toward Mataranka, where the aquifer discharges into the Roper River and supports significant groundwater dependent ecosystems including the Roper River at Elsey National Park and Red Lily/57 Mile Waterhole. These discharge features occur around 100 km north-west of the Beetaloo Basin. Dry season flow in the Roper River has been gauged at 95 000 – 126 000 ML/yr and provides an estimate of the magnitude groundwater discharge from the CLA. Large decadal changes in the discharge to the Roper River suggests that most recharge input occurs close to the discharge zone (i.e. beyond the Beetaloo Basin region). Groundwater recharge mechanisms to the CLA are poorly characterised but are likely to be dominated by infiltration through sinkholes and preferential recharge through soil cavities.

The Velkerri Formation represents the primary unconventional gas target in the Beetaloo Basin, although small hydrocarbons intersections have been recorded in other Roper Group formations. Vertical pressure gradients between the Roper Group and the CLA are not well characterised, however, well formation tests indicate there is an upward pressure gradient from the Roper Group to the CLA. Over much of the basin the CLA is separated from these formations by multiple aquitards including the Antrim Plateau Volcanics and Hayfield Mudstone. Thick, unweathered and undeformed basalt sequences in the Antrim Plateau Volcanics (190 m average) and tight claystone beds within the Hayfield Mudstone (320 m average thickness) form a barrier that restricts the mixing of hydrocarbons and brines in the Roper Group with high quality groundwater in the CLA and other shallow aquifers. Where these formations are absent or thinner, along the eastern margin and in the south of the Beetaloo Basin, there is greater potential for interconnection between the Roper Group and the CLA. Potential for interconnection also exists along the major faults and structures that bound the Beetaloo Basin. The risk of fluid migration through faults between formations is considered limited because most faults don’t extend to the shallow formations.

Water allocation and licensing in the Northern Territory is regulated primarily by the Department of Land Resource Management through the Water Act. Under the Water Allocation Plan Framework administrative areas can be declared for the purpose of managing the water within a specific area or resource. The north-west of the Beetaloo Basin falls within one such water management area, the Daly-Roper Water Control District (WCD). Bores drilled within a WCD require an extraction license unless used for stock and domestic purposes. Water extracted for Petroleum purposed is currently exempt from the Water Act and is governed by the Petroleum Act. However, the Department of Mines and Energy recently released a set of "guiding principles" for petroleum activities, which requires water management to be consistent with requirements under the Water Act, this implies that an extraction licence is required for petroleum water supply bores drilled within the Daly-Roper WCD and for bores extracting greater than 15 l/s.

1 Introduction

Origin Energy engaged CloudGMS to undertake a desktop hydrogeological study of the Beetaloo Basin, a Proterozoic sedimentary basin located in the Northern Territory (NT) that is the focus of unconventional shale gas exploration. The

[1] Stock usage is estimated at 4400 – 5500 ML/year (4-5 cattle/km^2 x 60 000km^2 x 50 l/day), Community water supply is estimated at 400 ML/year (574 people x 1.8 KL/day)

study aims to benchmark hydrogeological knowledge within the Beetaloo Basin and adjacent groundwater basins including the overlying Georgina Basin, which provides a significant water resource for the region. The study has the following scope:

- Undertake a review of background literature;
- Describe the regional geological setting and the relationship between the Beetaloo Basin and adjacent basins;
- Compile a hydrostratigraphic sequence that describes the lithology of units and includes a hydrogeological characterisation (aquifer/aquitard) from surface units through to the McArthur Group;
- Summarise structural features within the basin including potential faulting controls on groundwater flow;
- Present two perpendicular diagrammatic cross sections through the axes of the basin;
- Document previous groundwater investigations across the basin;
- Summarise current understanding of recharge, flow and discharge mechanisms;
- Comment on vertical groundwater flow relationships;
- Describe any recognised environmental dependencies;
- Provide basic groundwater quality characterisation by aquifer
- Summarise existing groundwater usage by source aquifer including number of bores, purpose and extraction volumes or a description of groundwater usage if insufficient data is available to estimate volumes.
- Document the regulatory water management regime including the processes required to access both permanent and temporary water entitlements.

The Beetaloo Basin largely occurs subsurface at projected depths of up to 10 000 m and as a consequence the basin extent is not clearly defined. The study area for this review is defined by the Amungee gravity low and significant bounding structural elements described in Section 3.1, the review does not consider groundwater resources in the Proterozoic Basin defined by the adjacent Elsie gravity low. The geographic extent of the Beetaloo Basin is discussed in the further detail in Sections 2.1 and 3.1.

2 Regional Setting

2.1 LOCATION AND PHYSIOGRAPHY

The Beetaloo Basin is located in the central north of the NT approximately 180 km south-east of Katherine, the nearest regional centre (Figure 2-1). The basin extent is bounded by latitude 15.745° in the north and 18.03° in the south, and longitude 132.84° in the west and 135.33° in the east. The Beetaloo Basin underlies a surface area of roughly 21 000 km^2. It is bisected by the Stuart Highway from north to south and jointly by the Carpentaria and Buchannan Highways from east to west.

The topography is predominantly flat-lying with elevations ranging from 150 mAHD in the upper reaches of the Hodgson River to 320 mAHD in the east of the basin along the Carpentaria Highway on Tanumbirini Station. The landform comprises gently undulating plains and isolated ridges of the Sturt Plateau in the north-west, flat-lying laterite surfaces in the central basin and black soil plains of the Barkly Tablelands to the south-east. The south-west of the basin is punctuated by dissected ridges and sand covered plateaus of the Ashburton Ranges, while the physiography in the north-east is characterised by gentle valleys that drain outcropping Proterozoic rocks toward the Gulf of Carpentaria.

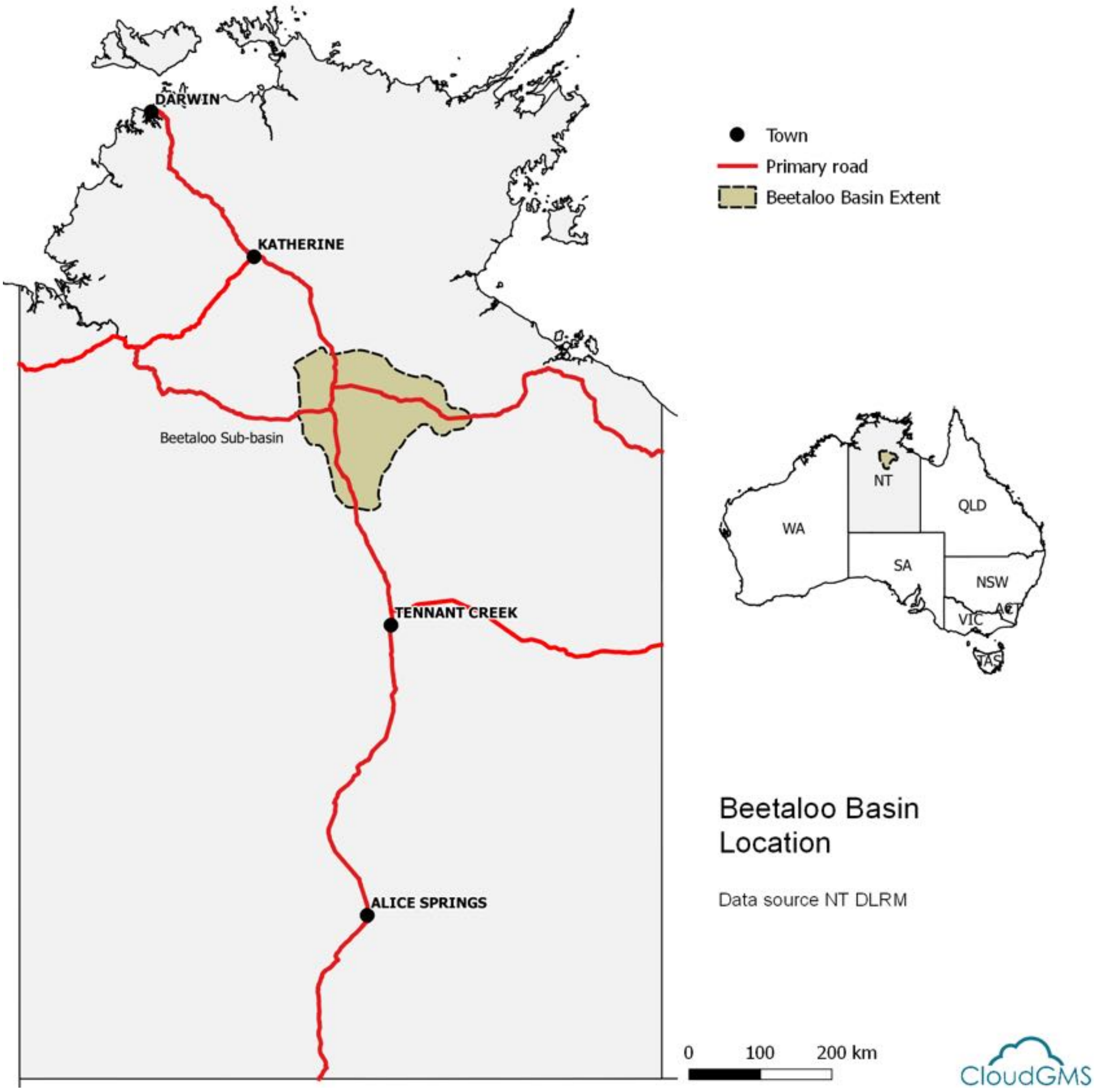

Figure 2-1 Location of the Beetaloo Basin.

2.2 LANDUSE AND POPULATION

Landuse within the Beetaloo Basin is divided between pastoral, Aboriginal Land Trusts (ALT) and freehold (Figure 2-2). Small envelopes of Crown Land exist around townships, major arterial roads, stock routes and conservation reserves. Perpetual pastoral leasehold accounts for over 90% of the basin land area with cattle grazing representing the principal pastoral activity within the region. The Murranji and Mambaliya Rrumburriya Wuyaliya ALTs extend over the western and eastern margins of the Beetaloo Basin respectively. The Bullwaddy Conservation Reserve is located on the Carpentaria Highway and covers an area of 115 km^2 excised from Amungee Mungee Station. The Reserve protects the lancewood/bullwaddy woodlands, a form of Acacia woodland that is characteristic of the Sturt Plateau and provides habitat for three “near threatened” species: the stone curlew, the spectacled-hare wallaby and the northern nail-tailed wallaby (PWCNT, 2005). The Junction Stock Reserve, located between Helen Springs and Newcastle Waters Stations is an area set aside for the conservation of Mitchell grasslands. Conservation covenants have also been established over Longreach Waterhole and Lake Woods in the south-west of the Beetaloo Basin. There are no active mines or identified mineral resources within the Beetaloo Basin.

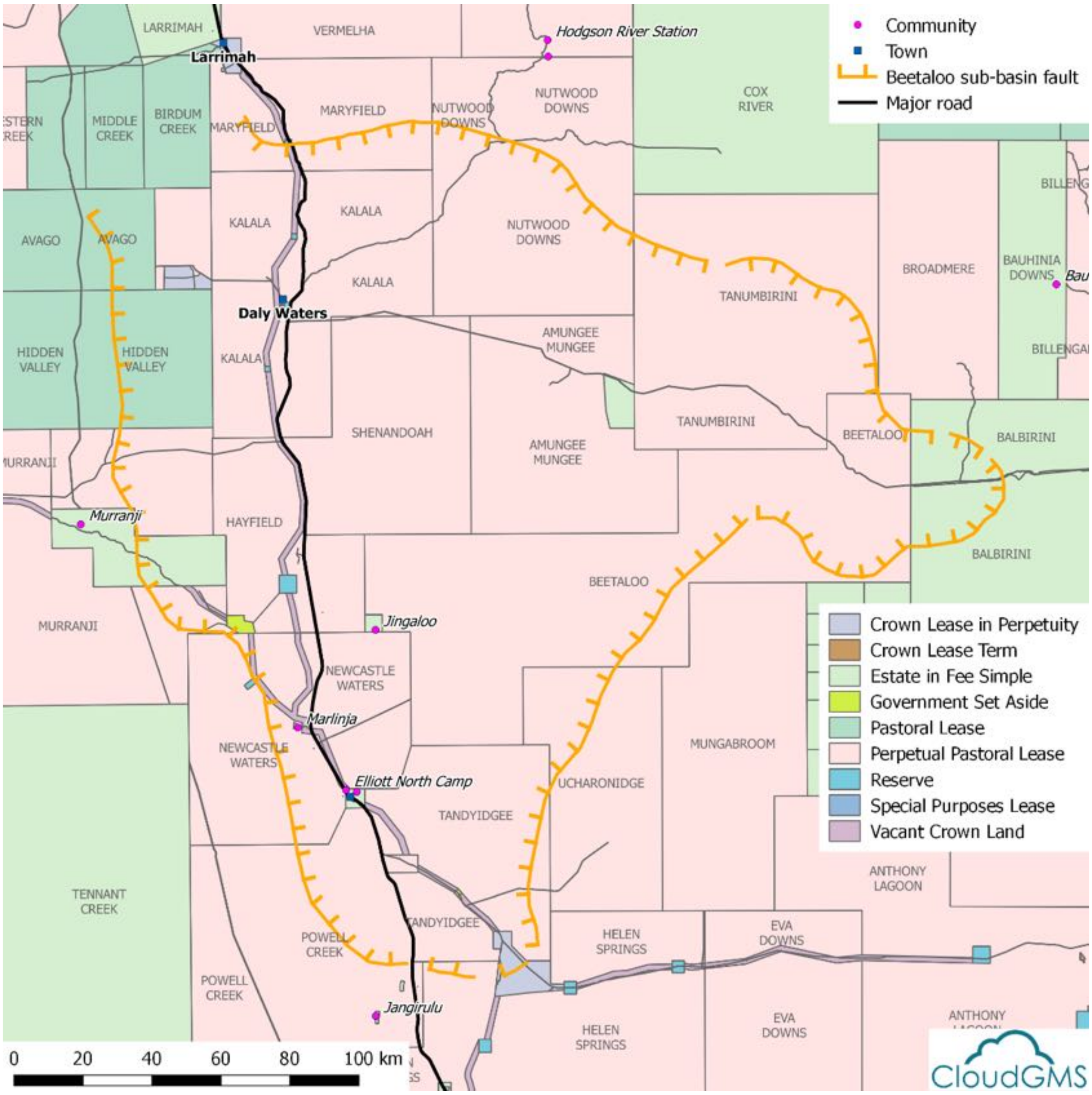

Figure 2-2 Property Tenure and Population Centres

The Beetaloo Basin is sparsely inhabited with a population of less than 1000 residents and a population density of one person per 21 km^2. The townships of Elliot and Daly Waters form the only significant population centres. Elliot is located in the south of the basin and has an estimated population of 188 (ABS, 2011). Daly Waters is located in the north of the basin, the township has an estimated population of 80 (ABS, 2011). Several indigenous outstations and small communities are located around Elliot including Jingaloo, Marlinja, Wilyuku (previously known as South Camp) and Gurungu (formerly known as North Camp). Outside of Elliot and Daly Waters the remaining inhabitants of the Beetaloo Basin are sparsely distributed across pastoral stations.

2.3 CLIMATE

General

Based on the Köppen Geiger classification (Peel et al., 2007) the climate of the Beetaloo Basin is classified as hot semi-arid (BSh). Typical of a semi-arid climate, rainfall in the region is highly variable in terms of quantity and timing both seasonally and across years. Broad patterns occur with the timing of rainfall events and the majority of rainfall occurs in the short hot monsoonal wet season between December and March. Rainfall events are associated with either intense thunderstorms or result from widespread monsoonal activity. Little rainfall is experienced during the remainder of the year from May to September (Figure 2-3 a and b).

The average rainfall varies slightly across the region with 665mm at Daly Waters in the north and 518mm at Newcastle Waters in the south. Similarly, pan evaporation ranges between 5 and 11 millimetres per day (average about 7-8 mm per day or 2.8 metres per year) in the region. Air temperatures are high throughout the year. The average monthly maxima at Daly Waters and Newcastle Waters range from about 29 degrees in June to 38 degrees in November.

Evaporation is high throughout the year with the average annual rate for the period 1961 to 1990 between 2400 – 2800 mm (http://www.bom.gov.au/jsp/ncc/climate_averages/evaporation/index.jsp) and potential evapotranspiration (PET) rates are consequently very high with the average annual PET for the period 1961 to 1990 between 1800 – 2100 mm (http://www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp?maptype=3&period=an). During a few months in the wet season rainfall exceeds potential evapotranspiration and this drives seasonal streamflow. Climatically, on an annual basis, rainfall is insufficient to meet evaporative demand and the landscape may be described as water-limited and surface water supplies are considered to have low reliability.

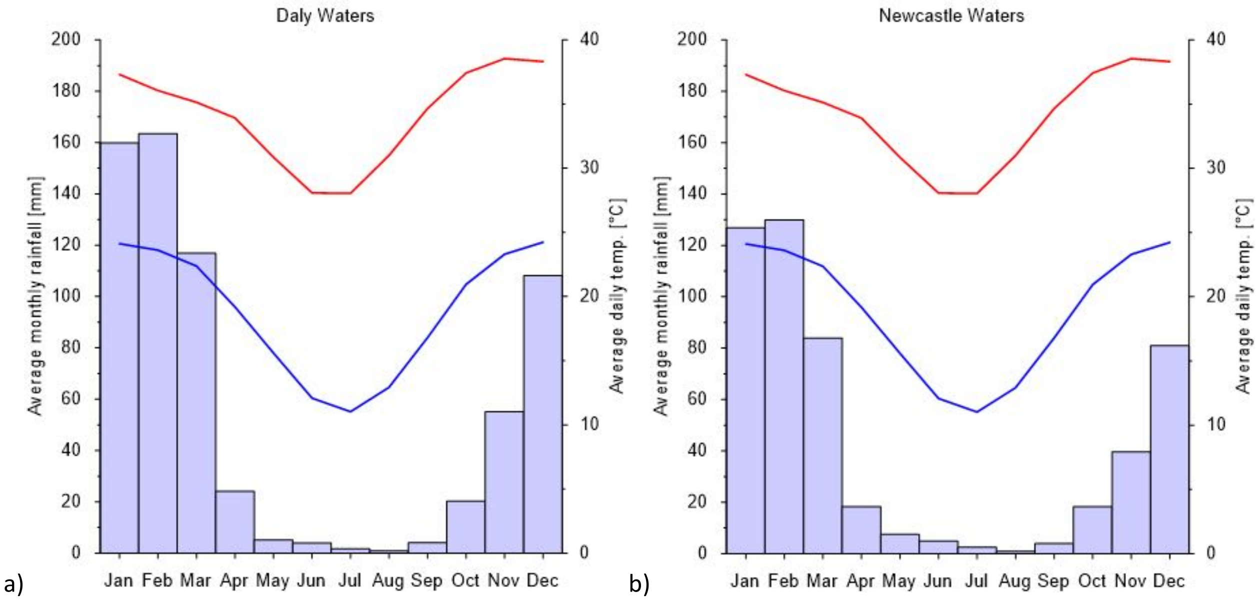

Figure 2-3 Average monthly rainfall and temperature for a) Daly Waters and b) Newcastle Waters.

Long Term Rainfall Trends

The average rainfall for the northern part study area is approximately 665 mm based on the Daly Waters record from 1900 – 2015. The average annual rainfall at Newcastle Waters is 518 mm for the period 1900 – 2015. The annual rainfall at Daly Waters and Newcastle Waters over the period 1900 – 2015 is presented in Figure 2-4. Included on the plot are the rainfall residual mass curves for both rainfall stations.

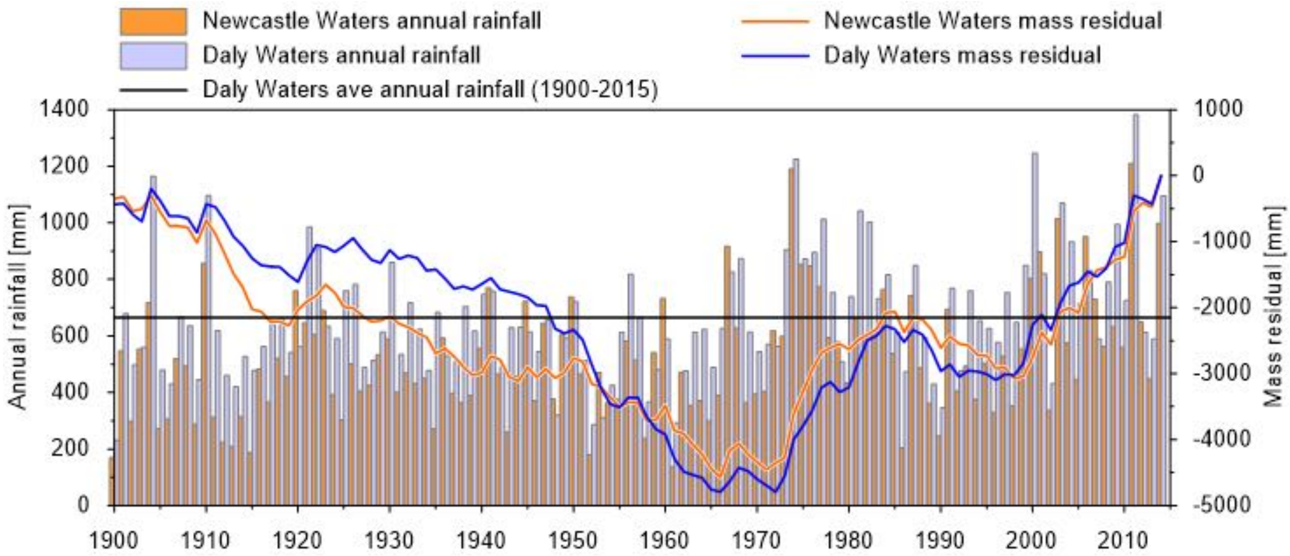

Figure 2-4 Annual rainfall at Daly Waters and Newcastle Waters for the period 1900 – 2015 and the rainfall residual mass curves for Daly Waters (blue trace) and Newcastle Waters (orange trace) demonstrating long term trends in rainfall.

The rainfall residual mass technique or cumulative difference from the mean reveals trends in the rainfall data. Declining trends indicate that rainfall is less than the long term average, rising trends indicate that rainfall is above the long term average. The actual values are not particularly useful, it is the slope or rate of change that is important (Crapper et al., 1997).

Despite a difference in average annual rainfall of ~100 mm, the rainfall and rainfall residual mass curves for Daly Waters and Newcastle Waters are quite similar reflecting the common climatic influences such as monsoonal activity. It can be seen that for the period 1900 – 1973 the annual rainfall is generally below average with the mass residual curve consistently declining. Within this there is a period during the late 1920s to the early 1940s with average annual rainfall. The trend from 1996 – present shows a period of well above average rainfall (approximately 350 mm/yr above the average).

2.4 BIOREGIONS

Bioregions provide a consistent and robust framework for biodiversity assessment and planning. The classification is based on common climate, geology, landform, native vegetation and species information. The study area occurs over three bioregions (Figure 2-3), with the majority of the study area over the Sturt Plateau bioregion, the Gulf Fall and Uplands bioregion occurs in the northeast and east and the Mitchell Grass Downs bioregion to the south.

The Sturt Plateau Bioregion

The Sturt Plateau bioregion mostly comprises a gently undulating plain on lateritised Cretaceous sandstones. Soils are predominantly neutral sandy red and yellow earths. The most extensive vegetation is eucalypt woodland (dominated by variable-barked bloodwood *Eucalyptus dichromophloia*) with spinifex understorey, but there are also large areas of lancewood (*Acacia shirleyi*) thickets, bullwaddy (*Macropteranthes keckwickii*) woodlands, Acacia shrublands on deep sands, and eucalypt open forests (dominated by a range of species including Darwin stringybark *Eucalyptus tetrodonta*) over tussock grass understorey.

The Sturt Plateau bioregion includes the most extensive areas of the distinctive lancewood-bullwaddy vegetation associations, with associated fauna including spectacled hare-wallaby. There are a range of small wetlands associated with sinkholes and minor depressions in the generally flat landscape.

Nationally important wetlands

The nationally significant Lake Woods (Figure 2-5) wetlands (wetland types B6 – seasonal/intermittent freshwater lakes, B13 – shrub swamps; shrub-dominated freshwater marsh, shrub carr, alder thicket on inorganic soils, B14 – freshwater swamp forest; seasonally flooded forest, wooded swamps; on inorganic soils and B10 – seasonal/intermittent freshwater ponds and marshes) occurs on the border of this bioregion and the Mitchell Grass Downs bioregion. The Mataranka thermal pools (wetland type B17 – freshwater springs, oases and rock pools) occur on the border of this bioregion and the Gulf Falls and Uplands bioregion.

There are no large perennial watercourses in the bioregion. The major drainage system is the Newcastle Creek system in the south, although the bioregion also includes smaller headwater areas of the larger Roper, Daly and Victoria River systems. There are a number of small wetlands associated with the intermittent, land-locked drainage systems in the south of the bioregion.

The Mitchell Grass Bioregion

The Mitchell Grass Downs bioregion occurs to the south of the study area (Figure 2-5) and is coincident with the Barkly Tableland, an elevated plain of grey and brown vertosols (self-mulching cracking clay or “black-soil”) overlying fine-textured calcareous parent materials, stretching from the centre of the Northern Territory to the Queensland border.

The bioregion has been divided into three provinces in the Northern Territory. The Barkly Tableland province occupies the majority of the bioregion and is typified by the elevated black-soil plain supporting treeless grasslands dominated by Mitchell grasses (*Astrebla spp*.).

The Barkly Lakes province is a large low depression within the Barkly Tableland province, with several intermittent freshwater lakes that flood out to cover a large proportion of the province when full, fed by short rivers and indistinct drainage lines from the surrounding Tableland. Soils in this province are also grey cracking-clays and the vegetation is predominantly *Eucalyptus microtheca* (Coolibah) low open-woodland with *Chenopodium auricomum* (Bluebush) shrubland swamps, interspersed with Mitchell grassland. Drainage on the Barkly Tableland is predominantly internal and is referred to as the Barkly Internal Drainage Basin.

The Gulf Fall and Uplands Bioregion

The Gulf Falls and Uplands bioregion comprises undulating terrain with scattered low, steep hills on Proterozoic and Palaeozoic sedimentary rocks, often overlain by lateritised Tertiary material. Soils are mostly skeletal or shallow sands. The most extensive vegetation is woodland dominated by Darwin Stringybark *Eucalyptus tetrodonta* and Variable-barked Bloodwood *C. dichromophloia* with spinifex understorey, and woodland dominated by Northern Box *Eucalyptus tectifica* with tussock grass understorey. The Mataranka Thermal Pools (wetland type B17 – freshwater springs, oases and rock pools) occurs on the border of the Gulf Fall and Uplands bioregion and the Sturt Plateau bioregion.

2.5 SURFACE WATER HYDROLOGY

The majority of the catchments drain north towards the Gulf Falls and Uplands bioregion to the Roper River and north-easterly towards the Gulf of Carpentaria (Figure 2-5). The major rivers include the tributaries of the Arnold River, Hodgson River and Strangways River. Limmen Bight River, October Creek and Cox River. The highest flows for these rivers occur during the wet season, predominantly due to cyclones and monsoonal rainfall. In contrast to these larger rivers, smaller streams and drainage lines such as the Relief, Tanumbirini and Lagoon Creeks are largely ephemeral and usually run dry during the dry season. Ephemeral rivers and streams are subject to short flow duration and high turbidity.

The rivers and creeks in the Sturt Plateau bioregion flow only for short periods after heavy rains and large areas have no apparent surface drainage. Permanent or semi-permanent natural surface water is limited to waterholes near the terminus of streams flowing into the internal basin (eg Cresswell Ck and Newcastle Ck) although the larger intermittent lakes, such as Lake Woods in the south of the study area, may hold water for months or even entire years in exceptional seasons (see Figure 2-5).

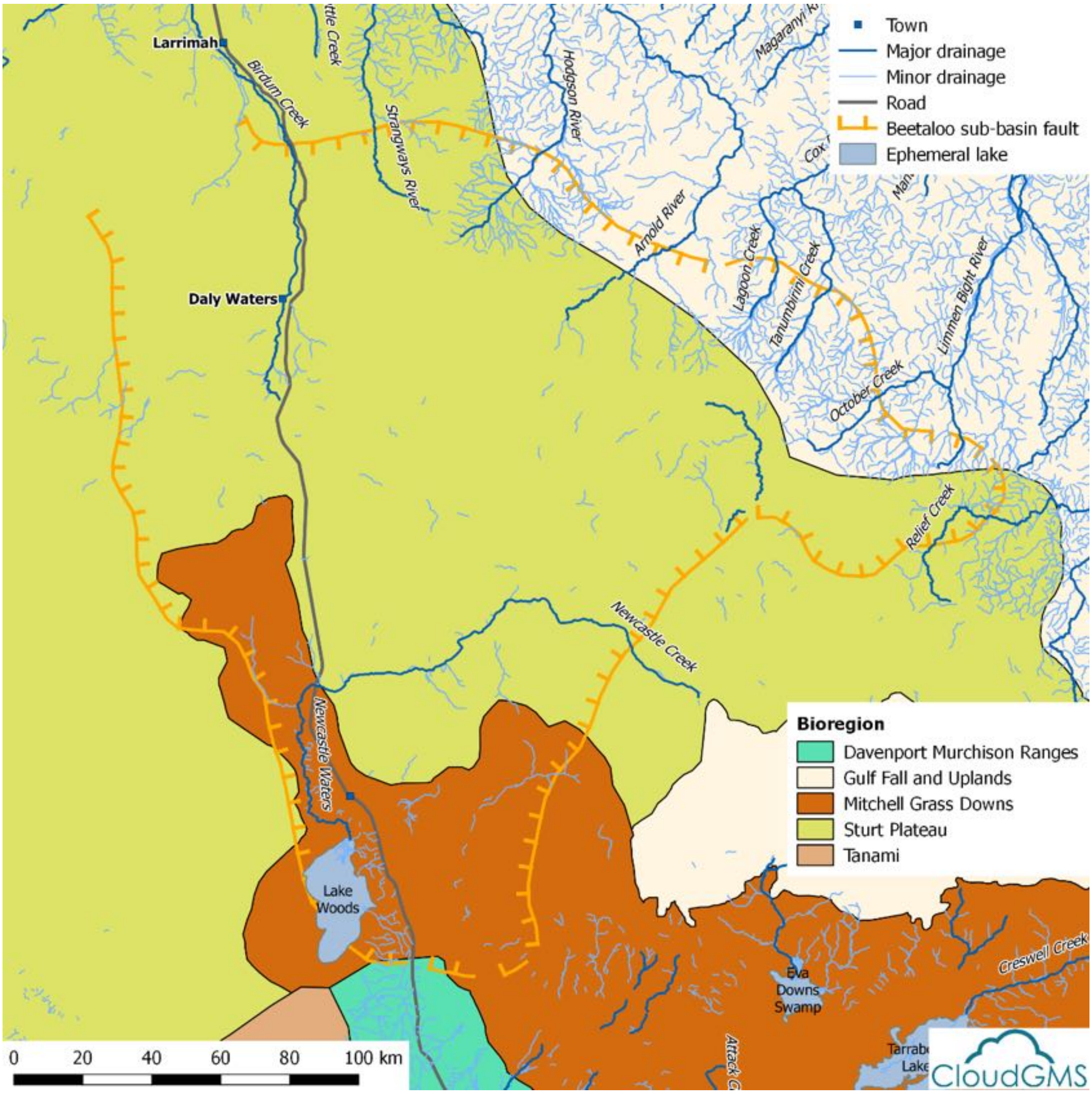

Figure 2-5 Surface water features and bioregions.

3 Geology

3.1 REGIONAL BASIN SETTING

The Beetaloo Basin is a Mesoproterozoic to Neoproterozoic sedimentary basin that overlies the western extension of the McArthur Basin (Ambrose, 2006). The basin occurs largely subsurface and is defined by a pronounced gravity low, as well as seismic, magnetotelluric and exploratory drilling data (Ahmed et al, 2013). The basin is bounded by several prominent structural elements including the Walton High to the north, the Bauhinia Shelf to the east and the Helen Springs High to the south (Figure 3-1). The western margin is defined by the Daly Waters Arch, which separates the Beetaloo Basin from the Elsey Gravity Low, also referred to as the Gorrie Sub-basin (Lanigan et al, 1994). Silverman (2007) notes that the boundary of the Beetaloo Basin is less well defined over the Daly Waters Arch relative to other areas of the basin and Munson (2014) extended the subsurface extent of the basin to incorporate the Gorrie Sub-basin. For the purpose of this review the western boundary of the Beetaloo Basin is broadly defined by the Daly Waters Arch.

The entire sedimentary sequence of the Beetaloo Basin is represented by the Roper Group, a thick package of quartz sandstones, siltstones and mudstones. Unconformably underlying the Roper Group is the sedimentary and minor volcanic succession of the McArthur Basin, which beneath the Beetaloo Basin comprises the Nathan Group, McArthur Group and basal Tallawallah Group. The northern Georgina Basin unconformably overlies the Roper Group and comprises the clastic Kiana Group, basalts of the Kalkarindji Province and the marine sedimentary succession of the Barkly Group. The Georgina Basin is unconformably overlaid by Cretaceous mudstones and sandstones of the Carpentaria Basin, which are discontinuously capped with a thin veneer of laterised Tertiary and Quaternary sediments. The total sedimentary sequence encompassing the McArthur, Beetaloo, Georgina and Carpentaria basins has an estimated thickness of over 10,000 m (de Vries et al, 2006) and rests unconformably on basement rocks of the North Australian Craton.

3.2 BASIN DEVELOPMENT

The McArthur Basin forms part of the North Australian Platform Cover, a group of mid-Proterozoic basins, which unconformably overlie the North Australian Craton (Plum et al, 1980). The McArthur Basin sequence comprises a thick sequence of relatively undeformed sedimentary rocks that are sub-divided into four groups: the Tallawah, McArthur, Nathan and Roper Groups. Prior to the deposition of the sequence the Barrumundi Extension (2000 - 1870 Ma) resulted in the development of NE-SW normal faulting and NW-SE directed transfer faults in the basement terrain (de Vries et al, 2008). By 1810 Ma large-scale tectonism had effectively ceased in the central part of the North Australian Craton (McArthur Basin region). The Leichhardt Extension (1800 - 1750) led to the development of an intracratonic basin in the North Australian Craton and resulted in the deposition of the lower Tawallah Group, the basal sequence of the McArthur Basin. The upper Tawallah Group was deposited in response to the north-south extensional Calvert Event (1730 – 1690 Ma). Sedimentation in the McArthur Basin resumed from 1660-1590 Ma due to thermal subsidence and resulted in the deposition of the McArthur and Nathan Groups as part of the Isa Superbasin (de Vries et al, 2008). Both of these groups are projected to underlie the present day Beetaloo Basin. During the deposition of Isa Superbasin the Liebig Event (1640 - 1630 Ma) re-activated basement faults and led to the development of N-S trending faults (de Vries et al, 2006). Between 1500 - 1430 Ma the Roper Group was deposited in an intracontinental basin on the North Australian Craton. The Derim Derim Dolerite intruded the Roper Group post deposition, it is dated at 1324 Ma and provides a maximum age for post-Roper Group deformation as the dolerite displays similar structures to the Roper Group (Ahmad and Munson, 2013). Regional tectonic and basin studies (de Vries et al, 2006) do not identify any major Proterozoic deformation events in the Beetaloo Basin post Roper Group deposition. However, Lannigan et al, (1994) notes that the dolerite intrusions might be associated with late Proterozoic tectonic activity that has led to the reactiviation of deeper seated faults and the development of domal structures and open folds that are visible in the Roper Group. The depositional age of the Jamison Sandstone and Hayfield Mudstone, the uppermost formations in the Beetaloo Basin Roper Group sequence, is not well constrained and Lanigan et al, 1994, suggests they may be as young as Neoproterozoic. Silverman (2007) indicates that many of the fracture and fault structures in the lower Roper Group do not penetrate the Hayfield Mudstone, which is consistent with a later deposition date for this formation.

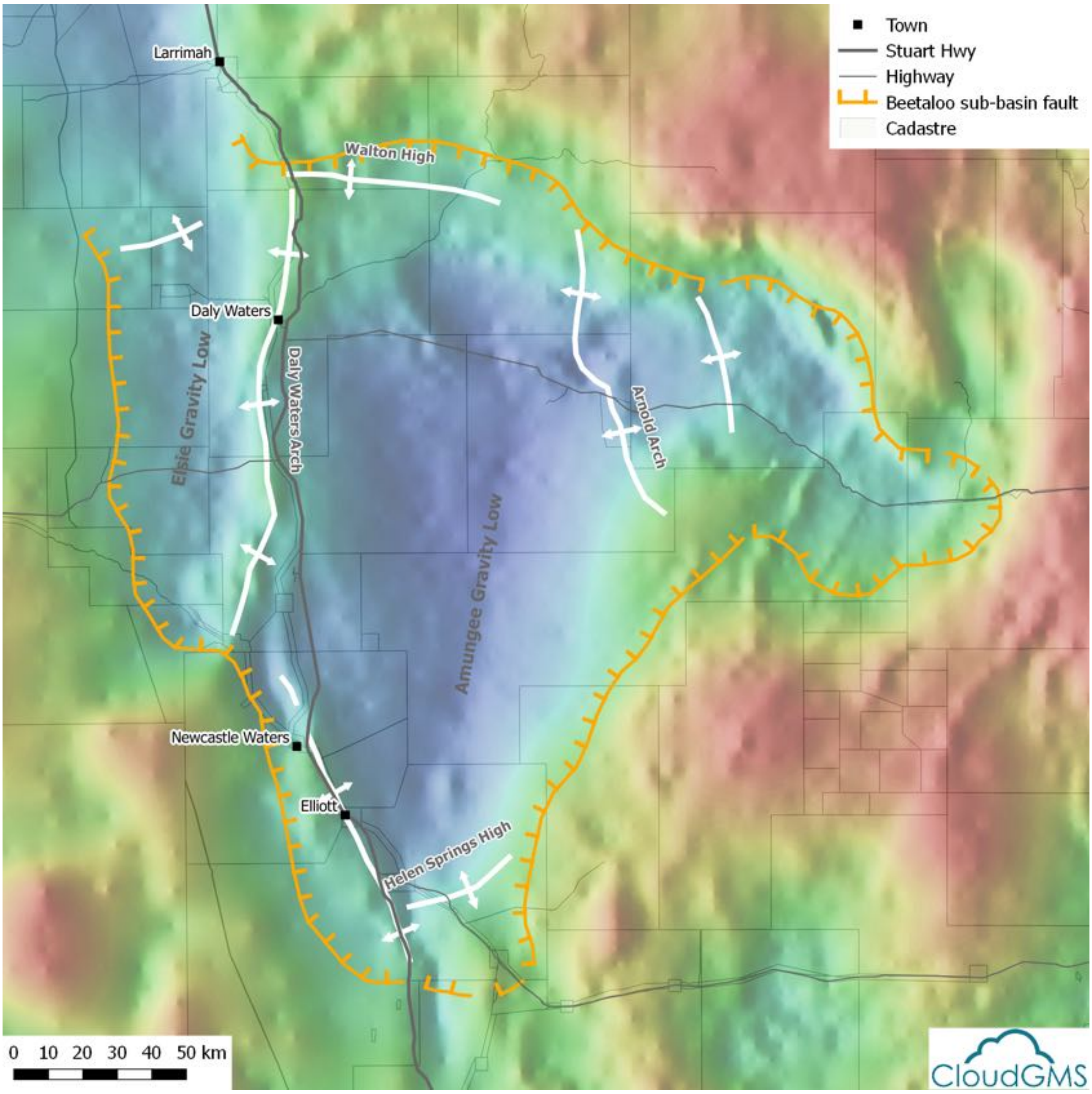

Figure 3-1 Beetaloo Basin Extent and Major Bounding Structures.

There appears to have been relatively little tectonic activity in the Beetaloo Basin through the Phanerozoic other than possible reactivation of existing structures (Lanigan, 1994) and erosional thinning of the upper Roper Group across the main structural highs (Walton High and Arnold Arch). The Bukalara Sandstone (Georgina Basin) was unconformably deposited over the Roper Group in the Ediacaran (630 - 542 Ma). In the early Cambrian, a continental scale NW-SE extensional event resulted in the extrusion of extensive flood basalts of the Kalkarindji Province. The Antrim Plateau Volcanics (505 - 511 Ma) were extruded over the Bukalara Sandstone and where absent the Roper Group in the centre and north of the Beetaloo Basin. The related Helen Springs Volcanics appears to have a distinct erruption point and was deposited over the southern margin of the basin. In the middle Cambrian the Georgina, Wiso and Daly Basins formed an extensive interconnected depositional zone referred to as the Centralian B Superbasin (Kruse et al, 2013). The Georgina Basin comprises two distinct depositional regimes and the Beetaloo Basin sequence forms part of the north-central depositional sequence. The marine limestone sequence of the Barkly Group (Gum Ridge and Anthony Lagoon Beds) was deposited between 505 – 497 Ma. Unlike the southern Georgina Basin, which underwent extensive deformation during the Alice Springs Orogeny, the north-central Georgina Basin has undergone minimal deformation since deposition and is gently folded. There has been a slight tilting of the Cambrian deposits to the south, in the order of 250 m over 175 km, but otherwise the structure of the basin is essentially the same as it was after the Cambrian (Robsearch, 1997). The Mesozoic and Cenozoic have seen minimal structural activity in the Beetaloo Basin apart from regional subsidence and uplift. Deposition of the Cretaceous Carpentaria Basin and Mesozoic sedimentary deposits has taken place with intermittent periods of non-deposition and erosion. Table 3-1 provides a summary of the major tectonic and depositional events involved in the evolution of the Beetaloo Basin and the overlying sequence.

Table 3-1 Summary of major tectonic and depositional events in the evolution of the Beetaloo Basin.

TIME BP (Ma)	EVENT	RELEVANCE TO BEETALOO BASIN DEVELOPMENT
2000 – 1870	Barramundi Extension	Major NW-NE and NE-SW structures develop in basement terrain beneath Beetaloo Basin
1800 – 1750	Leichardt Extension	Sedimentation in McArthur Basin initiates with deposition of lower **Tawallah Group**. Tectonics leads NNE-SSW development of transfer faults and perpendicular normal faults
1730 – 1690	Calvert Event	Deposition of upper Tawallah Group. N-S extensional event results in results in development of N-S oriented structures within Beetaloo Basement and Tawallah Group
1660 – 1590		**McArthur Group** and **Nathan Group** deposition as part of the Isa Superbasin
1640 - 1630	Liebig Event	Reactivation of basement faults leads to further deformation along a N-S alignment
1500 – 1430		**Roper Group** deposition, upper sequence (Jamison Sandstone and Hayfield Mudstone) may have been deposited later in the Proterozoic
1324		Derim Derim Dolerite intrudes Roper Group, minimum age for post-Roper Group deformation
1324 – 630		Unclassified tectonism leads to reactivation of deeper seated structures causing domal structures and open folds observed in the Roper Group. Possible deposition of Jamison Sandstone and Hayfield Mudstone.
630 - 542		Deposition of **Bukalara Sandstone**
530 - 510	Antrim Event	Continental scale extensional event resulted in volcanism and emplacement of NW-SE and NE-SW structures in terrain surrounding Beetaloo Basin
511 – 505		Extrusion of the **Antrim Plateau Volcanics** and Helen Springs Volcanics
505 – 497		Deposition of the Georgina Basin **Gum Ridge Formation** and **Anthony Lagoon Beds**
497 – present		Limited tectonic activity, gentle tilting of Cambrian surface to the south and some reactivation of older faults (e.g. Birdum Creek Fault). Deposition of **Undifferentiated Cretaceous.** Intermittent periods of erosion and sedimentation during Quaternary lead to development of laterite profiles, black soil plains and deposition of alluvial sediments

3.3 STRUCTURE

The Beetaloo Basin sequence is largely flat-lying and undeformed except for areas on the basin margin and around the major structural elements (see Figures 3-3 to 3-5). These major elements include the Helen Springs High, the Walton High and the Arnold Arch. Drilling at Walton-2 and McManus-1 indicate around 1000 m of displacement occurs in the Roper Group across the Walton High, in contrast seismic data reveals that pre-upper Roper Group deformation is less severe over the Arnold Arch (Silverman, 2007). North-east to north-west trending zones of crustal weakness were established in the underlying basement terrain during the Barramundi Extension before the deposition of the McArthur Basin sequence. Reactivation of these faults and the subsequent alignment of younger structures has resulted in discrete fault zones of up to 10 km in which faulting and folding is largely concentrated (Lanigan et al, 1994). Most significant deformation in the Beetaloo Basin pre-dates the Roper Group deposition, though a number of faults still penetrate the lower and middle formations. Seismic data suggests that faults and fractures do not generally extend into the Hayfield Mudstone (Silverman, 2007), which has significance for its ability to retard gas and fluid migration from underlying Roper Group sequence. Limited tectonic activity has occurred since the deposition of the Antrim Plateau Volcanics and the Cambrian Limestone sequence, and these formations form a flat-lying drape over the more deformed Proterozoic sequence. An exception occurs in the north-west of the Beetaloo Basin, where Yin Foo (2002) identified a NW-SE trending fault informally named the Birdum

Creek Fault that has resulted in a 200 m displacement across the Cambrian limestone sequence. Seismic profiles also suggest that faults may penetrate the Cambrian sequence on the eastern margin of the Beetaloo Basin.

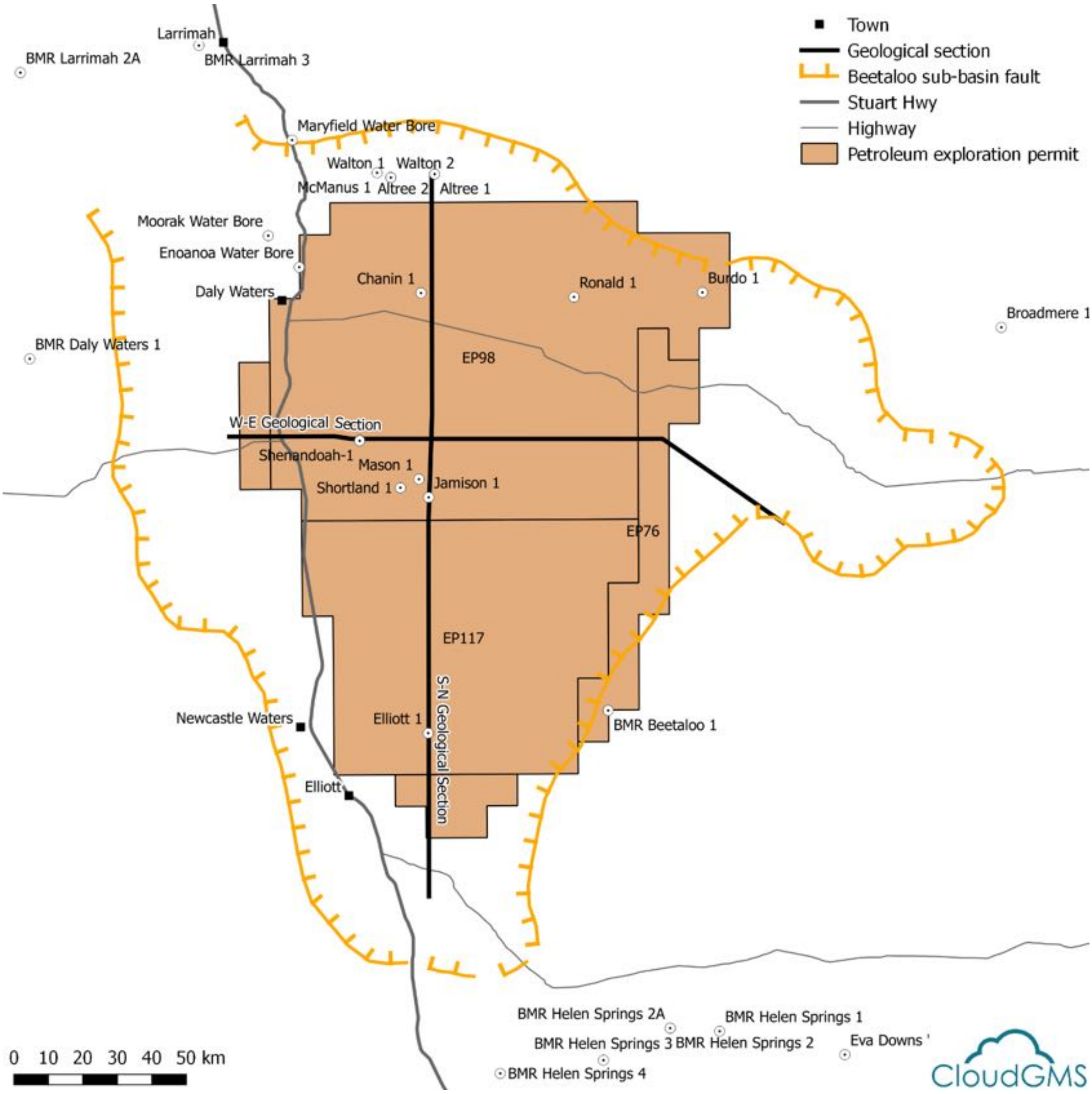

Figure 3-2 Location of geological sections and key stratigraphic bores.

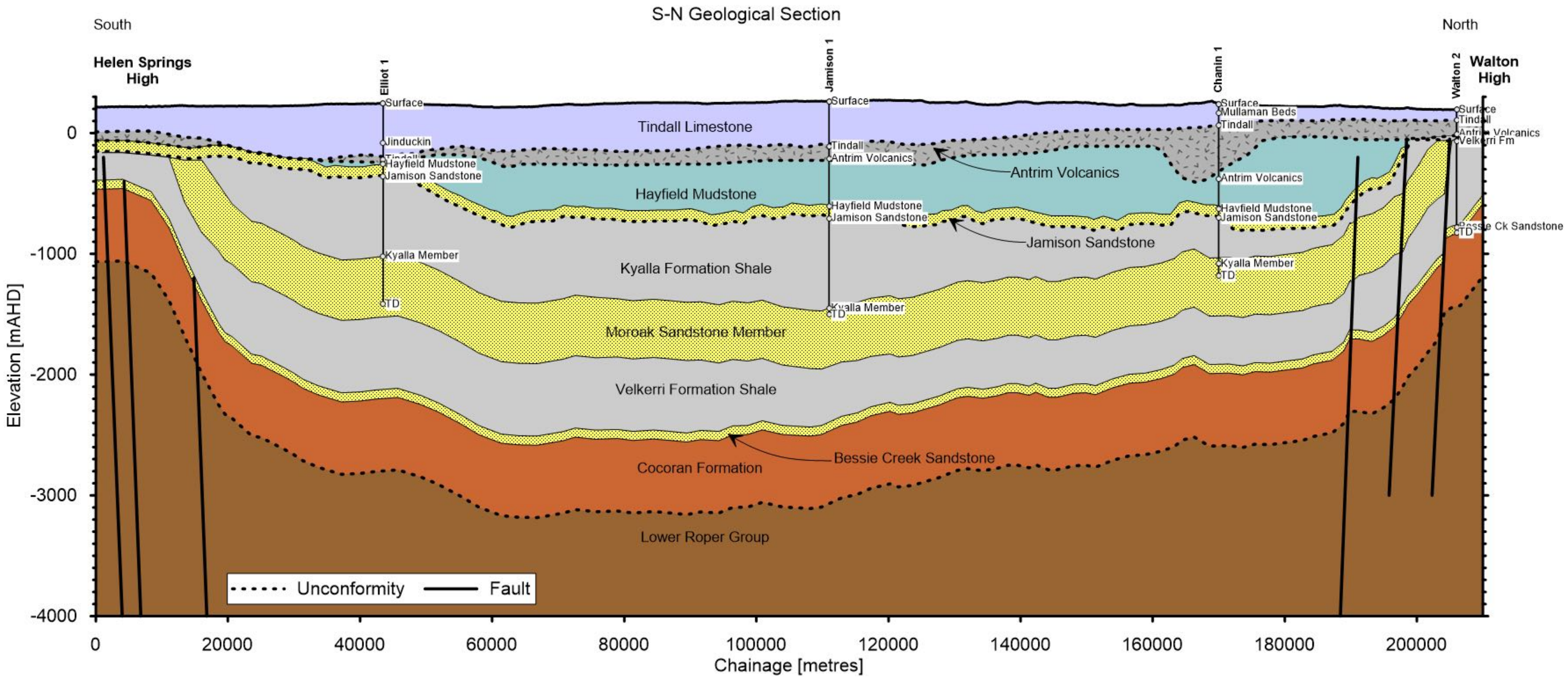

Figure 3-3 South to north geological cross-section through the Beetaloo Basin.

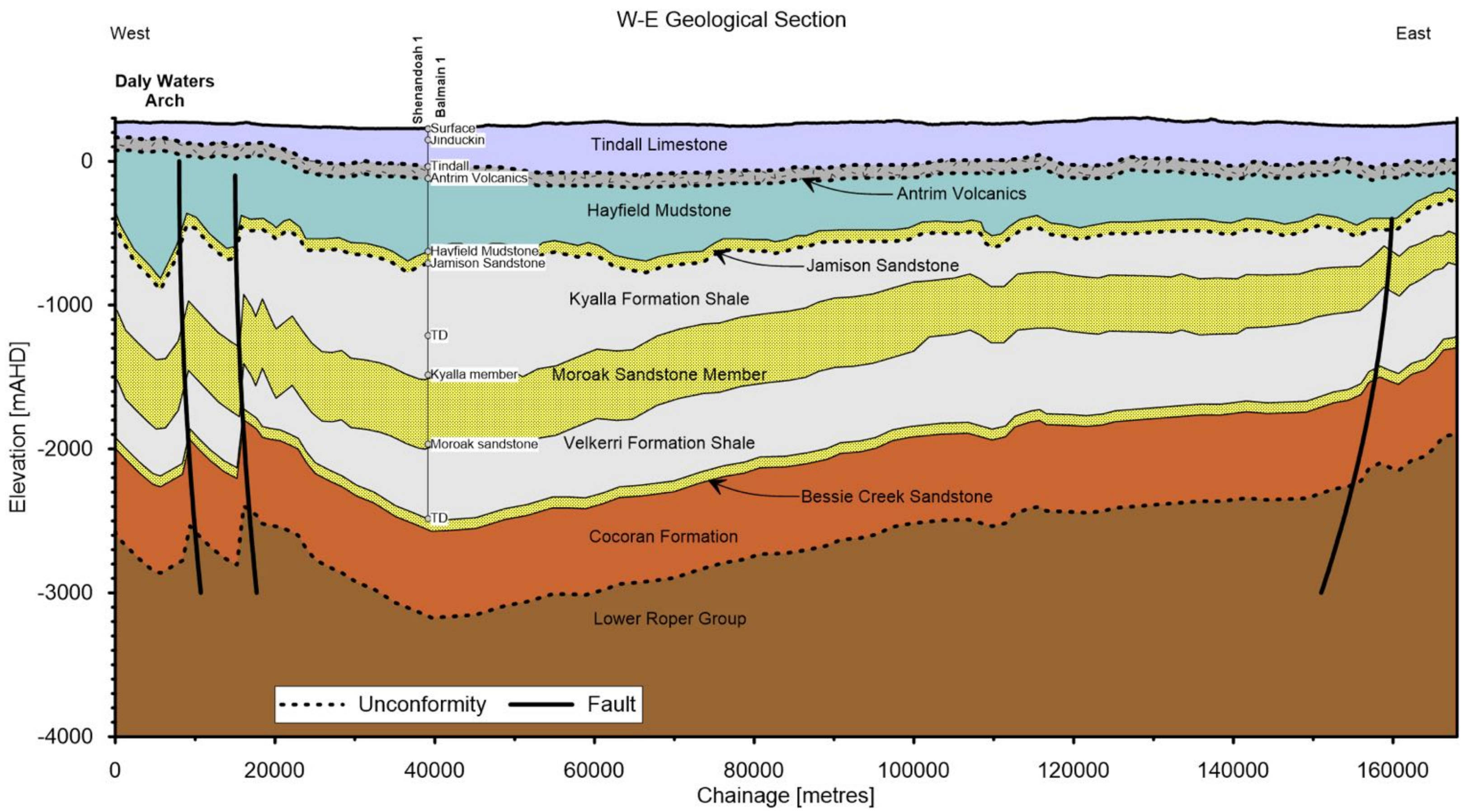

Figure 3-4 West to east geological cross-section through the Beetaloo Basin.

Structural elements mapped in the Beetaloo Basin are presented in Figure 3-5. These features are predominantly sourced from the OzSeeBase project (de Vries et al, 2006) and are categorised by deformation event. Figure 3-5 and Table 3-1 reveal that most categorised structural elements in the basin are related to tectonic activity that pre-dates the deposition of the Roper Group.

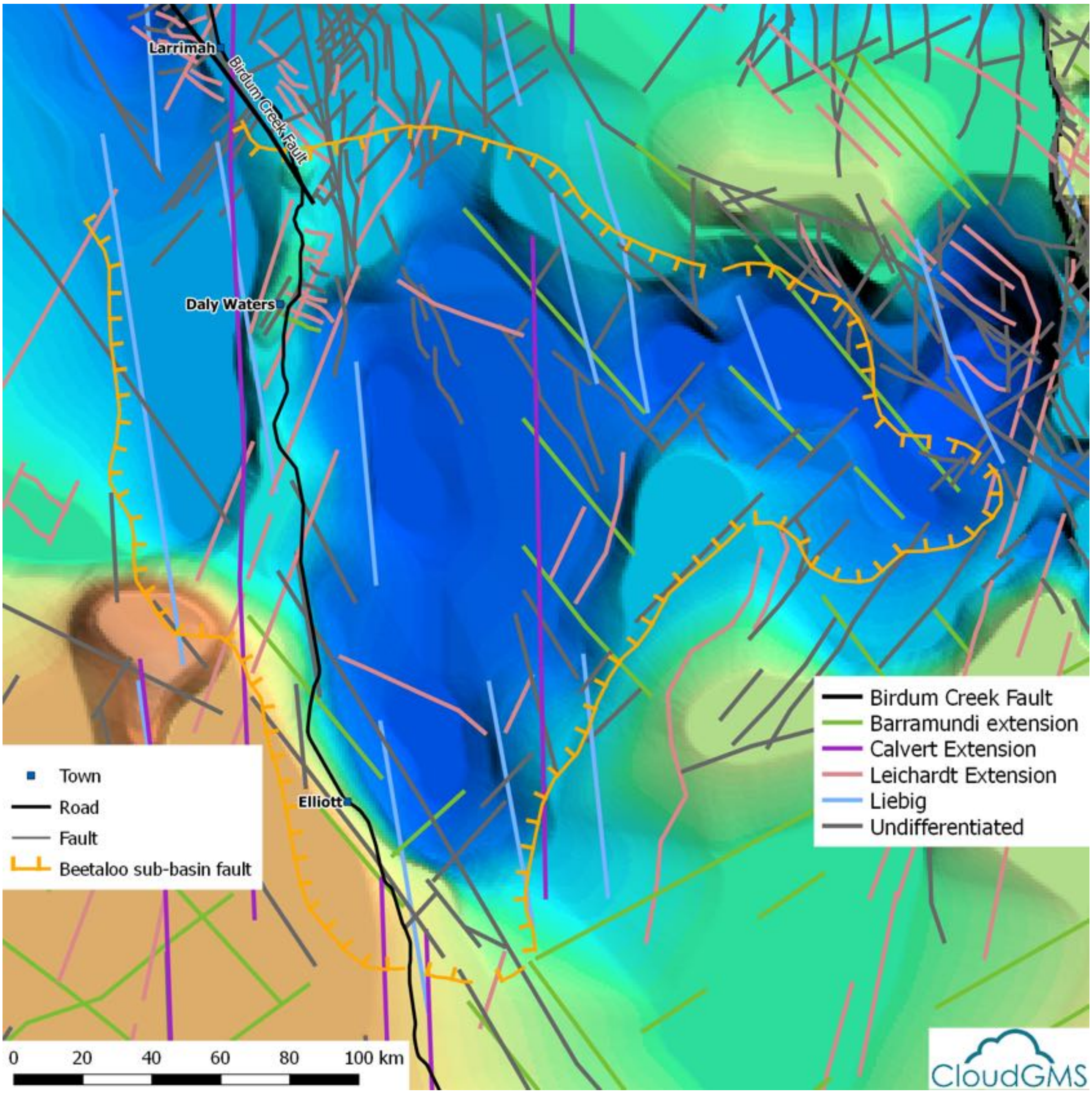

Figure 3-5 Beetaloo Basin structural elements defined by tectonic event. Background OzSeebase basement depth

3.4 BASIN STRATIGRAPHY

The following section provides a summary of the stratigraphic units occurring or expected to occur in the Beetaloo Basin tenements. The summary encompasses the stratigraphic sequence from the Proterozoic Nathan Group (McArthur Basin) through to recent surficial deposits.

3.4.1 Nathan Group (McArthur Basin)

The Nathan Group has not been intersected in drill hole in the Beetaloo Basin due to the successions significant burial depth, its occurrence is inferred from regional studies including the OzSeeBase Proterozoic Basins (De Vries *et al*, 2006), Ahmed et al. 2013 and Jackson et al. 1987. In the southwest McArthur Basin the Nathan Group comprises two formations: the Smythe Sandstone and the Upper Balbarini Dolostone (Ahmed et al. 2013). The following lithological descriptions are based on exposures and drill hole data from the McArthur Basin sequence to the northeast of the study area.

Smythe Sandstone

The Smythe Sandstone forms the basal unit of the Nathan Group in the south-western McArthur Basin. The formation comprises massive polymictic conglomerates, poorly sorted, cross-bedded lithic sandstones and minor dolomitic sandstone (Ahmed et al, 2013). To date, the formation has not been intersected in the Beetaloo Basin, a maximum thickness of 250 m is inferred from the McArthur Basin. The Smythe Sandstone unconformably overlies the McArthur Group and in the southwest McArthur Basin conformably underlies the upper Balbarini Dolostone.

Upper Balbirini Dolostone

The Balbirini Dolostone comprises stromatolitic dololutite, dolarenite, dolomitic siltstone and silicified ooid beds (Ahmed et al, 2013). The upper sequence of the formation is characterised by a recrystallised unit comprising bluish grey dolomite in which the original sedimentary structure was obscured by silicification and extensive karstic weathering prior to the deposition of the Roper Group (Jackson et al, 1987). The Balbarini Dolostone is inferred to occur at depth within the Beetaloo Basin. The full dolostone sequence has a maximum thickness of 1500 m in the McArthur Basin while the upper recrystallised sequence attains a thickness of 340 m (Jackson et al, 1987). The Balbirini Dolostone gradationally overlies the Smythe Sandstone and unconformable underlies the Roper Group.

3.4.2 Roper Group (Beetaloo Basin)

The Roper Group comprises an upward coarsening succession of marine mudstones and sandstones intruded by post-depositional dolerite sills. It is subdivided into a lower mudstone dominated sequence, the Collara Subgroup, and an upper sequence with a higher proportion of sandstones, the Maiwok Subgroup. The Roper Group outcrops along the north-east margin of the Beetaloo Basin but is otherwise concealed beneath the overlying Phanerozoic Georgina and Carpentaria basins. The Roper Group was deposited between 1490 – 1320 Ma (Ahmed et al, 2013) and attains an estimated thickness 5000 m in the Beetaloo Basin.

Limmen Sandstone

The Limmen Sandstone comprises a basal fluvial sequence of well indurated coarse quartz sandstone and an overlying shallow marine sequence of fine grained, quartz sandstone with micaceous sandstone and coarse siltstone interbeds (Abbott et al, 2001). The formation outcrops in the northeast of the Beetaloo Basin on the Tanumbirini and Broadmere stations where it records a thickness of 330 m (Abbott et al, 2001). The Limmen Sandstone forms the basal unit of the Collara Subgroup, it unconformably overlies the Balabrinni Dolostone and conformably underlies the Mainoru Formation.

Mainoru Formtion

The Mainorou Formation comprises a succession of fine grained shale and siltstone, glauconitic sandstone, limestone and calcareous mudstone. The unit has localised surface exposure on Tanumbirini Station along the northeast margin of the

Beetaloo Basin where it is estimated to reach 730 m in thickness (Pain, 1962). The Mainorou conformably underlies the Crawford Formation.

Crawford Formation

The Crawford Formation represents a succession of thick bedded, fine grained micaceous sandstone with thin interbedded siltstone and mudstone, and minor cross-bedded, medium grained sandstone. The formation is approximately 200 m in thickness on Tanumbirini Station where it outcrops along the north-east margin of the Beetaloo Basin (Paine et al, 1963). The Crawford Formation conformably underlies the Abner Sandstone.

Abner Sandstone

The Abner Sandstone is a clastic sequence formally divided into the basal Arnold Sandstone, the Jalboi Formation and the Hodgson Sandstone. In the southern McArthur Basin it forms a single undifferentiated sandstone succession (Abbott et al, 2001). The Arnold Sandstone and Hodgson Sandstone formations consist of massive cross-bedded quartz sandstone while the intervening Jalboi Formation comprises interbedded fine sandstone and siltstone punctuated with thick beds of coarser grained quartz sandstone. All three formations outcrop along the north-east margin of the Beetaloo Basin on Tanumbirini and Beetaloo stations. The formation thickness in this vicinity is estimated at 180 m for the Arnold Sandstone and Jalboi Formation respectively and 300 m for the Hodgson Sandstone Formation (Paine et al, 1963). The Abner Sandstone unconformably underlies the Corcoran Formation.

Corcoran Formation

The Corcoran Formation comprises upward fining cycles of laminated mudstones and siltstones with thin beds of fine sandstone that increase in frequency toward the top of the sequence (Lanigan, 1994). The formation outcrops in the north-east of the Beetaloo basin on Tanumbirini Station where it reaches 430 m in thickness (Paine et al, 1963). Alltree-2 records the only intersection in the Beetaloo Basin, the drill-hole penetrated 41 m of the formation before terminating in a dolerite sill that intrudes the Corcoran Formation along the northern margin of the basin. The Corcoran Formation forms the basal unit of the Maiwok Subgroup and forms a gradational contact with the overlying Bessie Creek Sandstone.

Bessie Creek Sandstone

The Bessie Creek Sandstone comprises a very fine to fine grained quartz sandstone, massive to planar in structure. The formation displays visible compaction, silicification and fracturing, and original porosity has been occluded by silica, chlorite and clays (Lannigan, 1994). The Bessie Creek Sandstone outcrops on Tanumbirini and Carpentaria stations along the north east of the Beetaloo Basin. Alltree 2 is the only drillhole to fully penetrate the formation intersecting 442 m of fine grained sandstone. The Bessie Sandstone conformably underlies the Velkerri Formation.

Velkerri Formation

The Velkerri Formation represents a thick upward coarsening shale succession informally divided into and a “Lower”, “Middle” and “Upper” sequence. The “Upper” and “Lower” units broadly contain an organically poor succession of mudstone, claystone and siltstone with minor sandstone interbeds. The “Middle” Velkerri forms a sequence of predominantly organic rich mudstone, claystone and minor siltstone. The “Middle” Velkerri represents the primary target for unconventional shale gas exploration in the Beetaloo Basin. The full thickness of the Velkerri Formation is intersected in Alltree-2 (838 m) and Walton-2 (709 m). These wells are situated on the Walton High where the “Upper” Velkerri Formation has been partially eroded. In Walton-2 the “Lower” Velkerri is intruded by a dolerite sill 109 m in thickness. Partial sequences of the Verlkerri Formation are recorded in McManus-1 (879 m) in the north of the basin and Shenandoah-1 (514 m) in the center of the basin. The Velkerri Formation unconformably underlies the Moroak Sandstone.

Moroak Sanstone

The Moroak Sandstone comprises a sequence of fine to coarse grained cemented quartz sandstones, which in the top section of the formation are massive and display a coarsening upwards trend. The Moroak Sandstone displays characteristic fracturing, which contributes to the permeability of the sandstone (Silverman, 2007). The Moroak Sandstone is absent in drill holes on the north of the Walton High (Alltree-1, Walton-2) where the formation has been eroded but is otherwise extensive in the Beetaloo Basin. The formation thickens towards the centre of the basin attaining a maximum recorded thickness of 483 m in Shenandoah-1. The Moroak Sandstone conformably underlies the Kyalla Formation.

Kyalla Formation

The Kyalla Formation represents a silty mudstone with thin planar interbeds of siltstone and sandstone. More significant intervals of fine sandstone up to 70 m in thickness are recorded in the lower half of the formation (Lanigan et al, 1994). The Kyalla Formation is absent north of the Walton High and has been eroded across the Arnold Arch, resulting in a thinner sequence over this structural feature. The formation is otherwise extensive across the Beetaloo Basin, it thickens towards the centre of the basin reaching a maximum thickness of 776 m in Shenandoah-1. The Kyalla Formation unconformably underlies the Jamison Sandstone.

Jamison Sandstone

The Jamison Sandstone comprises a very fine to coarse grained quartz sandstone that is moderately to well sorted and displays an upwards coarsening trend. The top third of the formation characteristically contains a cleaner sand unit, 10 – 20 m thick, that becomes progressively shalier and grades into the overlying Hayfield Mudstone (Silverman et al, 2007). The Jamison Sandstone can be distinguished from underlying Roper Group sandstones by the presence of feldspathic and lithic grains and a higher clay content (Lanigan et al, 1994). Unlike the underlying Roper Group formations, which are also present in the southern McArthur Basin, the occurrence of the Jamison Sandstone is restricted to the Beetaloo Basin where it is absent on the Walton High but otherwise extensive. The formation has a minimum thickness of 73 m at Chanin-1 in the west of the basin and thickens from west to east increasing to 160 m at Burdo-1. The Jamison Sandstone forms a gradational contact with the overlying Hayfield Mudstone.

Hayfield Mudstone

The Hayfield Mudstone represents a sequence of silty mudstone and claystone, which is massive to fissile and contains minor intervals of fine sandstone. Similar to the Jamison Sandstone, the Hayfield Mudstone is restricted in extent to the Beetaloo Basin. It has been eroded and is not present north of the Walton High or in the southern reach of the basin around Elliot-1 but is otherwise extensive. The formation reaches a maximum thickness of 450 m in Balmain-1 and Shenandoah-1 in the centre of the basin and thins radially toward the basin margins. The Hayfield Mudstone unconformably underlies the Bukalara Sandstone, and where absent basalts of the Antrim Plateau Volcanics.

3.4.3 Georgina Basin

The Georgina Basin is a Neoproterozoic to Devonian aged sedimentary basin that extends across 330,000 km^2 in the east of the Northern Territory and the west of Queensland (Kruse et al, 2013). The basin is divided into two depositional domains, a southern sequence and a central-northern sequence, with a distinct stratigraphy and tectonic history. The Beetaloo Basin underlies the central-northern sequence, which comprises sedimentary rocks of the Kiana Group, a volcanic sequence associated with the Kalkarindji Province and the Barkly Group, a succession of marine limestone, dolostones and siltstones. Georgina Basin sediments overlie the entire Beetaloo Basin sequence and range in thickness up to 550 m. Surface exposure is largely obscured by the overlying Carpentaria Basin with limited outcrop on the northern and southern margins of the Beetaloo Basin.

Bukalara Sandstone

The Bulkalara Sandstone represents the basal member of the Neoproterozoic Kiana Group. The formation comprises a thickly bedded quartz, feldspathic and lithic sandstone sequence with pebble conglomerates and minor interbedded shale. The Bukalara Sandstone is considered porous and permeable due to minimal cementing (Lanigan et al, 1994). The finer grained units display desiccation cracks and the formation is strongly jointed in outcrop (Kruse et al, 2013). The Bukalara Sandstone has a discontinuous coverage within the Beetaloo Basin, it outcrops on Nutwood Downs Station on the northern margin of the basin where it has an estimated thickness of 60 m. It is intersected in six of the 12 exploration holes in the basin and ranges from 0 – 73 m in thickness. The Bukalara Sandstone unconformably underlies the Antrim Plateau Volcanics.

Antrim Plateau Volcanics

The Cambrian Antrium Plateau Volcanics - previously referred to as the Nutwood Downs Volcanics - forms part of the extensive Kalkarindji Province volcanic succession (Ahmed and Munson, 2013b). The volcanic sequence contains a series of predominantly fine grained, massive basalt flows with vesicular flow tops. The Antrim Plateau Volcanics outcrops on the northern margin of the basin on Nutwood Downs Station but elsewhere underlies Cambrian and Cretaceous sediments. Airborne magnetic surveys, particularly 1st vertical derivative images, provide a powerful mapping tool and accurately define the subsurface extent of the Antrim Plateau Volcanics. The image (Figure 3-6) shows the basalts are extensive in the Beetaloo Basin except the south and east. This is corroborated by drill hole data from Elliot-1 which was the only well drilled in the basin that did not intersect the volcanic sequence. Where present the Antrim Plateau Volcanics range in thickness from 83 to 440 m, with the thickest intersections occurring in the north of the basin. The Antrim Plateau Volcanics unconformably underlies the Gum Ridge Formation.

Gum Ridge Formation

The Gum Ridge Formation represents the lower unit of the Cambrian Barkly Group and comprises massive and commonly dolomitised limestone beds with minor siliclastic mudstone (Kruse et al, 2013). Solution seams and solution collapse breecias are present throughout the limestone sequence. The Gum Ridge Formation outcrops on Powell Station on the southern edge of the Beetaloo Basin and forms a continuous subsurface coverage that dips gently from north to south. The formation ranges in thickness from 40 – 295 m, with the thickest intersections recorded in the central and southern basin. In the northern and central Beetaloo Basin the Gum Ridge Formation unconformably overlies the Antrim Plateau Volcanics, in the southern reach of the basin where the volcanics are absent the Gum Ridge Formation unconformably overlies the Roper Group. The Gum Ridge Formation conformably underlies the Anthony Lagoon Beds and where this formation is absent forms an unconformable contact with the Cretaceous Mullaman Beds.

Anthony Lagoon Beds

The Anthony Lagoon Beds form the upper unit of the Barkly Group and represent a sequence of dolomitic siltstone and interbedded dolostone, dolomitic sandstone and quartz sandstone. The formation outcrops on Tandyidgee and Helen Springs stations in the south of the Beetaloo Basin but is absent in the north and west where it pinches out against the Gum Ridge Formation. The sequence has an average thickness of 70 m with a maximum intersection of 205 m recorded at Elliot-1 in the south of the basin. The Anthony Lagoon Beds unconformably underlie the Cretaceous Carpentaria Basin sequence, except where it is absent in the south of the basin where it unconformably underlies a veneer of Quaternary and Tertiary sediments.

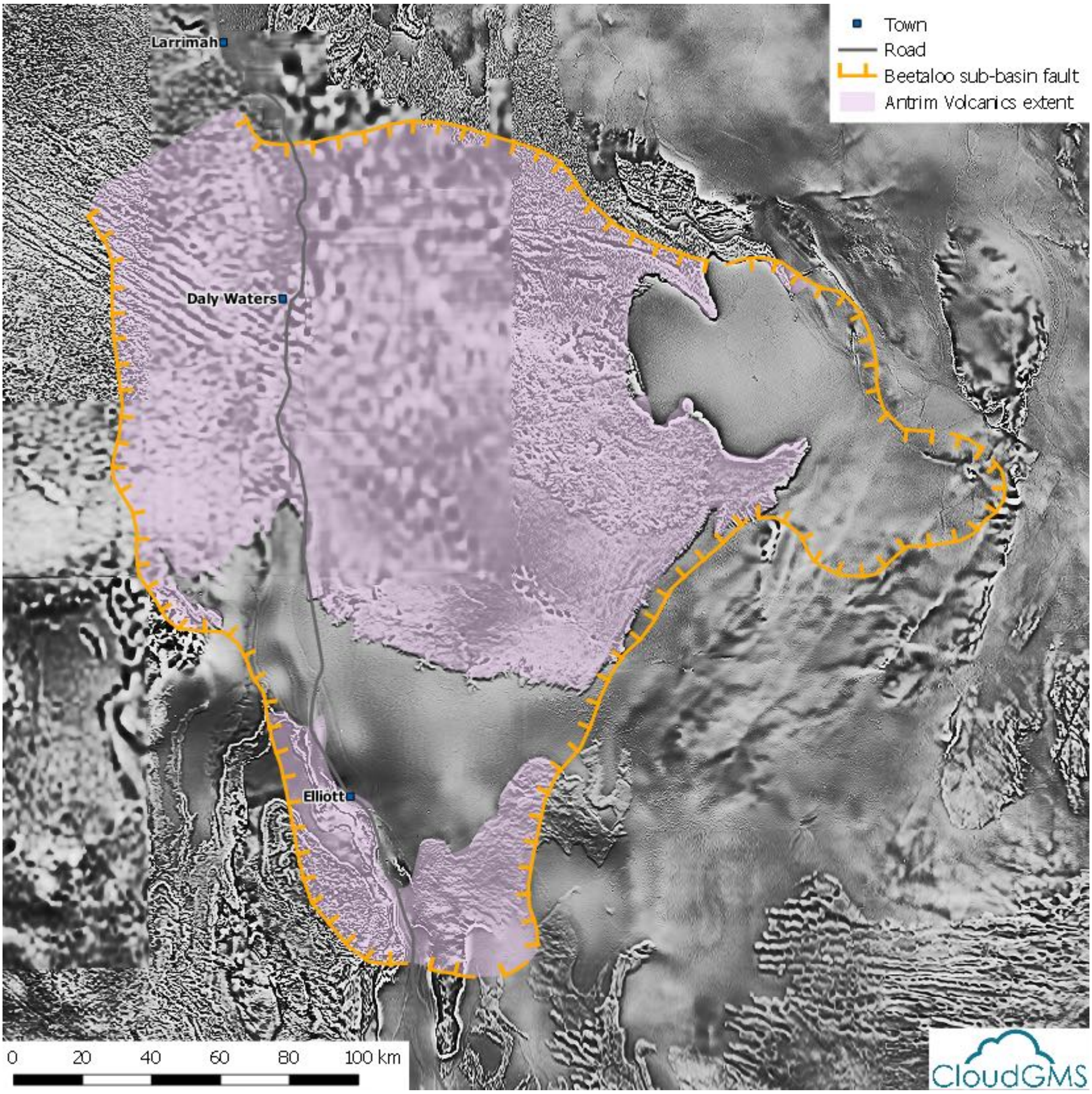

Figure 3-6 Extent of the Antrim Plateau Volcanics, background shows Magnetic First Derivative.

3.4.4 Carpentaria Basin

The Carpentaria Basin is a Jurassic to Cretaceous sedimentary sequence that extends over 680,000 km^2 in the Northern Territory, Queensland and the adjacent offshore area (Ahmed et al, 2013). In the Beetaloo region it encompasses the former Dunmarra Basin and forms a near continuous drape across the study area.

Undifferentiated Cretaceous Sediments

In the Beetaloo Basin the Carpentaria Basin is represented by an undifferentiated sedimentary sequence, previously referred to as the Mullaman Beds but now not formally named (Ahmed et al, 2013). The sequence is divided into three informal units. The basal "A" unit comprises a massive, quartz sandstone which reaches a maximum thickness of 37 m (Browne and Randal, 1969). Unit "B" consist of a thin fossiliferous siltstone layer which is overlaid by a fine grained sandstone, the total thickness of the unit is approximated at 10 m (Skwarko, 1966). The uppermost unit "C" comprises claystone with minor lenses of sand, it has a reported thickness of up to 60 m (Browne, 1969). Drillhole data from water bores and exploration wells indicate the total thickness of the Cretaceous sequence within the Beetaloo Basin ranges from 0

- 132 m with an average thickness of 50 m. The undifferentiated Cretaceous sequence forms a continuous veneer across the Beetaloo Basin with the exception of the south-west margin. The sequence unconformably underlies undifferentiated Quaternary and Tertiary units.

3.4.5 Cenozoic Deposits

Cenozoic deposits form a discontinuous surface cover across the Beetaloo Basin and comprise laterite profiles, freshwater limestone of the Golliger Beds and Quaternary black soil plains, alluvial and colluvial sedimentary deposits. Laterite profiles are extensively developed in the top of the Cretaceous sequence and are represented by a massive, ferruginised and pisolitic upper section and a strongly kaolinised lower section (Randal et al. 1966). Laterite profiles of up to 24 m have been recorded in water bores in the west of the study area (Randal, 1970). The Golliger Beds are a Miocene aged sandy, freshwater limestone of up to 3 m in thickness that has very localised exposure on Tanumbirini Station. Quaternary black soil plains occur in the south of the Beetaloo Basin on the Barkly Tablelands, Randal (1970) reports thicknesses of up to 6 m. Quaternary alluvial deposits comprising sand, gravel and clay deposit occur across the study area along drainage lines, floodouts, swamps and lakes. The thickest occurrence of 23 m is recorded adjacent to the Ashburton Ranges in the south of the study area. Thin colluvial deposits occur on the flanks of the Ashburton Ranges in the south and around exposures of Proterozoic rocks in the north-east of the basin.

4 Hydrogeology

4.1 PREVIOUS STUDIES

The most comprehensive investigation of water resources in the Beetaloo Basin region was undertaken by the NTG Water Resources Division (WRD), currently part of the Department of Land Resource Management (DLRM). Between 1996 and 2009 WRD completed three water resource assessment projects: the Barkly Tablelands (Tickell, 2003), the Sturt Plateau (Yin Foo, 2000) and the Gulf Study (Zaar, 2009). Combined, these studies map the shallow groundwater resources over approximately 95% of the Beetaloo Basin (see Figure 4-1).

The Water Resources Mapping of the Barkly Tablelands (Tickell, 2003) covers an extensive area of the Georgina Basin at 1:500 K scale. The southern region of the Beetaloo Basin coincides with the Region 3 Water Resource Map (Rooke and Tickell, 2003), which presents water resource development options based on typical bore yield, groundwater salinity and potential for stock dams. Field investigations, including drilling and aquifer testing, were undertaken in Regions 1 and 2 (Matthews and Rooke, 2003) but not in Region 3. Separate hydrogeology and water resource development maps were developed at 1:250 K scale for the Sturt Plateau (Yin Foo, 2002) with map Regions 3 and 4 overlying the western Beetaloo Basin. The study employed field and aerial geophysical methods to map the extent and structure of the Antrim Plateau Volcanics (Knapton, 2000) and included shallow soil profiling, hydrochemistry and isotope sampling programs (Yin Foo and Matthews 2000D). The Gulf Water study (Zaar, 2010) characterises the hydrology of the Roper River and Gulf region in five 1:250 K scale water resource maps. The hydrogeology of the north and central region of the Beetaloo Basin is described in Dumarra-Hodgson River Region sheet (Fulton and Zaar, 2009) and parts of the Limmen Bight River Region (Zaar, 2009a) and the McArthur River Region sheets (Zaar, 2009b). Field studies in the Dunmarra-Hodgson region included investigation drilling to assess the stratigraphy and thickness of the Cambrian limestone sequence in the west of the Beetaloo basin. Investigation bore RN36471 drilled under the Gulf Study program has recently been reconstructed as a nested monitoring site by DLRM as part of an ongoing investigation into the water resources of the northern Georgina Basin (pers. Comm. Tickell, 2015). The Gulf Water Study included the development of a coupled surface water groundwater model for the Roper River catchment, which captures the Beetaloo Basin region in the groundwater model domain (Knapton, 2009).

Earlier regional hydrogeological investigations were completed by the Bureau of Mineral Resources (BMR) and include the Northern Wiso Basin (Randal, 1973) and the Barkly Tablelands (Randal, 1967). The Wiso Basin study covers with the western portion of the Beetaloo Basin. Randal (1967) focuses on the groundwater regime in the eastern and central Barkly region but the hydrostratigraphy has relevance for the study area. The explanatory notes for the BMR 1:250 K Geological maps contain brief summaries of local water resources on each sheet area, of particular note is the Beetaloo and Helen Springs combined map (Randal et al, 1966) which contains a more substantial review and includes potentiometric and groundwater isohaline surfaces. In 1989, Power and Water Authority (PAWA) were commissioned to investigate the groundwater resource potential in the Tennant Creek Region and published the Helen Springs 1:250 K Hydrogeological Map and accompanying notes (Verma and Jolly, 1992). In 2000, WRD conducted further field studies in the Helen Springs area to investigate the local resource potential of the Cambrian limestone sequence (Paul, 2003). WRD also completed modelling studies to assess the impact of extraction at Shenandoah Station on the base flow in the Roper River (Knapton, 2004) and to assess water availability in the Tindall Limestone south of the Roper River (Jolly et al, 2004).

A number of local groundwater investigations have been completed by Territory and Commonwealth government agencies across the Beetaloo Basin region. These include water supply assessments (Nutwood Downs Station (MacKay, 1957) and Hayfield and Shenandoah Stations (Tickell, 2004)), WRD bore completion reports for road water supply bores along the Stuart, Buchanan and Carpentaria Highways, supply bores for the Alice Springs to Darwin railway, PAWA water supply investigations (Daly Waters and Elliot) and PAWA outstation bore completion reports (Hodgson River, Beetaloo, Newcastle Waters and Powell Creek).

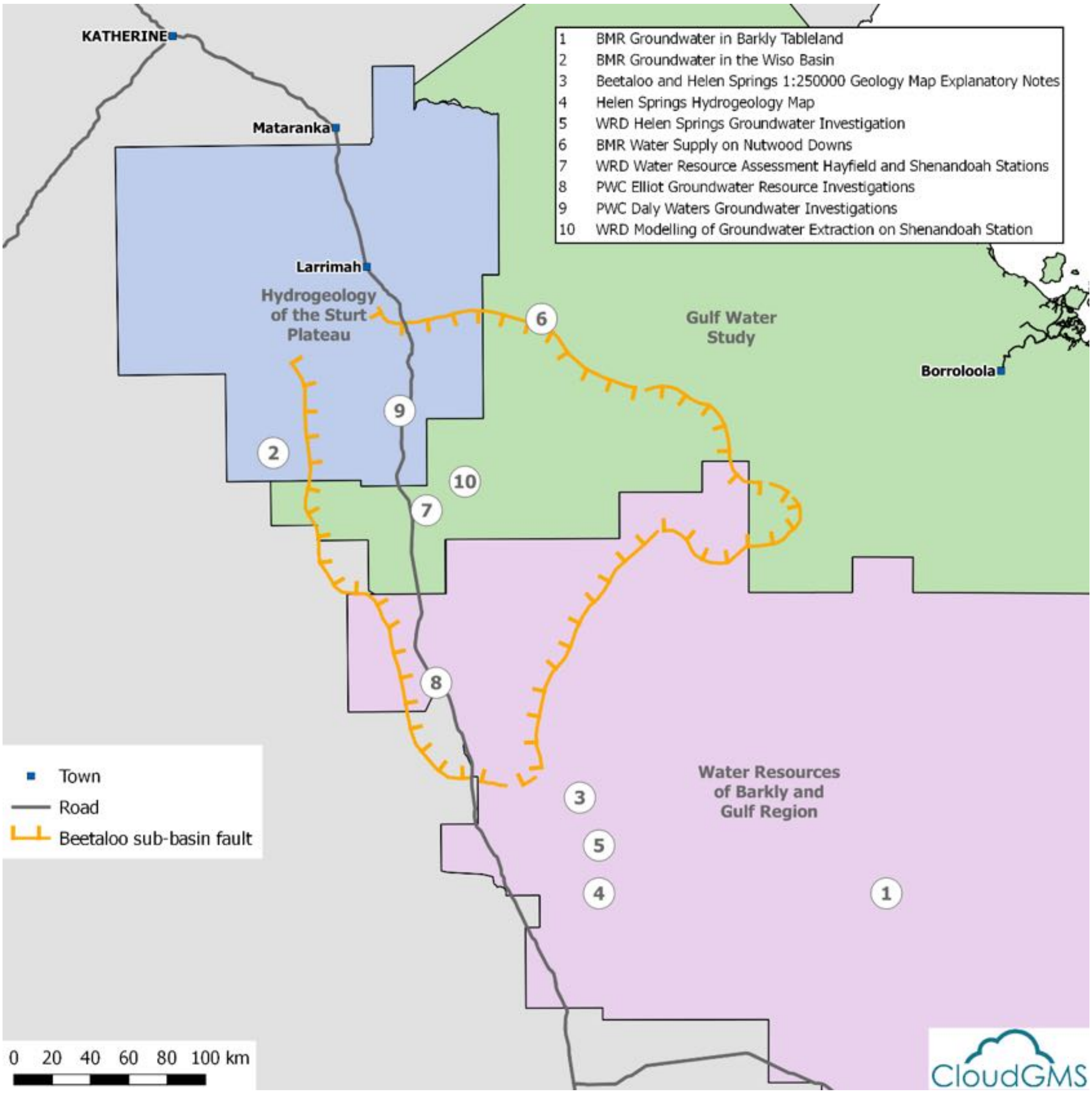

Figure 4-1 Extent of regional and local groundwater studies in Beetaloo Basin.

4.2 HYDROSTRATIGRAPHY

The following section is based on a review of over 800 water bores drilled in the Beetaloo Basin and within a 25 km radius of the basin margin. Where lithology logs were available from drilling completion reports an interpretation was made to determine formation intersections and the screened aquifer for each bore. In around 13% of bores there was either no data or the driller's log was too basic to provide a reasonable interpretation of the stratigraphy. Information on groundwater intersections was also collated making it possible to identify the number and location of failed bores in the region. Across the basin approximately 7% of all bores drilled failed to intersect a useable quantity of groundwater.

A map of groundwater bores categorised by source aquifer is provided in Figure 4-2. The Cambrian Limestone Aquifer (CLA), comprising the Gum Ridge Formation and equivalents and the Anthony Lagoon Beds, forms the major water resource in the region with approximately 80% of bores targeting this aquifer system. Proterozoic fractured rock aquifers are utilised with varied success in the east and south of the basin where the CLA is absent. The Bukalara Sandstone forms a productive local fractured rock aquifer on the northern margin of the basin and in the north-west where the CLA has limited saturated thickness marginal aquifers in the Antrim Plateau Volcanics are targeted. In the centre of the Beetaloo Basin where a thick Cretaceous sequence is present a basal sandstone aquifer provides water for stock and domestic supply.

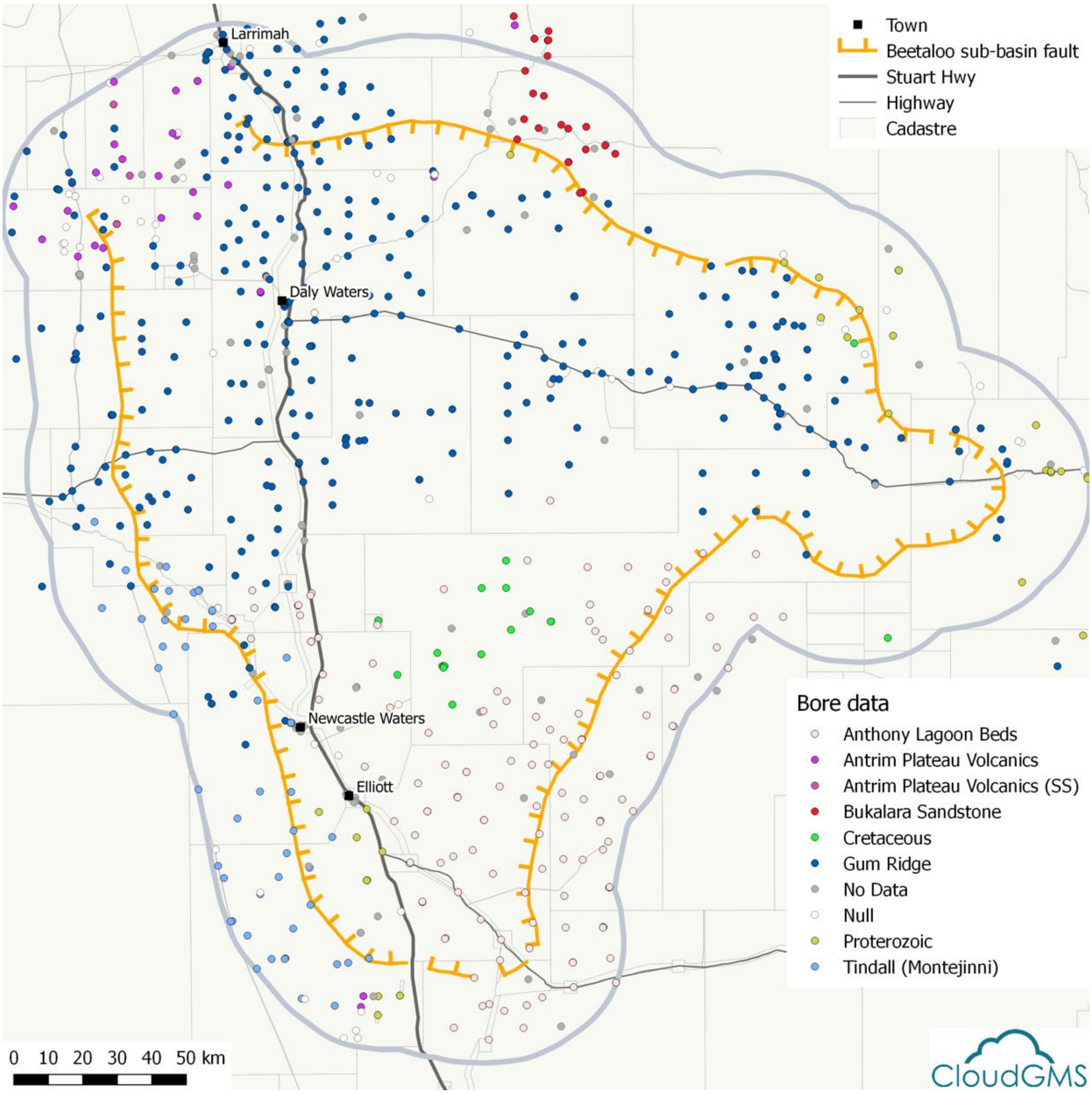

Figure 4-2 Groundwater bores classified according to source aquifer.

4.2.1 Proterozoic

A limited number of water bores penetrate the undifferentiated Proterozoic rocks where they outcrop on the north-east margin of the Beetaloo Basin and the Tomkinson Province formations along the Ashburton Range in the south of the basin. The Proterozoic hydrostratigraphy draws on these drilling records as well as water resource studies from the greater McArthur Basin (Zaar, 2009a) and inferred aquifer characteristics based on petroleum exploration drilling data from within the Beetaloo Basin.

Tomkinson Creek Beds and Renner Group

Local fractured rock aquifers occur in the Tomkinson Creek Beds and Renner Group in the Tennant Creek Block in the south-west of the Beetaloo Basin. Aquifers consist of consolidated quartz sandstone, calcareous siltstone, siliceous siltstone, chert, dolomite, limestone and dolerite sills. Verma and Jolly (1994) report low yields of 0.1 – 0.5 l/s unless fracture zones, coarse sandstone or carbonaceous lithologies are encountered. Within the study area 13 sites have targeted groundwater in the Tomkinson Creek Beds/Renner Group. Bores drilled at five sites failed to intersect significant groundwater and were abandoned. Twelve successful bores have been drilled at the remaining eight sites, most of these obtain water from fracture zones with enhanced secondary porosity. Bore depths range from 52 – 123 m (average 83m), airlift estimates of bore yields range from 0.8 – 5 l/s (average 2 l/s) and groundwater levels range from 11 – 53 mBGL (average 24 mBGL). Pump test results for RN26497, drilled into the Renner Group, reports a Transmissivity of 1.7 m^2/day, no storativity estimates are available.

Undifferentiated Proterozoic

Local scale fractured rock aquifers occur where the Roper Group and older Proterozoic formations outcrop on the north-east and eastern margin of the Beetaloo Basin. Formations have been grouped together as an undifferentiated Proterozoic fractured rock aquifer because drilling records are generally not sufficiently detailed to differentiate between various formations. Twenty-seven bores have been drilled into the Proterozoic Formations with one third of these failing to intersect significant groundwater supplies. Successful bores intersect fractured siltstone, silicified sandstone, basalt and dolomite and range in depth from 23 – 185 m (average 84 m). Bore yields range from 0.5 – 15 l/s (average 3 l/s). The highest yield of 15 l/s was recorded in fractured basalts of the Settlement Creek Volcanics and is uncharacteristically high in comparison to other bores drilled in Proterozoic formations. Groundwater levels in the Proterozoic aquifers range from 6 – 35 mBGL (average 20 mBGL).

Nathan Group

There is no information on the groundwater characteristics of the Smythe Sandstone or the Balbarini Dolostone within the Beetaloo Basin. The Balbarini Dolostone outcrops on Bahunia Downs to the east of the study area. In this region Zaar (2009a) classifies the formation as a fractured and weather rock aquifer with an expected yield range of 0.5 – 5 l/s and a local flow system. The formation has poor aquifer development where fractured and weathered zones are not intersected and failed bores are relatively common (Zaar, 2009b). However, Jackson et al (1997) notes that the upper section of the formation is likely to have enhanced secondary permeability due to karstic weathering and silicification that took place before the overlying Roper Group was deposited suggesting groundwater prospects are greater within the upper sequence of the Balbarinni Dolostone.

Roper Group

The Roper Group formations have been divided into coarse grained clastic sediments and fine grained clastic sediments on the basis of lithology (after Silverman, 2007 and Rawlings, 1999). In the absence of drilling data within the Beetaloo Basin or groundwater intersections in the greater McArthur Basin lithology has been used to infer the likelihood of a formation behaving as an aquifer or aquitard. The level of confidence in this assessment is significantly lower than the classification for Cambrian and Mesozoic sequences, in which groundwater occurrence is well documented at a local and regional level.

Coarse Clastic Formations (Aquifers)

The Limmen Sandstone and Crawford Formations represent quartz and micaceous sandstone sequences with minor interbedded siltstones located at the base of the Roper Group. Compaction and pressure solution may reduce primary porosity and permeability within these formations as they are projected to occur at significant depth within the Beetaloo Basin. The Limmen Sandstone and Crawford Formation have an inferred aquifer classification.

The Abner Sandstone comprises a sequence of two massive quartz sandstone units with an intervening lower permeability unit, the Jalboi Member. Zaar (2009b) indicates that the Jalboi Member is likely to act as a semi-confining unit limiting connection between the upper and lower sandstone members. The Abner Sandstone has not been intersected within the Beetaloo Basin but is projected to occur at depth across the basin. The sandstone forms the water supply aquifer for the township of Borroloola, where individual bore yields of up to 12 l/s have been recorded (Woodford et al, 1995). Aquifer transmissivity at Borroloola is reported at between 34 and 83 m^2/day and storativity is estimated to range from 8.2×10^{-6} – 1.7×10^{-5} (Woodford et al, 1995). Permeability is attributed to the effects of weathering and the dissolution of carbonate cementing within the sandstone, it is noted to be greater in outcrop and appears localised as the high bore yields observed at Borroloola have not been achieved in the formation elsewhere in the region. Zaar (2009b) classifies the Abner Sandstone as a fractured and weathered rock aquifer with a local scale flow system and a likely yield range of 0.5 – 5 l/s.

The Bessie Creek Formation, Moroak Sandstone and Jamison Sandstone represent the main conventional reservoir targets within the Beetaloo Basin. These formations display good preservation of porosity and permeability around the dominant structural elements within the basin, however, off structure these attributes are more variable as diagenesis has significantly reduced the original porosity and permeability through the occlusion of pore space by quartz overgrowth, authigenic clays and carbonates (Silverman, 2007). Compaction and pressure solution have also affected reservoir properties where the formations occur at greater burial depths.

Surface and core samples from the north-east of the Beetaloo Basin suggest the Bessie Creek Sandstone has the best reservoir characteristics of all sandstones in the Roper Group (Robsearch, 1997). Porosity ranges up to 15% and reflect a combination of primary and secondary porosity, permeability ranges up to 359 mD (0.3 m/day). There are no water bores drilled in the Bessie Creek Formation within the study area. Seventy kilometres north of the basin at Minyerri local aquifer development occurs in the base of the formation where it forms a contact with the underlying Corcoran Formation. Supplies from the aquifer are marginal with bores rated at 1 l/s. In the Limmen River and McArthur River regions Zaar (2009b) classifies the Bessie Creek Sandstone as a local scale fractured and weathered aquifer with a yield of between 0.5 – 5 l/s.

The Moroak Sandstone is intersected in six of eleven exploration wells within the Beetaloo Basin. The formation comprises mostly cemented fine to medium sand with porosity and permeability that is predominantly secondary in nature and derived from natural fracturing (Robsearch, 1997). A zone of higher permeability is believed to be centred over the Arnold Arch in the east of the basin. Core porosities generally range from 5 – 15% with occasional samples recording 19% (Silverman, 2007). Drill stem tests report permeability values of 55 and 274 mD (0.05 and 0.23 m/day). There are no recorded water bores within the Moroak Sandstone in the Beetaloo Basin or the greater gulf study region. Zaar (2009b) categorises the formation as a fractured and weathered rock aquifer with local flow systems and a yield range of 0.5 – 5 l/s. This classification is based on the similarity in outcrop morphology and lithology between the Moroak Sandstone and other Roper Group sandstones.

The distribution of the Jamison Sandstone is restricted to the Beetaloo Basin where it is intersected at depth in ten exploration wells and has an average thickness of 100 m. The formation generally comprises very fine to fine sands, except in the eastern extent of the basin (Burdo 1) where coarser sequences are recorded. A conglomerate occurs at the base of the sandstone sequence but is considered to have no reservoir potential (Robsearch, 1997). Porosity vs depth and porosity vs permeability plots suggest that most porosity is secondary in nature. Porosities generally range from 6 – 18 % with rare values of up to 21% (Silverman, 2007). Permeability is commonly less than a few millidarcies (mD) but can reach 121 mD (0.1 m/day) in discrete sections. There are no recorded groundwater intersections in the Jamison Sandstone from water bores, the formation is inferred to form a local aquifer where fracture development has enhanced permeability.

Fine Clastic Formations (Aquitards)

Dominantly fine grained clastic formations within the Roper Group include the Mainoru Formation, the Corcoran Formation, the Velkerri Formation, the Kyalla Formation and the Hayfield Mudstone. With the exception of the Hayfield Mudstone these formations outcrop east of the Beetaloo Basin on the Limmen River and McArthur Basin mapsheets. In outcrop Zaar (2009b) groups the formations as fractured and weathered rocks with minor groundwater resources, the poorest water resource potential in the mapping classification. Where present aquifer development is likely to occur in minor sandy sequences, along contacts with underlying and overlying formations or where the formations display significant fracturing.

The Mainoru Formation represents the basal fine grained clastic unit in the Roper Group. It has not been intersected in the Beetaloo Basin but is estimated to reach thickness in excess of 700 m where it outcrops to the northeast of the basin on Tanumubirini Station. In areas where significant deformation has not occurred thick sequences of shale, siltstone and mudstone in the Mainoru Formation are inferred to operate as aquitards.

The Corcoran Formation comprises laminated siltstone and mudstone that becomes sandier toward the top of the sequence. Minor water resources have been encountered in this upper sequence. Seepage yields of up to 0.9 l/s have been recorded from a thin sequence of Corcoran Formation where it overlies the Abner Sandstone at Borroloola (Woodford et al, 1995). Minor yields are also recorded at the top of the Corcoran Formation where it forms a contact with the Bessie Creek Sandstone at Minyerri (Zaar, 2009b). The Corcoran Formation is intersected in All-Tree 1 and is inferred to occur at depth across the Beetaloo Basin. The formation has an estimated thickness of over 400 m where it outcrops on Tanumbirini Station. Thicker, undeformed sequences of mudstone and shale are inferred to operate as aquitard layers.

The Kyalla Formation and Velkerri Formation both represent unconventional shale gas targets within the Beetaloo Basin. Silverman (2007) notes that the Kyalla Formation has significant potential to act as a seal for the underlying Moroak Sandstone. The formation is continuous across the basin except north of the Walton High. It obtains a thickness of over 700 m in the centre of the basin and where substantial mudstone sequences are encountered it is likely to operate as an aquitard and retard vertical flow. The potential exception is over the Arnold Arch, where the upper section of the formation is eroded leaving a thinner basal sequence of Kyalla Formation (170 m) that has a higher proportion of sandstone interbeds and may display enhanced fracturing associated with the underlying structural feature.

The Velkerri Formation represents a substantial shale and siltstone sequence of up to 879 m that is extensive across the Beetaloo Basin. Silverman (2007) suggests that the Velkerri Formation is likely to provide a competent seal for the underlying Bessie Creek Sandstone and the formation is inferred to operate as a regional aquitard within the Beetaloo Basin isolating aquifers in the underlying Roper Group from the overlying Cambrian and Mesozoic systems.

The Hayfield Mudstone is a fine grained mudstone and claystone sequence with minor sandstone intervals that has an average thickness of 320 m. The formation is restricted to the Beetaloo Basin and is extensive except north of the Walton High and in the south of the basin. Silverman (2007) notes that the Hayfield Mudstone is likely to act as a seal for the underlying Jamison Sandstone. Where present it is considered to act as an aquitard separating the Roper Group from the overlying Cambrian sequence. Due to its relatively younger time of deposition the Hayfield Mudstone has not experienced the same level of deformation as older Roper Group sediments and a number of deeper seated faults do not penetrate the formation. Minor sandstone interbeds occur within the greater mudstone sequence and more significant layers may behave as local aquifers. One sandstone inlier, located around 60 m above the base of the formation has a thickness of 5- 15 m, porosities of 5 – 15 % and a permeability of up to 20 mD (0.02 m/day)

4.2.2 Bukalara Sandstone

The Bukalara Sandstone forms a fractured and weathered aquifer with a local scale flow system where it outcrops just beyond the northern margin of the Beetaloo Basin (Fulton and Zaar, 2009). The formation is also present at depth in the north and centre of the basin but is discontinuous between these areas. The Bukalara Sandstone comprises quartz sandstone with visible porosity (Lanigan et al, 1994) and minor shale interbeds, secondary porosity is likely to be enhanced by evident jointing within the sandstone outcrop.

Twenty-two bores have been constructed in the Bukalara Sandstone on Nutwood Downs and Hodgson River stations where it provides a stock and domestic water supply. Most bores penetrate the overlying Antrim Plateau Volcanics, which forms a local confining layer over the sandstone aquifer of varying in thickness between 10 and 140 m (Fulton and Zaar, 2009). To the north-east of the volcanic exposures the Bukalara Sandstone outcrops and is likely to be unconfined, though there are very few bores drilled in the outcrop area. Completion depths for bores screening the Bukalara Sandstone range from 32 – 150 m (average 89 m), while airlift estimates of bore yield range from 0.3 – 5 l/s (average 2.6 l/s). Pumping tests have been completed on two production bores and report an aquifer transmissivity of 18 – 79 m^2/day, estimates of storage coefficient are not available. Groundwater levels in the Bukalara Sandstone range from 3 – 34 mBGL (average 17 mBGL) and groundwater flow direction is to the north (Fulton and Zaar, 2009).

4.2.3 Antrim Plateau Volcanics

The Antrim Plateau Volcanics form a continuous base beneath the Cambrian limestone aquifer across the northern and central Beetaloo Basin but is absent in the south and east of the basin (see Figure 3-6 for distribution). Thicker sequences of the massive basalt flows have negligible primary porosity and where present the Antrim Plateau Volcanics are considered to form a regional basement to the overlying sedimentary sequence (Tickell, 2005, Yinfoo, 2002). At a local scale the Antrim Plateau Volcanics can form a viable aquifer and the basalt provides a water supply for a number of communities in the greater region including Lajamanu, Minyerri and Pigeon Hole. Localised aquifer development is commonly dependent on enhanced secondary porosity derived from fault related fracturing (Yin Foo, 2002).

In the Beetaloo Basin, the Antrim Plateau Volcanics forms a localised, fractured rock aquifer where it sub-crops at shallow depths beneath the Cambrian Limestone sequence in the north-west of the basin. The formation outcrops on the northern edge of the basin on Nutwood Downs Station, in this area the volcanics are competent with limited aquifer development and water bores target the underlying Bukalara Sandstone (McKay, 1957). Minor water resources have also been intersected in the Helen Springs Volcanics to the west of the Ashburton Ranges beyond the southern margin of the Beetaloo Basin.

On the Sturt Plateau in the north-west of the study area a review of drilling logs reveals that the Antrim Plateau forms a marginal fractured rock aquifer. Over a third of water bores drilled in this area failed to intersect significant groundwater within the volcanics and very few constructed bores exclusively screen the basalt sequence. The majority of successful water bores target the unconformable contact between the Antrim Plateau Volcanics and the Gum Ridge Formation or thin sandstone beds within and at the base of the volcanic sequence. Thirty-one water bores wholly or partially screen the volcanic sequence in this area of the basin with completion depths ranging from 61 – 240 mBGS (average 115 mBGS) and bore yields are estimated at between 0.3 – 5 l/s (average 1.5 l/s). Results from three pumping tests report a transmissivity range of 0.8 – 14 m^2/day. Test results from a fourth bore (RN30987) reports a transmissivity of 2370 m^2/day, however, this is not considered representative of the volcanics as the ionic signature of the groundwater and standing water level both suggest contribution from the overlying Gum Ridge Formation. The groundwater level in the basalt bores ranges from 14 – 89 mBGL (average 59 mBGL). Relative groundwater elevations do not reveal a consistent regional flow direction.

4.2.4 Gum Ridge Formation

The Gum Ridge Formation and Anthony Lagoon Beds are broadly grouped as the Cambrian Limestone Aquifer (CLA) (Fulton, 2009a), a significant regional aquifer system comprising fractured and karstic rocks that extends across the Georgina, Wiso and Daly Basins. Yin Foo (2002) describes the Gum Ridge Formation and Anthony Lagoon Beds as distinct hydrostratigraphic units in the Sturt Plateau region, however the recent construction of a nested piezometer site (RN36471) by DLRM south of Dunmarra and aquifer testing completed in the Helen Springs region (Rooke, 2002) suggest there is a level of vertical connection across the Cambrian Limestone sequence.

The Gum Ridge Formation and its lateral equivalents in the Wiso Basin, the Montejinni Limestone and Tindall Limestone, comprise an extensive aquifer system that forms the principle water resource in the northern half of the Beetaloo Basin; in the south of the basin the Gum Ridge Formation occurs at depth beneath the Anthony Lagoon Beds. The Gum Ridge aquifer is locally unconfined where it abuts outcropping Proterozoic Formations in the north-east of the Beetaloo Basin and also in the northwest on Avago, Sunday Creek and Birdum stations where the limestone sequence thins and has limited saturated thickness over the Antrim Plateau Volcanics. The Gum Ridge is confined by Cretaceous mudstones in the north and central Beetaloo Basin and by lower permeability layers within the Anthony Lagoon Beds in the south.

The aquifer comprises massive grey limestone beds that are heavily fractured and commonly karstic. Formation permeability is highly dependent on the development of these dissolution and fracture features. A review of water bores that intersect cavities or record circulation loss during drilling suggests that the karst development is widespread across the Beetaloo Basin and that aquifer permeability is generally not spatially correlated.

Within the study area over 415 operational and abandoned water bores screen the Gum Ridge Formation (and equivalents), with bore depths ranging from 34 – 221 m (average 105 m). Reported airlift yields range from 0.3 – 20 l/s (average 3.5 l/s), though this range generally reflects the bore water requirement which being largely for stock watering is modest. Pump test results and yields from irrigation bores drilled in the analogous Daly Basin Tindall Limestone suggest that yields of up to 100 l/s may be possible in specifically constructed bores. The standing water level (SWL) in the Gum Ridge Formation ranges from 23 to 155 metres below ground level (mBGL). The shallowest water levels (<50 mBGL) occur along the north-east margin and in the north-west of the Beetaloo Basin. The deepest groundwater levels (>125 mBGL) occur along the Carpentaria Highway on Amungee Mungee and Tanumbirini stations.

Results from 21 pumping tests undertaken by WRD in the study area report a Transmissivity (T) range of 3 – 3377 m^2/day for the Gum Ridge and Montejinni Limestone aquifer. The lowest T values (<50 m^2/day) occur in the northwest of the basin where the Gum Ridge Formation has very limited saturated thickness and aquifer development is restricted to the unconformity with the underlying Antrim Plateau Volcanics (Yin Foo, 2002). Five test reports did not provide an estimate of T due to negligible (< 10 cm) drawdown, the transmissivity for these bores likely to be at the higher end of the stated range. Most pumping tests identified were single well bore performance tests and do not provide an estimate of storativity. The exception is the Helen Springs groundwater investigation (Paul, 2003) which estimate the Gum Ridge storativity at 5.6×10^{-4}.

4.2.5 Anthony Lagoon Beds

The Anthony Lagoon Beds form the upper unit of the Cambrian Limestone sequence within the Georgina Basin. The formation contains the principle water resource and uppermost aquifer system in the south of the study area but thins progressively to the north pinching out around the Carpentaria Highway. The formation is absent west of the Ashburton Ranges but a similar sequence of interbedded siltstones, dolomite and limestone is reflected in the upper section of the Montejinni Limestone. The Anthony Lagoon Beds is unconfined where it outcrops on the southern edge of the Beetaloo Basin and along the eastern flank of the Ashburton Ranges. Outside these areas the aquifer is confined by the overlying Cretaceous sequence.

The Anthony Lagoon Beds is a fractured rock aquifer comprising silicified limestone, dolomitic siltstone, fine grained sandstone and dolomite. Similar to the Gum Ridge Formation the Anthony Lagoon Beds displays dissolution and karst features that significantly enhance the permeability of the formation. The distinction between the two Cambrian Limestone Formations is not clear in many water bore logs due to circulation loss during drilling, consequently some crossover between the bore and water quality statistics for these formations is expected.

Over 78 bores have been constructed in the Anthon Lagoon Beds with completion depths from 63 to 175 m (average 109 m). Estimates of bore yields from air lifting range from 1 to 10 l/s (average 2.9 l/s) and are consistent with pump test yields (10 l/s) at Elliot where the Anthony Lagoon Beds is tapped for town water supply. The standing water level in the aquifer ranges from 42 – 115 mBNS (average 76 mBNS) and is closest to the surface where the aquifer outcrops in the south of the basin. Results from 11 pump tests display significant variation in aquifer transmissivity which ranges from 13 – 1400 m^2/day, most of these tests were undertaken around Elliot and in the Helen Springs region (Paul, 2003) adjacent the southern edge of the study area. Storage coefficients for the Anthony Lagoon Beds are reported at between 2.5×10^{-3} and 9.7×10^{-5} (Paul, 2003).

4.2.6 Undifferentiated Cretaceous Sediments

Undifferentiated Cretaceous sediments form a continuous cover over the Cambrian Limestone with the exception of the southern edge of the Beetaloo Basin where the Anthony Lagoon Beds are exposed. The thickness of the Cretaceous sequence is variable ranging from less than 25 m in the north-west (Sturt Plateau) and in the south beyond Elliot to over 100 m in the central and north-eastern regions of the basin. Over much of the Beetaloo Basin the Cretaceous sequence lies above the regional groundwater surface and does not contain a groundwater resource. The exception is the central area of the basin on the south-west of Beetaloo Station where the basal sandstone unit forms a local aquifer that is exploited for stock and domestic water supply. Where the upper claystone and mudstone units are fully represented the Cretaceous sequence restricts diffuse recharge and acts as a local confining layer to the underlying CLA. In the north-west of the basin (Avago, Birdum Creek and Sunday Creek stations) the upper claystone units are eroded and the basal Cretaceous sandstones act as a recharge pathway to the underlying limestone aquifers (Yin Foo, 2002).

In the central Beetaloo Basin over 17 bores have been constructed in a fine to coarse grained quartz sandstone aquifer that forms the base of the Cretaceous sequence. Bore depths range from 71 – 145 mBGL (average 91 mBGL) and bore yields are estimated at between 0.3 – 4 l/s (average 2.3 l/s). Pump test results from a water supply bore for Beetaloo homestead report an aquifer transmissivity of 41 m2/day, no estimates of storativity are available. The standing water level in the Cretaceous aquifer ranges from 56 – 80 mBGL (average 64 mBGL), groundwater gradients are flat and there is no clear flow direction within the local aquifer.

4.2.7 Undifferentiated Cenozoic

There are no reported groundwater intersections with the Cenozoic laterite profiles, Golliger Beds or alluvial deposits and these sequences are situated above the regional groundwater surface. Laterite profiles in other areas of northern NT are observed to form ephemeral aquifers that become saturated in response to the wet season rainfall and drain quickly in the intervening dry seasons (Tickell, 2008). While not reported in the study area there is potential for the development of transient and localised perched aquifer systems where laterite profiles are well developed or within sandier alluvial sequences that overlie less permeable Cretaceous siltstones.

Table 4-1 Hydrogeological characteristics of geological formations of the Beetaloo Basin

FORMATION	LITHOLOGY	THICKNESS (m)	EXTENT	AQUIFER CLASSIFICATION	YIELD (l/s)	T (m2/day)	S	POROSITY (%)	HYD. COND. (m/day)	AVE. EC (µs/cm)	COMMENT
Tomkinson Creek Beds/Renner Group	Sandstone, siltstone, chert, dolomite, limestone, dolerite	2400	South of basin on outcrop of the Ashburton Ranges	Aquifer (Local)	0.8 – 5	1.7	-	-	-	760	Marginal fractured rock aquifer with high number of bores failing to intersect significant groundwater
Undifferentiated Proterozoic	Fractured siltstone, sandstone, dolomite, basalt	5000	North-east and eastern basin margins	Aquifer (Local)	0.5 – 5	-	-	-	-	760	Marginal fractured rock aquifer with high number of bores failing to intersect significant groundwater
Smythe Sandstone	Massive conglomerate, lithic and dolomitic sandstone	250*	Inferred to occur at depth within the Beetaloo Basin	Aquifer (inferred)	-	-	-	-	-	-	Very limited data - aquifer classification inferred on the basis of lithology
Balbarini Dolostone	Dolomite, dololutite and dolomitic siltsone	340*	Inferred to occur at depth within the Beetaloo Basin	Aquifer (Local)	0.5 – 5	-	-	-	-	-	Fractured and weathered rock aquifer. Limited primary porosity, groundwater prospects greater in weathered/silicified upper sequence.
Limmen Sandstone	Fine-coarse quartz sandstone with interbeded siltstone	330*	Inferred to occur at depth within the Beetaloo Basin	Aquifer (inferred)	-	-	-	-	-	-	Very limited data - aquifer classification inferred on the basis of lithology
Mainoru Formation	Siltstone, mudstone, shale with minor interbedded sandstone	730*	Inferred to occur at depth within the Beetaloo Basin	Aquitard (inferred)	-	-	-	-	-	-	Inferred aquitard on basis of dominant lithology and formation thickness
Crawford Formation	Fine micaceous sandstone with interbedded siltstone	200*	Inferred to occur at depth within the Beetaloo Basin	Aquifer (inferred)	-	-	-	-	-	-	Very limited data - aquifer classification inferred on the basis of lithology
Abner Sandstone	Massive quartz sandstone with intervening mudstone unit	660*	Inferred to occur at depth within the Beetaloo Basin	Aquifer (local)	0.5 – 12	39 – 83	8.2×10^{-6} – 1.7×10^{-5}	-	-	-	Permeability locally enhanced in outcrop by weathering. Yields of 12 l/s achieved at Borroloola but may not be representative of regional aquifer characteristics.
Corcoran Formation	Mudstone, siltstone and fine interbedded sandstone	> 41	Intersected All-tree 1, otherwise inferred within Beetaloo Basin	Aquitard Aquifer (local)	< 1	-	-	-	-	-	Inferred aquitard on basis of dominant lithology and formation thickness. Minor water intersections occur at contact with underlying/overlying formations
Bessie Creek Sandstone	Fine grained, silicified quartz sandstone	442	Intersected All-tree 1, otherwise inferred within Beetaloo Basin	Aquifer (local)	0.5 – 5		-	< 15	0.3	-	Aquifer development dependent on development of secondary permeability and porosity
Velkerri Formation	Mudstone, claystone, siltstone	709 – 879	Continuous across basin	Aquitard (Regional)	-	-	-	6 (mean)	-	-	Middle Velkerri represents the primary unconventional shale gas target
Moroak Sandstone	Fractured, cemented quartz sandstone	0 – 483	Absent north of Walton High otherwise extensive	Aquifer (local)	0.5 – 5	-	-	5 – 15	0.05, 0.23	*131000^*	Aquifer development dependent on development of secondary permeability and porosity
Kyalla Formation	Silty mudstone with thin beds of siltstone and sandstone	0 - 776	Absent north of Walton high, thins to 170 m over Arnold Arch	Aquitard	-	-	-	4 (mean)	-	-	
Jamison Sandstone	Very fine to fine grained quartz sandstone	0 – 160	Absent north of Walton High otherwise extensive	Aquifer (local)	-	-	-	6 – 18	< 0.1	*138000^*	Aquifer development dependent on development of secondary permeability and porosity
Hayfield Mudstone	Mudstone, claystone with sandstone interbeds	0 – 450	Absent north of Walton High and in the south of the basin	Aquitard (Regional) Aquifer (local)	-	-	-	5 – 15 (Sandstone)	0.02 (Sandstone)	*32000^*	Relatively undeformed and thick mudstone sequences likely to act as aquitard. Minor aquifers occur within sandstone interbeds, mostly in basal sequence
Bukalara Sandstone	Jointed sandstone and minor siltstone	0 – 73	Discontinuous, outcrops along northern margin of basin	Aquifer (Local)	0.3 – 5	17 – 78	-	12 – 21	0.004 – 0.95	1030	Local scale sandstone aquifer, permeability enhanced by visible jointing
Antrim Plateau Volcanics	Massive basalt and minor interbedded sandstone	0 – 440	Absent in south/east of basin, thickens toward outcrop area.	Aquitard (Regional) Aquifer (Local)	0.3 - 5	0.8 - 17	-	-	-	910	Thick undeformed basalt sequences are likely to operate as aquitard between Roper Group and CLA. Minor fractured rock aquifers occur at local scale.
Gum Ridge Formation	Fractured and karstic limestone	0 – 295	Continuous except where Proterozoic rocks outcrop	Aquifer (Regional)	0.3 - > 20	3 – 3377	5.6×10^{-4}	-	-	1390	Regional limestone aquifer (CLA) with karst development
Anthony Lagoon Beds	Fractured dolomite, dolomitic siltstones, fine sandstone	0 – 205	Absent in the north and west where it grades into Gum Ridge	Aquifer (Regional)	1 – 10	13 – 1400	2.5×10^{-3} – 9.7×10^{-5}	-	-	1590	Regional aquifer (CLA) with karst development in dolomite sequences
Undifferentiated Cretaceous	Siltstone and claystone with basal sandstone	0 - 132	Absent along southern margin of basin, otherwise extensive	Aquifer (Local) Aquitard (Local)	0.3 - 4	41	-	-	-	1780	Basal sandstone forms local aquifer in centre of Beetaloo Basin. Where thick the upper shale sequences may restrict recharge and confine the CLA.
Undifferentiated Cenozoic	Laterite, Limestone, Black soil, Alluvials (sand, gravels, clay)	< 24, < 3, < 6, < 23	Discontinuous distribution across Beetaloo Basin	Unsaturated	-	-	-	-	-	-	Laterite and sandy alluvial sequences may form transient, perched aquifers in response to wet season rainfall

* Thickness inferred from surface exposures on Bauhinia Shelf.
^ Indicative EC of formation water sourced from Drill Stem Test water quality analysis

4.3 GROUNDWATER FLOW

4.3.1 Regional Flow within the Cambrian Limestone Aquifer

The regional groundwater flow pattern in the CLA is presented in Figure 4-3, insufficient data is available to map flow directions in the local aquifers. The Beetaloo Basin straddles the basement divide that separates regional groundwater flow systems in the Georgina and Wiso Basins. Groundwater flow in the Georgina Basin emanates approximately 300 km south-east of the Beetaloo Basin where a major flow divide occurs in the CLA (see Figure 4-3 after Tickell, 2003). Groundwater south-east of this divide flows toward discharge points in the Lawn Hill Creek and the Gregory River in Queensland. Groundwater north-west of the divide flows through the Beetaloo Basin and discharges in the Roper River region. Recharge to the CLA forms a local flow component where the aquifer outcrops along the flanks of the Ashburton Ranges.

The regional flow direction within the Beetaloo Basin is to the north-west. Gradients in the CLA are flat-lying averaging around 10 m per 100 km (gradient of 0.0001) and flow rates are in the order of metres/year (Tickell, 2003). Along the northern edge of the basin groundwater flow in the CLA is channeled between outcropping Proterozoic rocks to the east and a zone of lower permeability Antrim Plateau Volcanics to the west. Groundwater flow emerges from the CLA in the Roper River 100 km north-west of the Beetaloo Basin and provides a major flow component of spring discharge in the Roper River between Matarkanka and Elsey National Park. High sulphate concentrations in the Bukalara Sandstone aquifer immediately north of the Beetaloo Basin suggests there is a component of flow north into local Proterozoic aquifers, see Section 4.6 for further detail.

In the west of the Beetaloo Basin in the Wiso Basin the regional flow direction is also to the north. The majority of groundwater flow in this area of the CLA originates from sinkhole recharge on the Sturt Plateau with throughflow from the Wiso Basin and the Georgina Basin only providing a small flow component (Yin Foo, 2002). Regional groundwater flow in the Wiso Basin is directed toward major discharge points in the Flora and Roper Rivers.

4.3.2 Vertical Flow Relationships

Proterozoic Formations and Cambrian Limestone Aquifer

There are no groundwater piezometers constructed in the Proterozoic Formations with which to assess vertical pressure gradients within the Beetaloo Basin. Bottom-hole pressure readings from formation tests, also known as drill stem tests (DST), have been used to make a general assessment of the vertical pressure gradients between the Roper Group Formations and the CLA. With the exception of Walton-2 the final hydrostatic head pressure reading from each DST has been converted to a relative pressure reading in metres reference to Australian Height Datum (AHD). For Walton-2 the conversion has been applied to an extrapolated formation pressure from the DST analysis. Results are compared with reduced water levels from the nearest water bore constructed in the CLA to estimate the direction and magnitude of the gradient between the test formation and the CLA. Density effects in the bore water levels are considered negligible due to the short water column depths (< 100 m), low salinity (< 1000 mg/l) and moderate temperature (< 30° C) of CLA groundwater.

DST results presented in Table 4-2 were analysed for three areas of the basin (north, central and south) across four Proterozoic Formations (Hayfield Mudstone, Jamison Sandstone, Moroak Formation and the Velkerri Formation). The analysis reveals consistent upward pressure gradients between the Roper Group Formations and the CLA with a pressure differential ranging from 49 m between the Moroak Sandstone and CLA in the south of the basin through to 135 m between the Hayfield Mudstone and the CLA in the central Beetaloo Basin.

Table 4-2 Comparison of DST Roper Group formation pressures and the regional CLA pressure surface

BEETALOO REGION	WELL TESTED	FORMATION	PROTEROZOIC FORMATION PRESSURE (mAHD)	CLA WATER LEVEL (mAHD)	GRADIENT DIRECTION WITH CLA	PRESSURE DIFFERENCE (mHEAD)
North	Walton-2	Velkerri Formation	209	154	Upwards	55
Central	Jamison-1	Hayfield Mudstone	291	156	Upwards	135
		Jamison Sandstone	271	156	Upwards	115
Central	Balmain-1	Hayfield Mudstone	264	153	Upwards	111
		Jamison Sandstone	233	153	Upwards	80
South	Elliot-1	Moroak Sandstone	206	157	Upwards	49

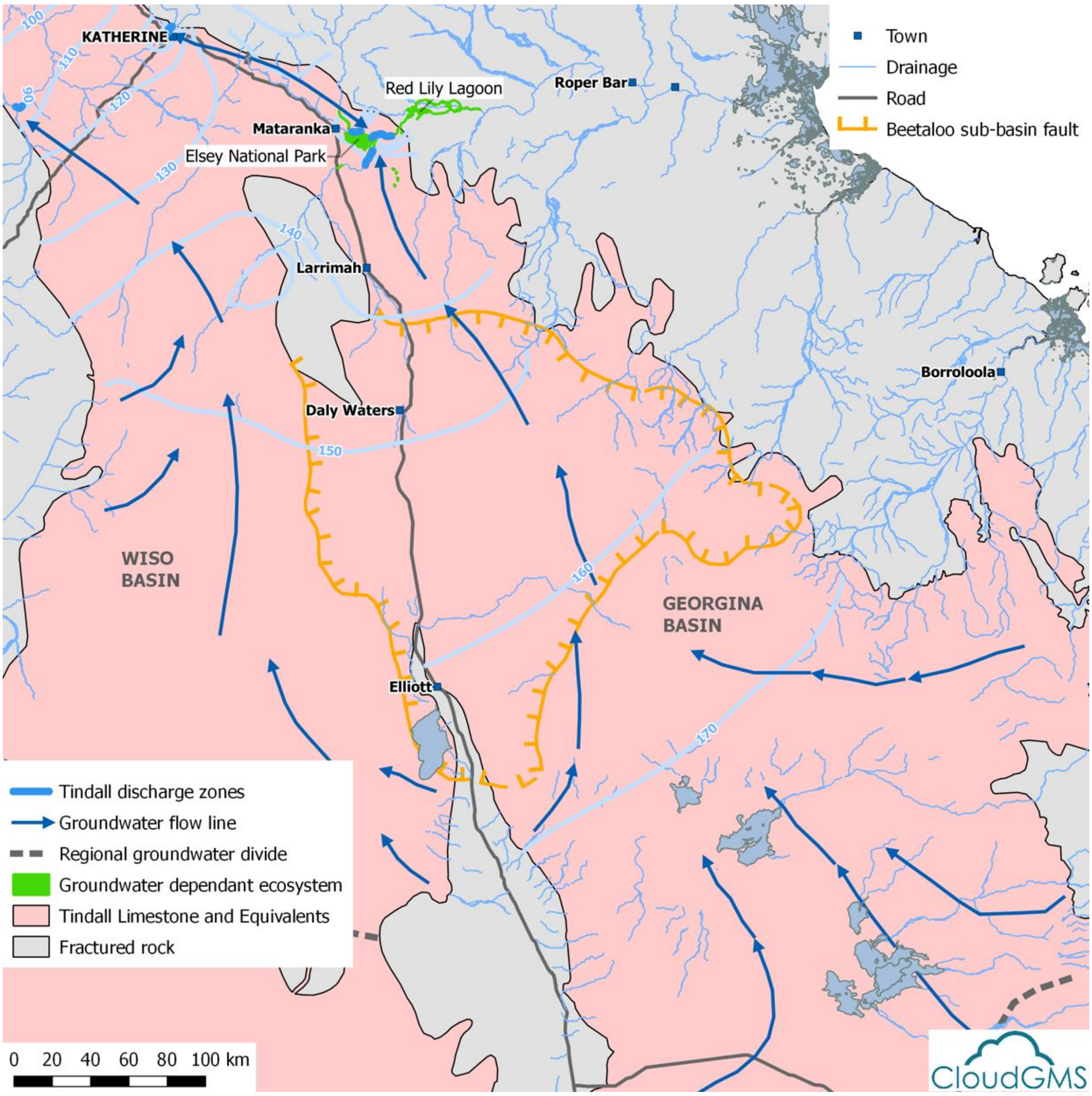

Figure 4-3 Regional groundwater flow in the Cambrian Limestone Aquifer (after Tickell, 2003).

4.4 RECHARGE PROCESSES

Groundwater recharge rates are variable across the landscape, and depend on soil type, vegetation and topography as well as rainfall amount and other climate variables. The complex interplay between these parameters means there is not a direct relationship between groundwater recharge rates and rainfall amount. There are also complex pathways for water infiltration to water tables.

Although the study area is described as semi-arid, there is a monsoonal influence and recharge occurs only in the wet season when rainfall intensity and duration are sufficient to overcome evapotranspiration (ET) and where the aquifers are unconfined. Recharge leads to the rise in groundwater levels and an increase in discharge to the rivers and at the springs. Recharge in the study area is thought to be via four mechanisms.

- direct recharge where water is added to the groundwater in excess of soil moisture deficits and evapotranspiration, by direct vertical percolation of precipitation through the unsaturated zone, it is thought that this is the dominant mechanism in areas with Cretaceous cover;
- macro-pores where precipitation is preferentially 'channelled' through the unsaturated zone and has a limited interaction with the unsaturated zone;
- localised indirect recharge where surface water can be channelled into karstic features such as dolines (sinkholes), this is a poorly understood component of recharge;
- localised indirect recharge along ephemeral drainage in the arid southern regions, this component is poorly understood and quantified. Limited study of recharge of regions with outcropping carbonates in the Daly River catchment, an area with similar hydrogeological characteristics to the study area, indicate it is dominated by macro-pore and local indirect recharge (Wilson et al., 2006).

Large decadal changes in the discharge to the Roper River suggest that most of the recharge input to the groundwater is relatively close to the discharge area. This is because the discharge from localised systems fluctuate more widely whereas discharge from larger scale systems is much steadier i.e. there is buffering present from the storage in the large groundwater system (Dahl and Nilsson, 2005).

An empirical estimate of the water balance for the Cambrian Limestone aquifer system discharging to the Roper River is presented by Jolly et al, (2004). This analysis was based on three separate methods and determined that recharge ranged from between 5 and 20 mm/yr. Using average annual discharge from the river of 120 000 ML/yr measured at G9030013 (3.8 m^3/s) and an assumed area of recharge (15 000 km^2) the estimated recharge rate was 8 mm/yr. Accounting for the estimated ET losses this was doubled to a value of 16 mm/yr (Jolly et al., 2004). The area contributing to recharge is expected to be half to two thirds the area identified in 2004, therefore diffuse recharge rates are probably two to three times greater than those estimated.

Recharge to the outcropping Cambrian Limestone in the Georgina Basin has been estimated using groundwater throughfow calculations. The CLA in the northern Georgina Basin is assumed to have a transmissivity of approximately 1000 – 2000 m^2/d (Read, 2003), the groundwater gradient is approximately 0.0001 (Tickell, 2003) across a section 200 km wide, the estimated throughflow is 20 000 – 40 000 m^3/d (or 230 – 460 l/s). The area of outcropping Cambrian Limestone is estimated at 19 750 km^2 a diffuse rate of 0.4 – 0.8 mm/yr is expected.

There is a component of groundwater flow from the southern portion of the Georgina Basin, which contributes to the discharge to the Roper River. Recharge in this arid region is expected to occur where runoff from the outcropping basement along the edges of the Georgina Basin flows over the outcropping Cambrian Limestone (Gum Ridge Formation) to the north east of Tennant Creek. The recharge volumes and mechanism are poorly understood at present, and only first order estimates are available. Recharge to the groundwater system in the southern Georgina Basin, which discharges to Lawn Hill and the Gregory River in Queensland is estimated to be between 2 and 6 mm/yr (Read, 2003). Based on throughflow calculations and the area of outcrop indicate a recharge of approximately 1 mm/yr (Tickell, 2003).

4.5 DISCHARGE PROCESSES

There are two known outlets for groundwaters of the Georgina Basin; the springs that drain into the Roper River at Mataranka to the north of the study area and the springs draining into Lawn Hill Creek and the Gregory River in Queensland (Tickell, 2003).

Major discharges occur along the headwaters of the Roper River as it intercepts the groundwater flow from the northern Georgina Basin. The groundwater from the Cambrian Limestone discharges along the bed of the river (eg Bitter Springs) and via discrete springs (eg, Rainbow Spring and Fig Tree Spring). Diffuse discharge occurs in the Elsey National Park where the basement approaches the surface forcing groundwater levels above the ground surface (Jolly et al., 2004; Tickell, 2005).

4.5.1 Discharge characteristics

The Roper River is one of the few rivers in northern Australia that exhibits perennial flows. The Roper River is characterised by a four month wet season with significant runoff and an eight month dry season with negligible surface runoff.

The highest mean monthly discharge along the Roper River occurs in March and ranges from 215 000 ML or 83 m^3/s downstream of Mataranka Homestead – aka Elsey NP (G9030176) to 1 100 000 ML or 424 m^3/s at Red Rock (G9030250). The lowest mean monthly discharge along Roper River occurs in September and October and ranges from less than 1.5 m^3/s downstream of Mataranka Homestead and 3.5 m^3/s at Red Rock (refer Figure 4-4). It should be noted that cease to flow has been observed at Red Rock.

The average annual discharge of the non-tidal section of the river is based on flows at Red Rock gauging station (G9030250). The average annual discharge 11/08/1966 to 06/01/2009 at this point was 3 289 GL (NRETAS, 2009).

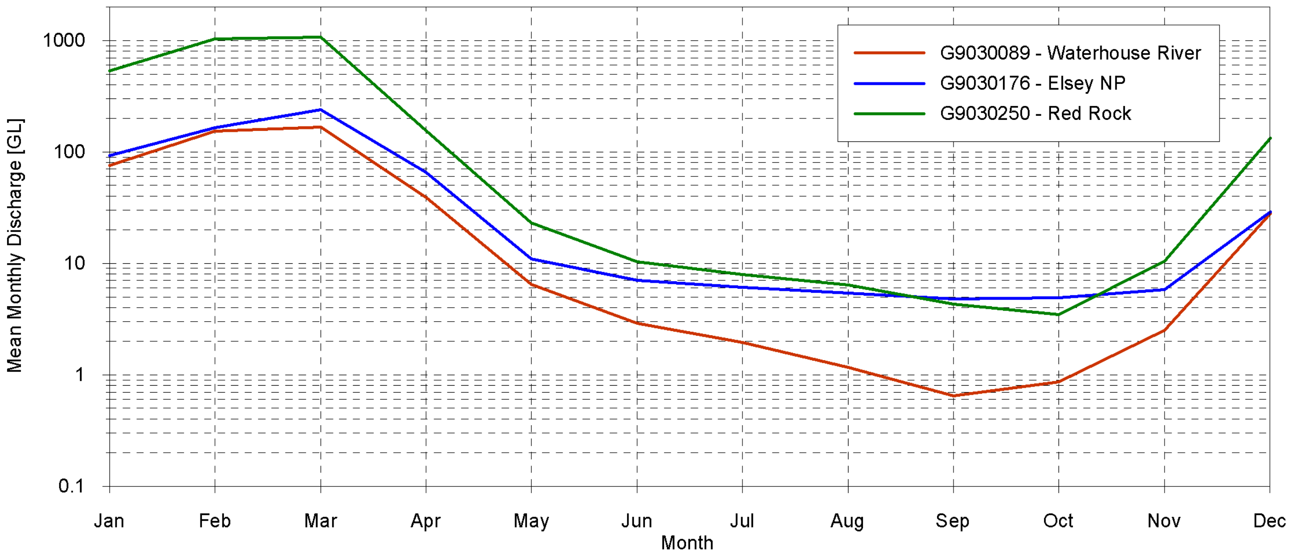

Figure 4-4 Mean monthly discharge for the Waterhouse River and the Roper River D/S Mataranka Homestead (G9030176) and Red Rock GS (G9030250).

4.5.2 Baseflow

During the dry season, aquifers within the Roper River catchment provide approximately 3 – 4 m^3/s (95 000 – 126 000 ML/yr) discharge through the river bed and springs as baseflow. In the wet-dry tropics groundwater inflow must be greater than evaporative demand to sustain a year round flow. The baseflow of the Roper River is sourced at its' headwaters where the river intersects the aquifers of the Cambrian aged Tindall Limestone near Mataranka (refer Figure 4-3**)**. The southern catchments of the Hodgson, Strangways and Elsey Creek provide little or no baseflow during the dry season. This is due to the underlying geology.

4.6 GROUNDWATER QUALITY

Water quality data has been sourced from the DLRM HYDRSTA data base and reflects a combination groundwater samples collected during airlifting, from pumping tests and regional sampling programs. Only water samples collected before 2000 are available from the database. Formation water quality samples have been sourced from drill stem tests (DST) for the Jamison Sandstone, Hayfield Mudstone and Moroak Sandstone. Vetting of the DST water samples was undertaken to exclude samples that were clearly contaminated with drilling mud. The average electrical conductivity (EC), pH and major ion concentrations are categorised by aquifer in

AQUIFER	NO. SAMPLES	EC (µs/cm)	Lab pH (mean)	MAJOR ION CONCENTRATIONS (mg/l)						
				Na	K	Ca	Mg	HCO_3	SO_4	Cl
Gum Ridge Formation	144	350 – 3000 (1390)	7.5	2 – 438 (130)	2 – 90 (27)	16 – 204 (86)	11 – 116 (53)	56 – 676 (440)	6 – 650 (147)	2 – 620 (159)
Anthony Lagoon Beds	86	670 – 6470 (1590)	7.6	9 – 381 (148)	9 – 98 (23)	12 – 303 (88)	25 – 134 (57)	86 – 525 (334)	18 – 979 (228)	16 – 570 (205)
Cretaceous Sandstone	7	340 – 4500 (1780)	7.5	42 – 395 (154)	10 – 24 (15)	13 – 120 (49)	20 – 95 (54)	127 – 336 (240)	5 – 642 (184)	70 – 1492 (213)
Antrim Plateau Volcanics	4	400 – 1840 (910)	7.9	43 – 166 (124)	2 – 6 (5)	8 – 76 (45)	2 – 64 (24)	178 – 380 (272)	17 – 176 (75)	4 – 327 (131)
Bukalara Sandstone	14	130 – 2130 (1030)	7.4	14 – 224 (100)	3 – 36 (9)	3 – 120 (57)	2 – 98 (35)	40 – 447 (223)	8 – 665 (179)	9 – 340 (129)
Proterozoic Outcrop	9	180 – 2320 (760)	7.5	2 – 376 (64)	1 – 32 (19)	6 – 89 (41)	7 – 84 (34)	74 – 493 (267)	5 – 325 (55)	2 – 427 (82)
Proterozoic Form. Water	5	32000 – 159000 (114000)	-	6100 – 64500	300 – 1500	1400 – 30000	600 – 5900	30 – 50	40 – 800	13500 - 147800

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Table 4-3 Summary of the water quality attributes of represented in the Beetaloo Basin.

AQUIFER	NO. SAMPLES	EC (µs/cm)	Lab pH (mean)	MAJOR ION CONCENTRATIONS (mg/l)						
				Na	K	Ca	Mg	HCO_3	SO_4	Cl
Gum Ridge Formation	144	350 – 3000 (1390)	7.5	2 – 438 (130)	2 – 90 (27)	16 – 204 (86)	11 – 116 (53)	56 – 676 (440)	6 – 650 (147)	2 – 620 (159)
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Proterozoic Form. Water	5	32000 – 159000 (114000)	-	6100 – 64500	300 – 1500	1400 – 30000	600 – 5900	30 – 50	40 – 800	13500 - 147800

Notes: Mean concentration vales provided in brackets

Groundwater resources within the Beetaloo Basin are of good quality, with the average EC for all aquifers within the accepted limit for potable water of 1875 µs/cm (converted from TDS 1200 mg/l, ADWG, 2011). The freshest groundwater is recorded in the fractured rock aquifers (Bukalara Sandstone, Antrim Plateau Volcanics and the shallow Proterozoic). This is likely a function of the local flow systems and shorter recharge flow paths in the fractured rock aquifers and contrasts with the regional flow systems in the Gum Ridge and Anthony Lagoon Beds. Formation waters are sourced from the Roper Group

Formations at depths from 780 to 1350 mBGS and are hyper-saline. Groundwater conductivities range from 31 800 μs/cm (Hayfield Mudstone) through to 159 000 μs/cm (Moroak Sandstone).

The spatial distribution of groundwater quality (EC) across the Beetaloo Basin is presented in Figure 4-5. The conductivity of groundwater in the CLA (Gum Ridge and Anthony Lagoon Beds) is relatively uniform in the Georgina Basin (east of the Stuart Highway) and does not display any clear trend associated with the regional SE-NW flow direction. In the Wiso Basin, to the west of the Stuart Highway, zones of better quality groundwater (< 1000 EC) occur in the Montejinni Limestone (CLA) south-west of Elliot and to the west of Daly Waters. Yin Foo (2002) links the lower EC in the north-west of the basin to direct recharge, which is enhanced in this area by the erosion of the upper siltstone units in the overlying Cretaceous sequence and by the presence of sinkholes in the landscape. In the south-west of the basin fresher groundwater in the CLA is likely to indicate recharge to the Montejinni Limestone where it sub-crops at shallow depths along the western flank of the Ashburton Ranges.

The relative major ion concentrations for the Gum Ridge Formation, Anthony Lagoon Beds and the Proterozoic Formation waters are plotted on a Tri-linear piper diagram in Figure 4-6. A significant overlap is observed on the plot between the domains of the Gum Ridge Formation and Anthony Lagoon Bed samples with both formations displaying a Na-Ca-Mg cationic signature and a HCO_3- SO_4 anionic signature.

The high proportion of Ca-Mg-HCO_3 is characteristic of groundwater in limestone and dolomitic aquifer systems. Relative to the Gum Ridge Formation the Anthony Lagoon Beds display a higher proportion of SO_4 and to a lesser degree Na, which results from the dissolution of evaporate deposits (halite and gypsum) that occur within the formation. Compared to groundwater in lateral equivalents in the Wiso Basin (Montejinni Limestone) and Daly Basin (Tindall Limestone) the Gum Ridge Formation has markedly higher concentrations of SO_4, which supports vertical connection with the Anthony Lagoon Beds in the Georgina Basin system. Proterozoic Formation waters plot have a Na-Cl signature and are clearly distinguished from CLA groundwater on Figure 4-6.

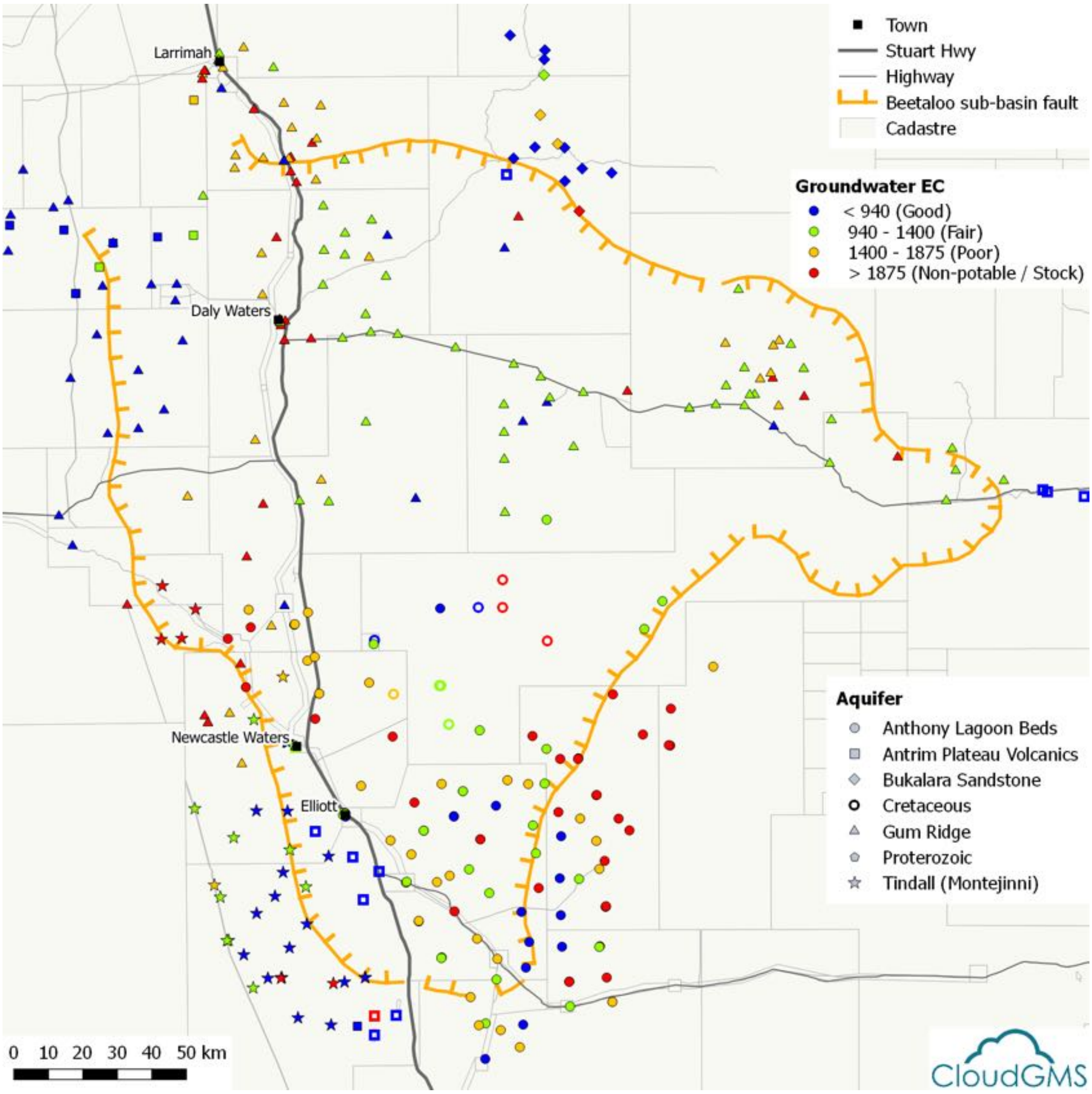

Figure 4-5 Distribution of Groundwater EC classified by source aquifer.

Groundwater samples from the other aquifers represented in the basin (not shown) do not display clear ionic groupings and plot across the Gum Ridge/Anthony Lagoon Beds domain. Groundwater within the Antrim Plateau Volcanics generally has a higher proportion of Na-Cl and a lower alkalinity than groundwater within the CLA (Yin Foo, 2002). Groundwater within the Cretaceous aquifer and the Bukalara Sandstone has a Na-HCO_3 dominant water type. The Bukalara Sandstone aquifer has uncharacteristically high SO_4 concentrations for an aquifer comprising quartz and feldspathic sandstone. The elevated SO_4 may indicate a component of regional groundwater flows north from the SO_4 rich CLA into the Bukalara Sandstone.

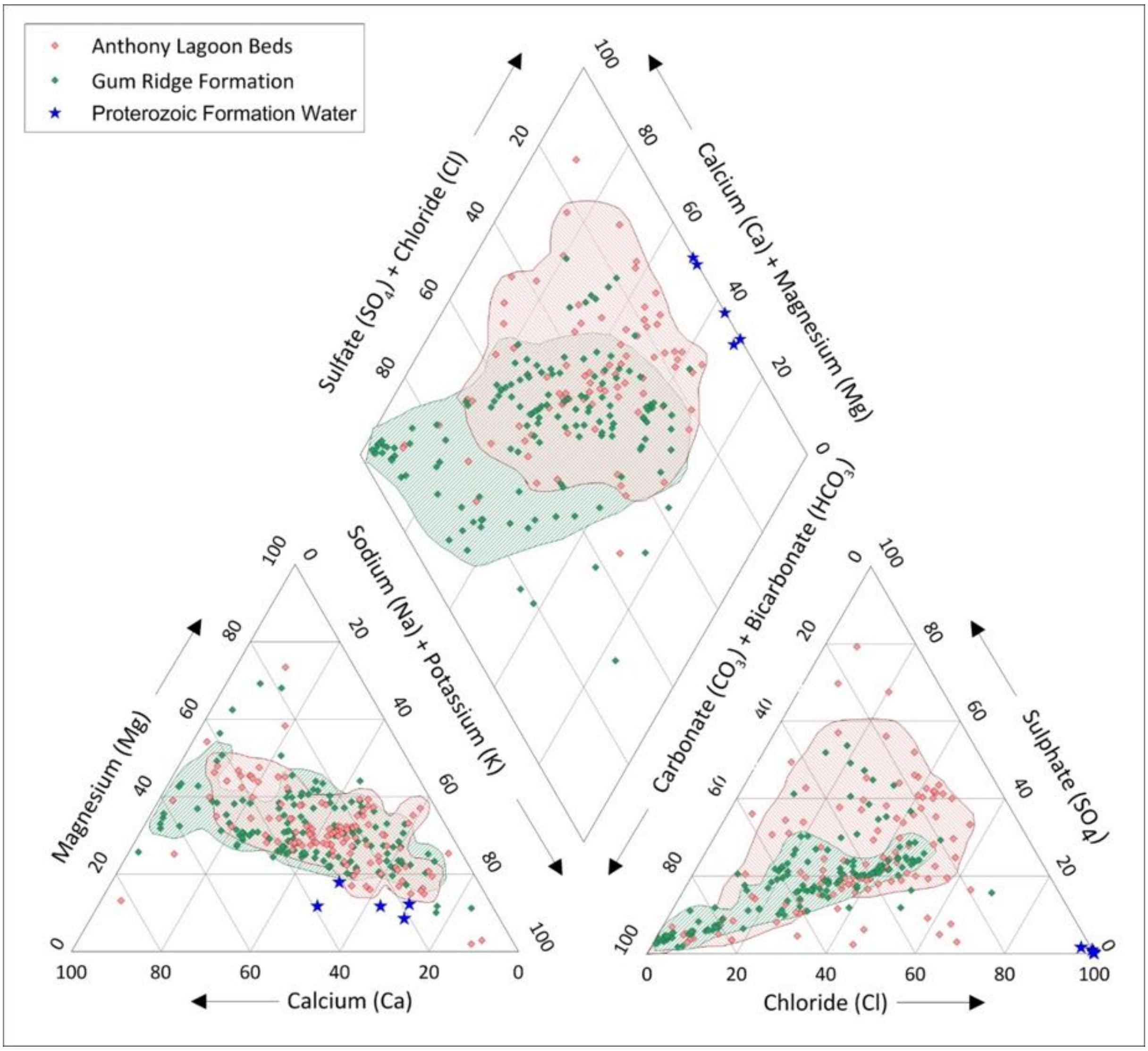

Figure 4-6 Piper diagram showing major ion signature of Gum Ridge, Anthony Lagoon Beds and Proterozoic formation water.

4.7 ENVIRONMENTAL DEPENDENCIES

4.7.1 Surface water dependancies

The southern portion of the study area overlies the Sturt Plateau bioregional zone that includes the nationally significant Lake Woods wetlands (wetland types B6 – seasonal/intermittent freshwater lakes, B13 – shrub swamps; shrub-dominated freshwater marsh, shrub carr, alder thicket on inorganic soils, B14 – freshwater swamp forest; seasonally flooded forest, wooded swamps; on inorganic soils and B10 – seasonal/intermittent freshwater ponds and marshes).

There are also a number of small wetlands associated with the intermittent, land-locked drainage systems in the south of the Sturt Plateau bioregion.

The four relevant criteria for the classification of the Lake Woods wetlands as nationally important are described by Environment Australia (2001) as:

- It is a good example of a wetland type occurring within a biogeographic region in Australia.
- It is a wetland, which plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex.

- It is a wetland, which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail.
- The wetland supports 1% or more of the national populations of any native plant or animal taxa.

4.7.2 Groundwater dependancies

SKM, (2001) identify six levels of dependency relating to groundwater dependent ecosystems (GDE's). However, all regimes involve:

- the level or pressure of the groundwater;
- the discharge flux of groundwater from an aquifer;
- the quality of the groundwater

Figure 4-7 demonstrates how the distribution of vegetation can be controlled by the availability of groundwater. Where the water table approaches the surface a greater density of vegetation is evident and can often be identified using remote sensing products such as MODIS normalised difference vegetation index (NDVI).

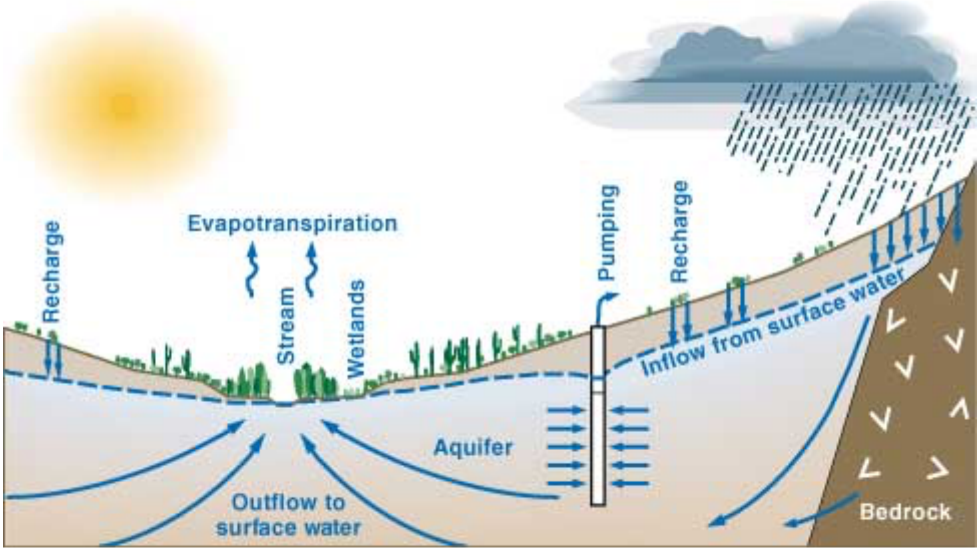

Figure 4-7 Diagram demonstrating recharge, throughflow and discharge via evapotranspiration.

Based on the criteria above the perennial sections of the rivers and the springs that have been identified in the Roper River catchment could be classified as groundwater dependent. The prominent areas identified as being potential GDEs are presented below. It should be noted that these areas are 100 – 200 kilometres distance from the study area (see Figure 4-3).

Elsey National Park

The perennial nature of the spring-fed Roper River; the floristic diversity and restricted range of the riparian vegetation; and the representation of "tufa" formations have been identified as important natural resources within Elsey National Park. The Mataranka Thermal Pools, located within Elsey National Park, are maintained by permanent thermal springs. The pools are fringed mainly by *Livistona rigida*, although Pandanus and *Melaleuca* spp. also occur. The *Livistona rigida* palm community has a restricted distribution in the Top End Region and, as such, is considered a special community (Faulks, 2001).

Water use studies along the riparian zone of the Daly River identified that *Melaleuca argentea* W. Fitzg and *Barringtonia acutangula* (L.) Gaertn. appear to be obligate phreatophytes as they use groundwater almost exclusively and are associated with riverbanks and lower terraces with shallow (<5 m) watertables (O'Grady et al., 2001). Distribution maps of *Melaleuca sp*. for the northern portion of the Northern Territory have been completed at 1:100 000 scale based on air-photo interpretation and field surveys (Brocklehurst and Van Kerckhof, 1994).

Red Lily Lagoon / 57 Mile Waterhole

The Red Lily Lagoon is an area of riparian vegetation associated with wetlands along a 20 km braided section of the Roper River immediately downstream of the major groundwater discharge zone from the Cambrian Limestone aquifer. It is estimated that ~1 m^3/s is used as ET from the Red Lily Lagoon (Knapton, 2009).

Riparian vegetation

Based on the broad criteria identified by SKM (2001), much of the riparian vegetation along the fringes of the Roper Rivers and tributaries which derive flow from the regional aquifers would be classified as groundwater dependent ecosystems as their source during the dry season is derived solely from groundwater. Riparian lands occupy only a small proportion of the landscape but they frequently have a much higher species richness and abundance of animal life than adjacent habitats. A broad-scale survey of bird distribution in riparian vegetation centred on the mid-reach of rivers with semi-permanent freshwater pools (that is, the Roper, Hodgson and Arnold Rivers within the Roper River catchment), (Woinarski et al., 2000), found that despite their relatively small total extent, riparian areas were extremely important for birds. The study concluded that the bird fauna of riparian areas is distinct from that of the surrounding savannas, and this was especially so in lower rainfall areas. Species richness and the total abundance of birds was greater in the riparian zones than in non-riparian zones especially where they contained more extensive cover of rainforest plants and *Melaleuca*, (Woinarski et al., 2000).

4.8 REGIONAL GROUNDWATER USE

An assessment of usage from the limestone aquifer (the main shallow groundwater source) in the study area was undertaken and reported on by Jolly (2004). Stock watering is the major use at present with small town supplies such as Elliott, Larrimah and Daly Waters and outstations also notable users. The registered bores in the study area have been classified by their purpose at time of drilling and are presented in Figure 4-8. A total of 813 registered bores have been drilled in the study area with the vast majority (684) being used for stock watering.

4.8.1 Community water usage

An estimate of groundwater usage by communities in the study area is based on per capita water consumption. Typically the daily per capita usage is estimated to be 1800 litres per person. Using Australian Bureau of Statistics of population figures for 2011 the community supplies are of the order of 400 ML/year (Table 4-4).

Table 4-4 Community water supplies

TOWN	POPULATION	KL/D/PERSON	ML/YR
Elliott	288	1.8	190
Daly Waters	80	1.8	53
Larrimah	50	1.8	33
Newcastle Waters and Jingaloo	156	1.8	100
Total	**574**		**376**

4.8.2 Stock and domestic water usage

Stock supplies are more difficult to quantify, due to the limited reporting of stock numbers in the area, but a rough estimate can be made by assuming a stocking rate of approximately 4 - 5 head per km^2 (DPIFM, 2004; DPIF, 2010). Assuming this stocking rate and an area of 60000 km^2 (accounting for the area of the Beetaloo Basin including a 25 km buffer) that there are approximately 240,000 - 300,000 cattle currently watered from the limestone aquifer. Applying a consumption of 50 litres/head/day, the stock usage is 4380 – 5475 ML/year.

Annual use in the study area from community supplies and stock usage is therefore currently of the order of 6000ML/year.

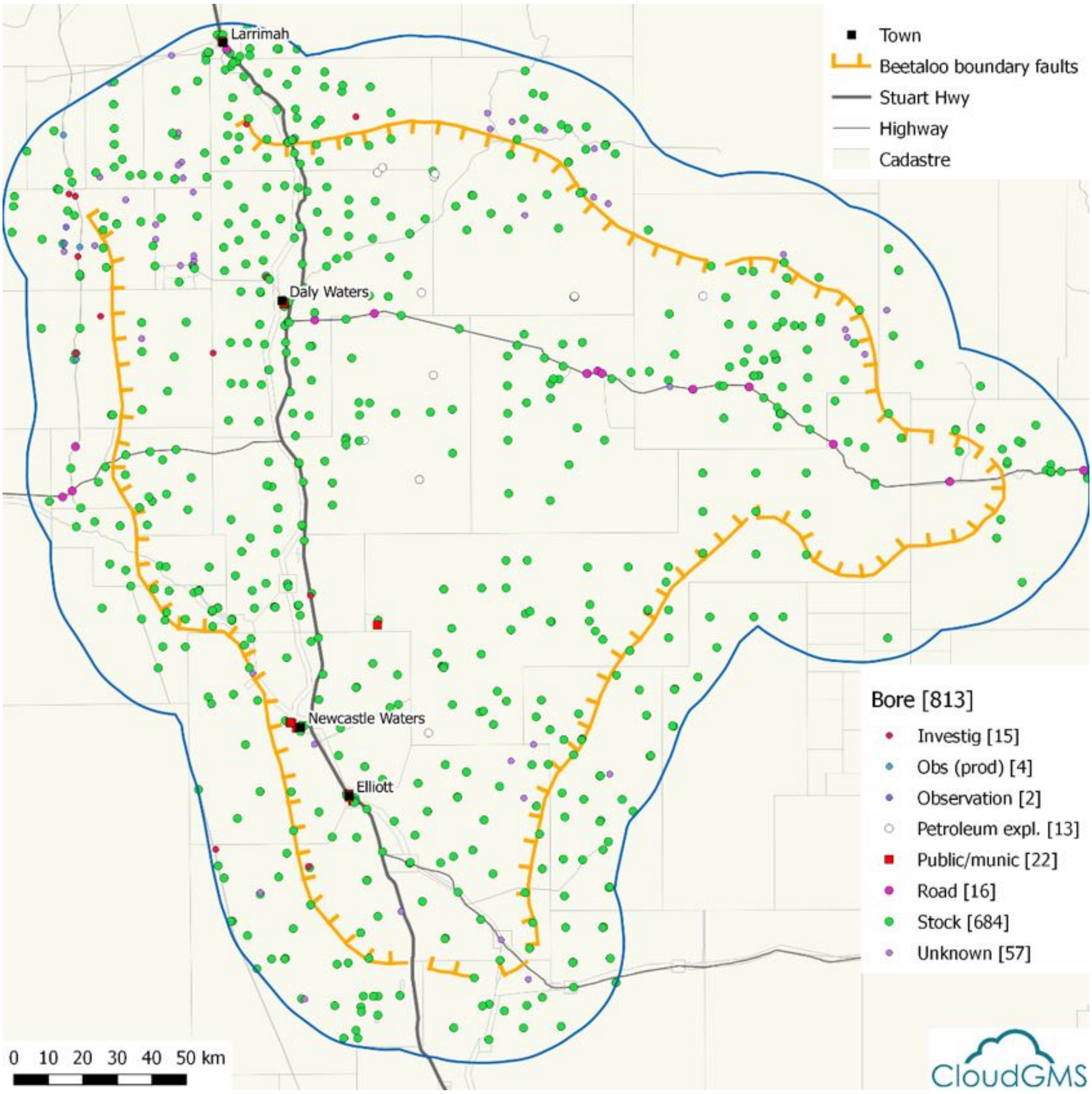

Figure 4-8 Registered bores in the study area classified by usage

4.9 SYNTHESIS

The Cambrian Limestone Aquifer (CLA), comprising the Gum Ridge Formation and equivalents and the Anthony Lagoon Beds, is an extensive regional aquifer system that forms the principal water resource in the Beetaloo Basin. The permeability of the CLA is commonly enhanced by the development of fractured and cavernous limestone which results in the aquifer producing bore yields of up to 100 l/s. Around 80% of all groundwater bores in the region are constructed in the CLA and the aquifer forms a key water supply for the pastoral industry and local communities including Elliot, Daly Waters, Larrimah and Newcastle Waters. Where the CLA is absent, has limited saturated thickness or is particularly deep, local scale aquifers are targeted in Proterozoic fractured rock, the Bukalara Sandstone, fracture zones in the Antrim Plateau Volcanics and in the base of the Cretaceous sequence. Groundwater resources in these aquifers are of limited extent and have a lower yield (< 5 l/s) relative to the CLA.

In the Beetaloo region the CLA forms the main aquifer of the Georgina Basin. Regionally, groundwater in the CLA flows toward Mataranka, located 100 km north-west of the Beetaloo Basin, where the aquifer discharges into the Roper River and supports significant groundwater dependent ecosystems. Dry season flow in the Roper River has been gauged at between 95 000 – 126 000 ML/yr and provides an estimate of the magnitude groundwater discharge from the CLA. Spring discharge in this area is supported by contributing groundwater flow from both the Daly and Georgina basins (see Figure 4-3). Large decadal changes in the discharge to the Roper River suggests that most recharge input occurs close to the discharge zone (i.e. beyond the Beetaloo Basin region). Groundwater recharge mechanisms to the CLA are poorly characterised but are likely to be dominated by indirect recharge through sinkholes and preferential recharge through macro-pores (soil cavities). Recharge to the CLA through outcropping limestone in the Georgina Basin is estimated at between 20 000 – 40 000 ML/year.

The CLA contains a significant but largely undeveloped groundwater resource with water availability from the Georgina Basin estimated to be in the order of 100 000 ML/year (NALWTF, 2009). Existing groundwater use in the Beetaloo Basin is approximately 6000 ML/year. Unconventional gas exploration in the Beetaloo basin is at a very early stage and the volume of water required to develop any potential resource is uncertain. However, a first order estimate of the water required to develop possible gas resources on Origin tenements (EP97 and EP118) is 1000 ML/year over the development phase. Combined, current groundwater extraction and projected demand for gas development in the Beetaloo Basin represents 7% of the estimated water resource available from the CLA in the Georgina Basin.

The Velkerri Formation represents the primary unconventional gas target in the Beetaloo Basin, although small hydrocarbons intersections have been recorded in other Roper Group formations. Vertical pressure gradients between the Roper Group and the CLA are not well characterised, however, well formation tests indicate there is an upward pressure gradient from the Roper Group to the CLA. Over much of the basin the CLA is separated from these formations by multiple aquitards including the Antrim Plateau Volcanics and Hayfield Mudstone. Thick, unweathered and undeformed basalt sequences in the Antrim Plateau Volcanics (190 m average) and tight claystone beds within the Hayfield Mudstone (320 m average thickness) form a barrier that restricts the mixing of hydrocarbons and brines in the Roper Group with high quality groundwater in the CLA and other shallow aquifers. Where these formations are absent or thinner, along the eastern margin and in the south of the Beetaloo Basin, there is greater potential for interconnection between the Roper Group and the CLA. Potential for interconnection also exists along the major faults and structures that bound the Beetaloo Basin. The risk of fluid migration through faults between formations is considered limited because most faults don’t extend to the shallow formations.

5 Water management in the Northern Territory

5.1 INTRODUCTION

5.1.1 General

This section provides an overview of the legislation and policies relating to water resource management on petroleum exploration leases in the Northern Territory. It should be noted that at the time of writing the key legislation dealing with water management on petroleum exploration leases was under review, and it is likely that the current framework will change.

This section, therefore, describes the legislation currently enacted and their interactions, the petroleum legislation review process, the timeline for future legislation to be drafted and enacted and the interim guidelines issued in response to the review process. Government briefings with industry (late March 2015) on the regulatory review process have indicated that the overall timeline may now more realistically extend to second Quarter 2017 with the new or amended legislation to apply from 1 July 2017.

5.1.2 Key legislation and policies relating to water resources in the Northern Territory

The main legislation relating to water resources and petroleum exploration and production sites in the Northern Territory are the:

- *Water Act 1992 (WA 1992)*
- *Water Regulations 1992 (WR 1992)*
- *Petroleum Act 1984 (PA 1984)*
- *Petroleum Regulations 1994 (PR 1994)*
- Schedule of Onshore Petroleum Exploration and Production Requirements 2012
- *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) (Cth)

5.1.3 Regulators

The Northern Territory Department of Land Resource Management (DLRM), through the Controller of Water Resources, is responsible for administering and enforcing the laws and regulations relating to water access and pollution through the Water Act 1992 (WA 1992) and the Water Regulations 1992 (WR 1992).

The Northern Territory Department of Mines and Energy (DME) is responsible for enforcing laws and regulations about water access and pollution on petroleum sites through the Petroleum Act 1984 and Petroleum Regulations 1994.

The Australian Government Department of Environment is responsible for administering and enforcing laws and regulations relating to the EPBC Act 1999.

5.2 ENVIRONMENT PROTECTION AND BIODIVERSITY CONSERVATION ACT 1999 (CTH)

Some proposals may need consideration under Commonwealth legislation Environment Protection and Biodiversity Conservation Act. The Commonwealth's EPBC Act provides protection for matters of national environmental significance

(NES). The Commonwealth agency determines whether a proposal could potentially affect a NES matter and whether it requires assessment and approval under the EPBC Act. The NES matters are:

- World Heritage properties;
- National Heritage places;
- Ramsar wetlands of international importance;
- Nationally threatened animal and plant species and ecological communities;
- Internationally protected migratory species;
- Commonwealth marine areas;
- Great Barrier Reef Marine Park;
- Nuclear actions (including uranium mines); and
- A water resource, in relation to coal seam gas development and large coal mining development.

Although there are Nationally Important Wetlands in the study area (refer to section 2.4), there are no Ramsar wetlands.

Under the EPBC Act an action (such as petroleum exploration and extraction) requires approval from the Australian Government Environment Minister if it is likely to have a significant impact on a matter of national environmental significance (MNES). Such matters include nationally threatened species and ecological communities, migratory species, Ramsar wetlands, world heritage properties and national heritage places.

The list of MNES was recently amended to include water extraction in relation to Coal Seam Gas and large coal mining developments, but this does not apply to shale gas projects. Detailed guidelines describe the process for assessing whether an action is likely to have a “significant” impact on MNES, and it is the proponent’s responsibility to refer the action to the Department of Environment for a decision about whether it is a controlled action under the EPBC Act.

5.3 WATER ACT 1992 (DEPARTMENT OF LAND RESOURCE MANAGEMENT)

5.3.1 General

The NT Water Act, which was enacted in 1992 but subsequently amended several times, and the NT Water Regulations, also enacted in 1992, provides the legislative framework for water planning and entitlements for NT water resources.

The WA 1992 identifies that the Crown owns all surface and groundwater (Water Act (NT) s. 9). Water is provided to users through a system of permits, licences and exemptions under the management of the Controller of Water Resources.

The WA 1992 provides for the investigation, allocation, use, control, protection, management and administration of water resources. It also defines the beneficial use categories of surface water and groundwater, which include the environment, cultural use, stock and domestic, public water supply, aquaculture, agriculture and industry (including mining and petroleum activities). DLRM has primary responsibility for water planning.

Current DLRM policy states that adequate provision will be made to maintain cultural and environmental requirements (referred to as ‘aquatic ecosystem and cultural beneficial uses’), although there are no guidelines for measuring or estimating these requirements.

The Controller of Water Resources also has other functions for assessing and investigating the Northern Territory's water resources. To enable effective planning for environmental protection, the Controller of Water Resources must ensure as far as possible that a continuous program for the assessment of water resources of the Northern Territory is carried out.

5.3.2 Environmental water allocations

The legal process for management of water resources allocates water to "beneficial uses"; these are categories of water use that are explicitly identified in the WA 1992 as requiring water allocation. Providing water to the environment to maintain the health of aquatic ecosystems is a listed beneficial use in the WA 1992. When DLRM undertakes water planning in a given area there is a requirement that some water must be allocated to the environment.

5.3.3 Proposed changes to water resource management legislation and policy

In October 2013 the Minister for Land Resource Management announced a proposed approach to the management of the NT's water resources, including a review of the WA 1992 and the development of an overarching water policy for the NT (NT Hansard 09/10/2013). According to the Ministerial statement, the review of the WA 1992 will 'include systems for water trading and water markets, reconsider some of the current exemptions to the Act to provide transparency' and 'enable the issuing of water licences in perpetuity'.

Further to this, the proposed overarching water policy aims to:

- define principles for governing water use for economic purposes, as well as water quality for the environment and public water supplies;
- cover the identification, assessment, development and allocation of all water resources;
- clearly define water access rights;
- promote sustainable water resource use and development and consider surface and groundwater connectivity;
- set time horizons for planning and outline stakeholder participation rights.

Water resource management legislation is currently under review, however, it is unclear when or if these proposed water policy changes will impact on the interaction between the WA 1992 and the PA 1984.

5.3.4 Water allocation planning framework

Subject to alternative arrangements that may be specified in water allocation plans (WAPs), the NT has implemented its Water Allocation Planning Framework (WAPF).

The WAPF guides both the formal water allocation process in Water Control Districts and regional licensing decisions outside these districts. The WAPF establishes precautionary water allocation rules when relevant science is not available.

Under the precautionary water allocation rules the WAPF establishes contingent allocations for environmental and other public benefit uses as the first priority where detailed environment and cultural water requirements have not been established. Allocations for consumptive use are made subsequently from the remaining available water.

Under the WAPF at least 80 per cent of surface water flow or annual groundwater recharge is allocated for environmental and other public benefits. In the arid zone, where surface water flows and recharge are episodic, at least 95 per cent of surface water flow is reserved for environmental and other public benefits, and total groundwater extraction over a period of 100 years is not to exceed 80 per cent of the total aquifer storage at the start of extraction. Licence applications that, if granted, would exceed these thresholds need to be supported by scientific research into public benefit water requirements.

WAPs establish how water will be shared between environmental and other public benefit needs and consumptive use. They describe the area and water resource to which a plan applies as well as the objectives, strategies and performance indicators of the plan. WAPs also detail the rules and operating mechanisms that ensure that water is shared among the beneficial uses in the plan area, and outline monitoring programs to evaluate the performance of the plan and to inform a review. A WAP has a maximum life of 10 years and must be reviewed within five years.

The WA 1992 provides for water advisory committees to be convened at the Minister's discretion to support the development and oversight of WAPs to maximise their social and economic benefits within ecological restraints. The composition of the committee is at the Minister's discretion, although committees typically consist of representatives from relevant government, industry, environmental, Indigenous and community interests.

5.3.5 Administrative areas

Under the WAPF there are three levels of administrative area relating to the management of water resources in the Northern Territory.

The three levels are:

- Water Control Districts (8);
- Water Allocation Plan Areas (4); and
- Water Plan Management Zones.

Water Control Districts provide a basis for administering the management of surface water and groundwater resources covering all aspects of sustainable water resource management including the investigation, use, control, protection and allocation. Water Control Districts (WCD) can be proclaimed in areas where there is a need for close management of water resources. This is to avoid stressing groundwater reserves, river flows or wetlands. Eight (8) Water Control Districts have been declared, these are for Alice Springs, Daly Roper, Darwin Rural, Gove Peninsula, Great Artesian Basin, Tennant Creek, Ti Tree and Western Davenport regions (DLRM, 2015).

Water Allocation Plan Areas are declared under the NT WA 1992 and apply to specific water resources within a WCD to ensure that water extraction of the resource is undertaken in a sustainable and equitable manner. Declaration of a water allocation plan establishes the maximum amount available for consumption and as part of their development take into account both the current and estimated future water demands for mining and petroleum extraction.

Plans are declared by the Minister for a specific time frame with a maximum of ten years and a maximum review period of five years.

Plans are developed at the Minister's discretion for single or multiple water resources (surface water and/or groundwater), but the WA 1992 does not stipulate the process by which plans are developed.

WAPs are informed by detailed technical and scientific assessment as well as extensive community consultation to determine the right balance between competing requirements for water. The location, extent and status of the current Water Allocation Plan Areas are presented below in Figure 5-1.

Four (4) WAP areas currently have declared plans: Alice Springs Water Resource Strategy, Water Allocation Plan for the Tindal Limestone Aquifer -Katherine 2009-2019, the Ti Tree Water Allocation Plan 2009 and the Western Davenport Water Allocation Plan. Five (5) water allocations plans are in progress.

Water Plan Management Zones apply to specific areas located within a Water Allocation Plan Area and are generally established to reduce local short term impacts of extraction. Rules for each zone are defined in water allocation plans to determine how water can be used and/or traded.

The boundary extents of DRAFT zones are subject to change. Individual maps and spatial data are available for each specific water management zone at http://www.lrm.nt.gov.au/water/water_allocation.

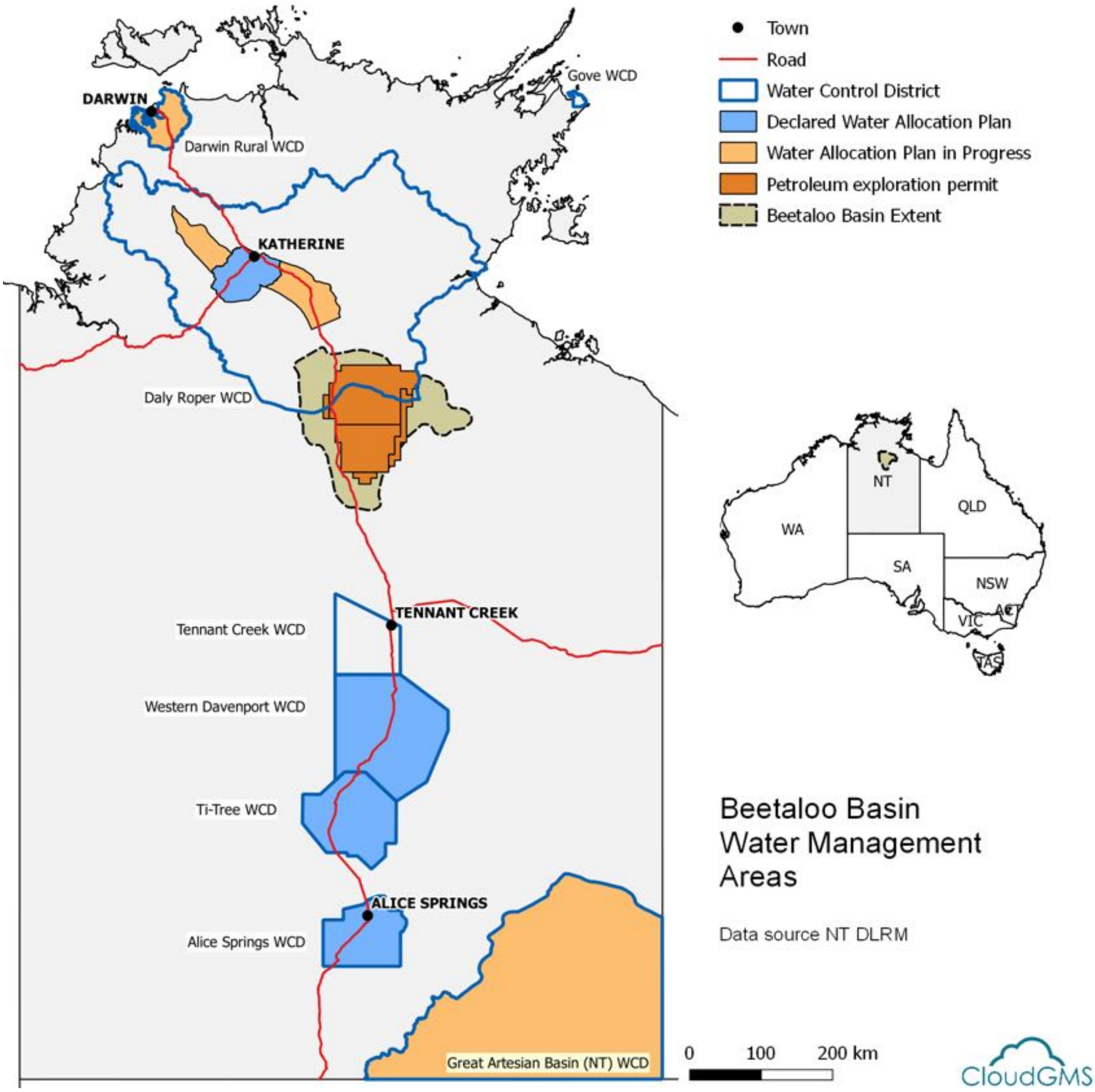

Figure 5-1 Water allocation planning areas (as of September 2014) in the Northern Territory in relation to the Beetaloo Basin.

5.3.6 Beetaloo Basin and Water Control Districts

The northern extent of the Beetaloo Basin is within the Daly Roper Water Control District (refer Figure 5-1) and 150 km to the south of the southern margin of the Beetaloo Basin is the Tennant Creek Water Control District. The location of the Beetaloo Basin, Origin's EP licences and the Day-Roper Water control District are presented below in Figure 5-2. It should be noted that no Water Allocation Plans have been developed in areas where an EP exists.

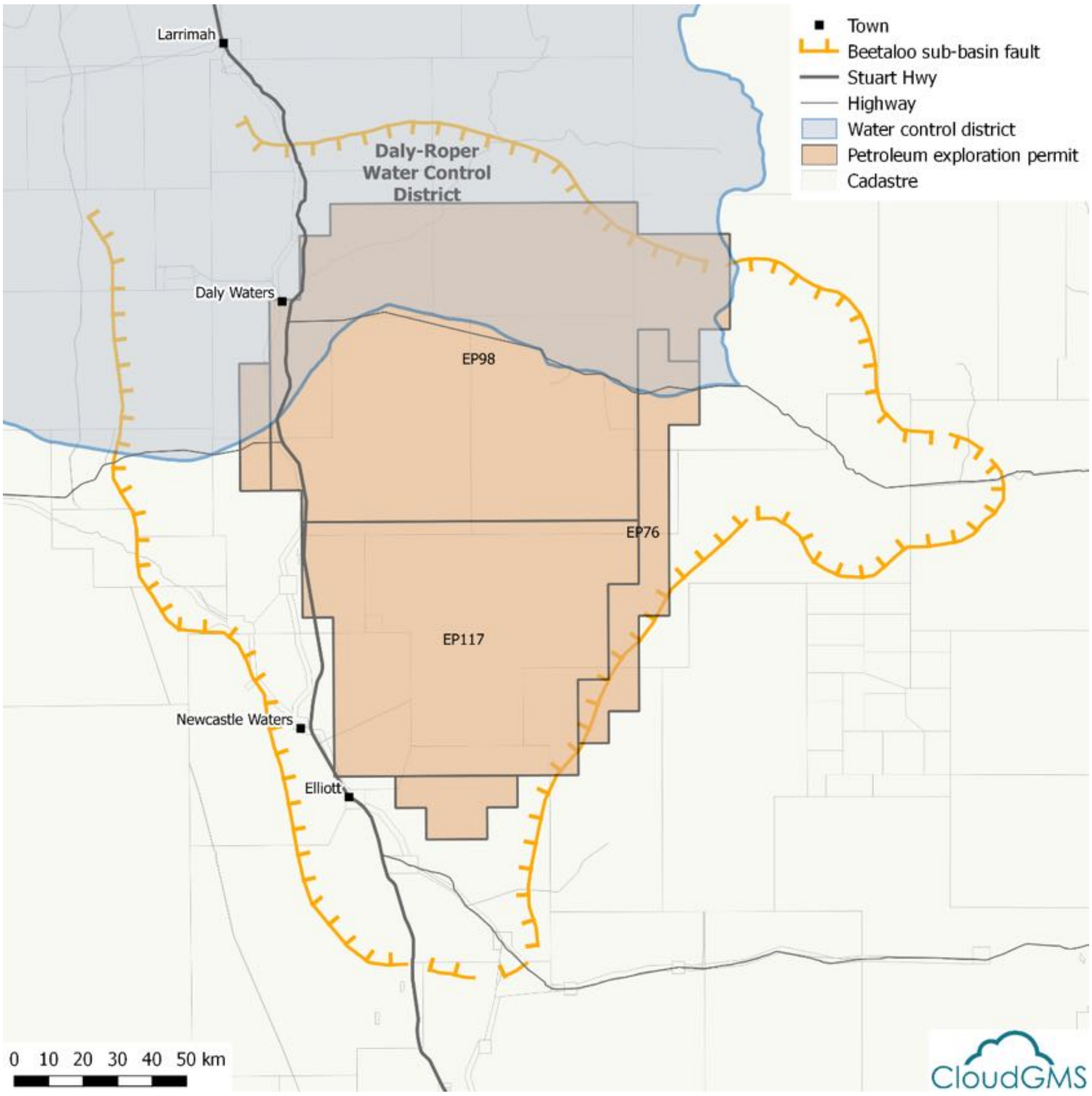

Figure 5-2 Location of the Beetaloo Basin, Origin's EP licences and the Day-Roper Water Control District

5.3.7 Process to undertake water bore drilling in the NT

In the case where a water bore is to be drilled outside of a Petroleum Lease, all drilling activities shall be conducted in accordance with the WA 1992 and its Regulations.

Drillers must be licensed to drill in the NT and are required to:

1) Obtain a Registered Number (RN) from the DLRM. RN is a unique identification number and must be clearly and permanently displayed on the bore and included on the Statement of Bore form;

2) Sight the valid Bore Construction Permit if conducting any drilling work within a Water Control District;

3) Read, understand and implement all the conditions on the Bore Construction Permit; A permit is currently not required if you are conducting a petroleum activity.

4) Complete and submit the Statement of Bore to the department for every bore within 28 days of completion;

5) Submit required strata and water samples to the department for every bore drilled within 28 days of completion. Strata samples are to be approximately 250g secured in sealed bags of each change in strata observed in the bore. Representative water samples of 1 litre are to be taken from each water bearing strata found in the bore (unless an exemption is provided on the Bore Construction Permit).

Further information about water bore drilling, driller's licensing requirements and a list of NT licensed drillers is available from DLRM link below:

http://www.lrm.nt.gov.au/water/permits/drilling

5.3.8 Water extraction in the Northern Territory

Water extraction from a bore for most purposes must be licensed under s. 59 of the WA 1992. Licences are not perpetual and commonly have a term of 10 years (Water Act (NT) s. 60). The assessment processes associated with a water licence application is approximately 3-4 months and its determination can be extensive.

The WA 1992 requires public notice to be given about all new and increased water licence applications. The notice is advertised by the department with the cost of the advertisement paid by the applicant. The purpose of this notice is to seek public input to the assessment of licence applications. Public submissions are accepted within a 30 day period after the notice has been advertised.

The WA 1992 also requires another public notice to be published when a decision has been made for a water licence application. The notice will include the reasons for the decision and opportunity to appeal. The cost of this advertisement is paid by the department.

Compliance with a water extraction licence requires:

- installation and maintenance of a water meter;
- report monthly extraction (pumpage/meter readings) to DLRM;
- use no more than your maximum water entitlement;
- apply for an increase in your water entitlement if needed; and
- renew your licence before it expires.

The following situations are currently exempt from requiring a licence to extract water from a bore (Water Act (NT) s. 14):

- The WA 1992 provides rights to take water from waterways and groundwater for stock and domestic uses without a licence;
- A groundwater bore that is located outside of a Water Control District and has a yield of less than 15 litres per second does not require a licence.
- According to s. 7 of the WA 1992 the licensing provisions of the WA 1992 do not apply to the take of water for petroleum activities Water Act (NT). Water for these purposes is authorised under the Petroleum Act (Petroleum Act (NT) s. 29.2(d)).

However, recent review into the legislation relating to petroleum activities has resulted in a set of Guiding Principles (DME, 2015) being released for public comment (refer to section 5.7). These Guiding Principles dictate that:

- Water Management Strategies must be consistent with requirements under the Water Act 1992; and

- where groundwater extraction on a petroleum lease falls within a Water Control District, proposed water extraction will be consistent with any Water Allocation Plans (WAPs)

It should be noted that no WAPs occur in the study area (refer Figure 5-2), however, to be consistent with the WA 1992 a water licence is required:

- for all bores pumping over 15 litres per second;
- if you do not have direct access to the source of water; and
- if you are located within a Water Control District.

5.4 PETROLEUM ACT 1984 (DEPARTMENT OF MINES AND ENERGY)

5.4.1 General

The Petroleum Act 1984 (PA 1984) and Petroleum Regulations 1994 (PR 1994) are the principal legislation dealing with petroleum tenure, exploration and production activities onshore and inland waters of the Territory.

The Department of Mines and Energy is responsible for administering and enforcing laws and regulations under the PA 1984 and to ensure that the activities of authorised petroleum operations are undertaken in accordance with provisions of the Act.

A petroleum exploration permit, while it remains in force, gives the permittee the right to, subject to any prior lawful activity and to the directions, if any, of the Minister, use the water resources of the exploration permit area for his domestic use and for any purpose in connection with his approved technical works programme and other exploration (Petroleum Act (NT) s. 29.2(d)), but must not use water artificially conserved by the landowner without consent.

The Schedule of Onshore Petroleum Exploration and Production Requirements 2012 provides guidance (as they are not based in legislation, although may be included in the future refer to section 5.5 below) as to water related issues including the:

- approval for operations to drill a new exploration well requiring a statement of proposed environmental protection and rehabilitation measures (DME, 2012c s. 501.2(o));
- abandonment of wells on encountering fresh water zones (DME, 2012c s. 529.1 & 529.11)
- encountering formation water that had not been previously identified (DME, 2012c s. 610);
- measurement of produced water (DME, 2012c s. 612).

5.4.2 Environmental plans

All activity must be approved by the Department of Mines and Energy before activity commences and must meet necessary criteria outlined in the Act and regulations, including such things as complying with environmental care and rehabilitation requirements. The SoOPEPR 2012 requires a statement of proposed environmental protection and rehabilitation measures. These are in the form of an Environmental Plan with the requirements detailed in the Environmental Plan (EP) Guideline (DME, 2012a).

The guideline requires an Environment Description section documenting items such as:

> “*Existing natural physical environment including geography, geology, climate, hydrogeology, hydrology, soils etc.* ”

The guideline requires an Environmental Risks and Impacts, Description and Assessment section documenting the identification, description and assessment of the environmental impacts and risks, (rising directly or indirectly from the activity) and their significance such as:

> "*Reduced water quality. (A baseline water quality assessment may be required.)*"

Through a memorandum of understanding between NT EPA and DME (refer section 5.5.2) all petroleum activities are also assessed under the Environmental Assessment Act (DME, 2012b).

5.4.3 Water extraction on petroleum leases

The petroleum industry in the Northern Territory is generally exempt from most of the requirements of the WA 1992, (Water Act (NT) s. 7.1 and s. 7.2) particularly with regard to limits on water extraction and use. This means that companies exploring and mining oil, or gas can:

- take surface water without a licence
- drill and construct bores and extract groundwater without a licence
- construct a dam or alter the flow of a waterway without a permit
- interfere with or obstruct waterways in situations where this would ordinarily be an offence

5.4.4 Water pollution on petroleum leases

The WA 1992 pollution provisions do not apply to water pollution that occurs in the course of carrying out petroleum activities on petroleum sites (Water Act (NT) s. 16). Instead, this type of water pollution is regulated by the PA 1984 and its' Regulations.

The only times when the pollution provisions under the WA 1992 apply to the petroleum industry are when:

- water pollution caused by mining escapes from a petroleum site to a non-mine site area (Water Act (NT) s. 7.2(b))
- underground waste disposal associated with petroleum activities takes place and the waste is not confined to the petroleum site (Water Act (NT) s. 7.4)

5.5 INTERACTION BETWEEN THE WATER ACT 1992 AND THE PETROLEUM ACT 1984

- Currently there are no statutory links between WA 1992 and other Legislation.
- Currently there are no formal requirement for consultation between various agencies and Departments.
- Water Allocation Plans are not integrated with other Resource Management Plans or Strategies.

However, the Minister responsible for the Petroleum Act can direct the holder of a petroleum exploration or production permit to provide relevant information (Water Act (NT) s. 39.1 and s. 39.2) relating to:

(a) water samples of, and data about, underground water encountered during exploration drilling;

(b) a geological sample, including a drill core and cutting;

(c) a report relevant to the mineral title, licence or permit.

This is regardless of any provision in the PA 1984 relating to confidentiality and without the need to obtain the permission of the holder of the mineral title, licence or permit (Water Act (NT) s. 39.3).

5.5.1 Memorandum of understanding between DLRM and DME

A Memorandum of Understanding (MOU) exists between the Department of Land Resource Management and the Department of Mines and Energy (originally a MOU between the DIPE and the DBIRD, 2003) provides some measure of integrated management of water for mining and petroleum operations and for other purposes, although this has no legislative base. This MOU is currently under review as part of the review of the petroleum legislation Hunter (2014).

Under the MOU proposed new or amended activities that trigger agreed referral criteria are referred to the DLRM for comment and the recommendations may be included in the issuing of petroleum exploration and production permits.

Under the MOU, mining and petroleum interests are also to be consulted in the water allocation planning process so that licences issued under the WA 1992 do not impact on mining and petroleum activities.

Whilst allocations for petroleum take may be considered and accounted for under the NT water allocation planning process, the arrangements for doing this and for regulating petroleum water extraction to safeguard existing users and the environment is not transparent.

An exploration application must provide detail on water management, well integrity and well control and cover all reporting requirements before being approved by the Department of Mines and Energy as the industry regulator. Water management requires significant monitoring and testing of all known aquifers as well as continual water quality testing and reporting to a third party environmental auditor. The Water Act is also under review and water matters will form a part of the legislative review process in the coming year.

5.5.2 Memorandum of understanding between NTEPA and DME

All activity relating to petroleum exploration and extraction must be approved by the Department of Mines and Energy before activity commences. Under a memorandum of understanding between the NT EPA and the DME all petroleum activities are referred to the NT EPA and assessed under the Environmental Assessment Act, although it should be noted that currently this mechanism has no legislative base.

The MOU is only in draft form and still under discussion. In the absence of a formal MOU, the DME by default are referring all Applications to Drill to the EPA for their comment.

For all projects reviewed by the NT EPA, comments and/or recommendations are provided back to DME. For low risk projects (not requiring assessment as an NOI) the comments generally include instructions for the proponent to develop and implement Environmental Management Plans to ensure the development and effective implemented to mitigate environmental impacts including a Ground and Surface Water Management Plan.

5.6 PETROLEUM LEGISLATION REVIEW

Due to the significant increase in interest in oil and gas exploration in the Northern Territory including new emerging technologies and economic opportunities with unconventional oil and gas exploration and development; the Northern Territory Government has instigated a review of the Petroleum Legislation (Hunter, 2014) in parallel with an inquiry into hydraulic fracturing in the Northern Territory (Hawke, 2014).

Concurrently the Government also formed an interagency Petroleum Task Force (PTF) with three main areas for consideration:

1. Provide short-term regulatory certainty to industry by developing interim regulatory requirements, specifically for the regulation of new technologies to include well integrity, water management controls, and increased transparency of activity reporting.

2. Developing a broader regulatory regime to appropriately regulate onshore petroleum activities and a communications strategy by holding public information meetings in conjunction with Industry, Industry Associations and CSIRO independent experts.

3. Developing energy policy on future emerging issues for onshore petroleum exploration.

Through consultation with Industry and other stakeholders and on advice from the PTF, the Department of Mines and Energy introduced a number of interim regulatory requirements (DME, 2015) to apply to all future petroleum activities.

An outcome from this process is to develop regulations to address environmental management relating to onshore petroleum exploration and production.

5.6.1 Hunter 2014 petroleum legislation review

The 2012 Hunter review independent expert (Dr Tina Hunter) from the Bond University in Queensland was engaged in 2012 to undertake a review of the Northern Territory onshore petroleum legislation, specifically the capacity of the current legal framework to regulate the development of onshore shale, tight and coal seam gas.

The review entailed the analysis of petroleum laws in numerous jurisdictions, and drafted legislation for Australian and international governments. Twenty six (26) recommendations were made indicating that the current legislation, although adequate to regulate new technologies, could be improved with more prescriptive regulations (Hunter, 2014). Four (4) recommendations (Recommendations 18-21) reference water resources management directly with the response from the Government citing a review of the current MOU between DLRM and DME (refer section 5.5.1).

5.6.2 Hawke 2014 hydraulic fracturing review

A separate independent Inquiry into hydraulic fracturing in the Northern Territory was commissioned in 2014 and undertaken by Dr Allan Hawke (Hawke, 2014).

During the Inquiry, Dr Hawke consulted extensively with the community, interested stakeholders and experts, and considered reports, knowledge and industry practices from interstate and overseas.

5.6.3 Timeframe for drafting and enacting new regulations

Following the release of the recommendations of the Petroleum Legislation Review and the Hydraulic Fracturing Inquiry the Northern Territory Government (NTG) announced that new Regulations are to be developed. The timeframe for this process is detailed in Table 5-1. In the interim a set of Guiding Principles for the onshore oil and gas industry have been released by the Northern Territory Government (DME, 2015).

Government briefings with industry (late March 2015) on the regulatory review process have indicated that the overall timeline may now more realistically extend to second Quarter 2017 with the new or amended legislation to apply from 1 July 2017.

Table 5-1 Proposed timeline for the review and enactment of petroleum legislation **DME (2015).**

Timeframe	Process
1st quarter 2015	Release Report of Inquiry into Hydraulic Fracturing in the Northern Territory. Draft Onshore Oil and Gas Guiding Principles - consult with industry and community. Commence review of Northern Territory legislation.
2nd - 3rd quarter 2015	Release Onshore Oil and Gas Guiding Principles. Finalisation and implementation of draft Petroleum (Environment) Regulations. Commence review of approvals, compliance and monitoring processes. Commence legislative and regulatory amendments - consult with industry and community.
4th quarter 2015	Introduction of new or amendment legislation. Finalise and agree to approvals, compliance and monitoring processes across agencies.
1st quarter 2016	Passage of amendment legislation. Amendments to Northern Territory legislative and regulatory framework.
2nd quarter 2016	Commencement of enhanced Northern Territory legislative and regulatory framework.

5.7 INTERIM ONSHORE OIL AND GAS GUIDING PRINCIPLES

The Guiding Principles for the onshore oil and gas industry released by the Northern Territory Government (DME, 2015) set out the minimum expectations of how industry will conduct itself while the review of the Northern Territory's existing legislative and regulatory framework is undertaken.

These principles will be utilised by the Department of Mines and Energy when assessing future petroleum exploration and production licences and evaluated on the alignment of their application with these Guiding Principles. These principles, including the requirement for transparency in reporting, are enforceable via the Department of Mines and Energy's approval processes.

It is important to note that many aspects of the principles are already captured in petroleum legislation and regulation, particularly the Schedule of Onshore Petroleum Exploration and Production Requirements 2012 (DME, 2012).

Government briefings with industry (late March 2015) on the regulatory review process have indicated that the overall timeline may now more realistically extend to second Quarter 2017 with the new or amended legislation to apply from 1 July 2017.

5.8 INTERIM GUIDING PRINCIPLES RELEVANT TO WATER RESOURCES MANAGEMENT

The following sections detail the Guiding Principles for onshore oil and gas industry relevant to water resources management.

5.8.1 Operating principles

Two of the Guiding Principles relating to operational considerations relate directly to water resource management these are:

3. Site specific hazard assessments

- Site specific hazard assessments must be undertaken to determine what control measures are required for each well. Considerations as part of this assessment must include local geology and hydrogeology, potable groundwater resources and the general environment.

5. Well integrity

- Well integrity must be demonstrated (including cement coverage, consistency and quality for the entire length of the well and pressure tests) prior to any hydraulic fracturing being undertaken. Records must be kept to demonstrate well integrity to the Department of Mines and Energy (DME).

5.8.2 Water management strategies

Under the Guiding Principles Water Management Strategies (WMS) must be developed early and in consultation with local communities and regulators and be consistent with requirements under the Water Act 1992.

1. Plan to manage water strategically:

- Predict and plan water production and usage requirements and delineate in a WMS.
- Where operations fall within a Water Control District, proposed water extraction will be consistent with any Water Allocation Plan.
- The construction and works on water investigation, production and monitoring bores will be consistent with the requirements of the Water Act, including the use of licenced drillers and the compliance with the minimum construction standards for water bores in Australia.

2. Understand and minimise potential impacts to water resources:

- Ensure potential impacts of water extraction to groundwater and rivers are understood and documented in the water management strategy.
- Non–potable water will be sourced for fracking in preference to potable water.
- Minimise water take requirements through methods such as choosing water efficient technology and water re-use.
- Obtain water from the most sustainable source possible.
- Prioritise water management options that can reduce and mitigate impacts.
- Ensure landholders are not adversely impacted by reduced water supplies.

5.8.3 Hydraulic fracturing

Under the Guiding Principles requires fully understand the geological and hydrogeological setting of the area to be fractured, including stress regimes, pre-existing faults, formation fracture closure pressures and proximity to other formations:

- Ensure that there is no interconnection of the target formation with aquifers.
- Ensure there is sufficient safe separation distance between expected maximum fracture propagation height and aquifers.
- Identification of any impermeable layers between target zones and aquifers.

3. Choose fluid additives, which do not pose an unacceptable risk to health, safety and the environment:

- Consider risks to nearby groundwater resources.
- Ensure surface management of chemicals (including possibility of spills) minimises risk of environmental harm as well as the possibility of exposure of workers and landholders to the chemicals.
- BTEX compounds must not be used in hydraulic fracturing fluids.

5. Thorough risk-focused monitoring must be undertaken in order to demonstrate that there have been no detrimental impacts caused by the hydraulic fracturing:

- Monitoring must be undertaken to understand the pre-existing conditions and avoid uncertainty around perceived impacts. Monitoring must include at least water quality monitoring of nearby water bores as well as supply capacity and gas content.
- Monitoring of chemical concentrations in the hydraulic fracturing fluids.
- Monitoring to understand the propagation of fractures, such as micro- seismic monitoring and review of fracture propagation simulation model.
- Monitoring to detect any induced seismicity in the region.
- Flowback monitoring to determine whether naturally occurring toxic compounds or radioactive material have been released and to ensure no interconnections with aquifers has been caused where aquifers are in proximity.
- Post fracturing groundwater monitoring to consider down gradient water quality

6. Environmental plans must include contingencies to address (at a minimum):

- chemical and fuel spills
- loss of well integrity
- lack of surface containment of flowback (e.g. spills, overtopping or seepage)
- management of contaminants (e.g. naturally occurring radioactive materials)
- interconnection with overlying or underlying aquifers

5.8.4 Chemical And Waste Handling And Management

Two (2) of the Guiding Principles relate to waste management and water resources:

3. Ensure waste storage facilities (e.g. ponds, dams and tanks) are appropriately designed for the waste contained:

- Appropriately lined (e.g. HDPE).
- Designed to account for appropriate average recurrence interval rainfalls.

- Located away from sensitive areas and watercourses.

5. Where wastes are to be disposed of, ensure appropriate facilities are used:

- No wastes are to be discharged to waterways.
- Ensure chosen waste disposal facilities are appropriately licenced under the Waste Management and Pollution Control Act.
- Ensure long term environmental risks are managed.
- On-site disposal of wastes will require detailed environmental studies and control measures.

All waste endpoints to be stated in an approved environment management plan.

5.8.5 Rehabilitation And Decommissioning

The rehabilitation and decommissioning of onshore gas projects is critical in ensuring a positive legacy is left behind. Following appropriate standards is critical in maintaining community confidence in the industry and avoiding potential future harm and liabilities.

1. Wells must be decommissioned appropriately in accordance with good engineering practice in consideration of the local geology, hydrogeology and environmental values. As a minimum, the following must be achieved:

- Isolation of groundwater aquifers within the well from each other and hydrocarbon zones.
- Isolation of hydrocarbon zones within the well from each other, from groundwater aquifers or from zones of different pressure.

2. Details of well decommissioning must be provided to the DME and these details must give sufficient information to demonstrate that the well has been decommissioned successfully and all regulatory requirements have been met.

5.9 SUMMARY

It should be noted that the current legislation relating to both water resources management and petroleum activities are currently under review with a timeframe for legislation drafting and implementation estimated at 1½ - 2 years.

With this in mind the following points summarise the relevant aspects of current water management in the Northern Territory:

1. The Water Act 1992 does not <u>currently</u> apply to petroleum activities.
2. The <u>current</u> key legislation relating to water resources on petroleum leases is the Petroleum Act 1994 and the Schedule of Onshore Petroleum Exploration and Production Requirements 2012.
3. There is a MOU between DLRM and DME regarding referral of water related management issues on petroleum exploration leases.
4. The current legislation relating to petroleum activities is currently under review with a proposed timeline indicating mid 2016 as the date of enactment.

5. The legislation relating to water resources management (Water Act 1992) is currently under review, although the timeframe for the drafting and implementation of the new legislation has not been specified.

6. Draft interim Guiding Principles for onshore oil and gas activities, which are currently out for public comment, will require aspects of water management on Petroleum Leases to align with the Water Act (NT) 1992 these include:

- Water management strategies on petroleum leases must be developed early and in consultation with local communities and regulators and be consistent with requirements under the Water Act (NT) 1992.

    a. The construction and works on water investigation, production and monitoring bores will require the use of licenced drillers and the compliance with the minimum construction standards for water bores in Australia.

    b. This requires an extraction licence to be obtained for water bores inside a Water Control District; and

    c. An extraction licence to be obtained for water bores >15 l/s outside of a Water Control District.

- Also, where operations fall within a Water Control District, proposed water extraction will be consistent with any Water Allocation Plan (although no WAPs are coincident with Petroleum Leases).

- The construction and works on water investigation, production and monitoring bores will be consistent with the requirements of the Water Act 1992, including the use of licenced drillers and the compliance with the minimum construction standards for water bores in Australia.

- Ensure potential impacts of water extraction to groundwater and rivers are understood and documented in the Water Management Strategy.

- Ensure landholders are not adversely impacted by reduced water supplies.

The Guiding Principles for onshore oil and gas identify that specific issues regarding hydraulic fracturing are also addressed to ensure:

- that there is no interconnection of the target formation with aquifers.

- there is sufficient safe separation distance between expected maximum fracture propagation height and aquifers.

- the identification of any impermeable layers between target zones and aquifers.

- monitoring must be undertaken to understand the pre-existing conditions and avoid uncertainty around perceived impacts. Monitoring must include at least water quality monitoring of nearby water bores as well as supply capacity and gas content.

- post fracturing groundwater monitoring to consider down gradient water quality

The Guiding Principles for onshore oil and gas identify that specific issues relating to Chemical And Waste Handling And Management include:

- Ensuring that chosen waste disposal facilities are appropriately licenced under the Waste Management and Pollution Control Act.

6 Summary

The Beetaloo Basin is located in the central north of the NT approximately 180 km south-east of Katherine, the nearest regional centre. The region is sparsely inhabited with an estimated population of less than 1000. The only significant settlements occur along the Stuart Highway at Elliot and Daly Waters. Pastoral leasehold accounts for over 90% landuse within the basin with the remaining tenure including Aboriginal Land Trusts and freehold, Crown Land and small conservation reserves. The study area occurs over three bioregions: the Stuart Plateau bioregion, the Mitchell Grass bioregion and the Gulf Falls and Uplands bioregion. The area has a semi-arid climate with average rainfall ranging from 665 mm in the north to 518 mm in the south of the basin. Rainfall is linked to the north Australian monsoon and almost exclusively occurs between December and March. The topography of the basin is predominantly comprised of the flat-lying Sturt Plateau and Barkly Tablelands to the south. Surface drainage is limited in these areas water ways only flow briefly in response to heavy rainfall. Lake Woods, a large ephemeral lake in the south of the study in the most notable drainage feature. In the north-east, a more substantial surface water system drains the Gulf Falls and Uplands Bioregion toward the Gulf of Carpentaria.

The Beetaloo Basin is Proterozoic sedimentary basin with a predominantly subsurface occurrence. The basin is defined by a pronounced gravity low and is bounded by several prominent structural elements including the Walton High to the north, the Bauhinia Shelf to the east and the Helen Springs High to the south. The Roper Group forms the key component of the Beetaloo Basin sequence and represents a conventional and unconventional petroleum and gas target. The Roper Group comprises an upward coarsening succession of marine mudstones and sandstones intruded by post-depositional dolerite sills; it has eleven recognised formations and is estimated to reach over 5000 m in thickness. Within the Beetaloo Basin the Roper Group forms the upper succession of the McArthur Basin and unconformably overlies the earlier McArthur Basin Nathan and Tawallah groups. The Roper Group is unconformably capped by the Georgina Basin, a largely Cambrian sequence that includes widespread flood basalts and an extensive marine limestone sequence. The Georgina Basin underlies the Cretaceous Carpentaria Basin which along with more recent laterite development and alluvial sediments forms the surface geology within the Beetaloo Basin.

The Beetaloo Basin sequence is largely flat-lying and undeformed except for areas on the basin margin and around the major structural elements. Most significant deformation in the Beetaloo Basin pre-dates the Roper Group deposition, although a number of faults penetrate the lower and middle formations. Seismic data suggests that faults and fractures do not generally extend into the Hayfield Mudstone, which has significance for its role in inhibiting the upward migration of gas and fluid from the underlying Roper Group to shallow aquifers. Limited tectonic activity has occurred since the deposition of the Antrim Plateau Volcanics and the Cambrian Limestone sequence, and these formations form a flat-lying drape over the more deformed Proterozoic sequence. An exception occurs in the north-west of the Beetaloo Basin, where Yin Foo (2002) identified a NW-SE trending fault informally named the Birdum Creek Fault that has resulted in a 200 m displacement across the Cambrian limestone sequence. Seismic profiles suggest that faults also extend into the Cambrian sequence on the eastern margin of the Beetaloo Basin.

The Georgina Basin Gum Ridge Formation and Anthony Lagoon Beds form an extensive regional groundwater flow system, the Cambrian Limestone Aquifer (CLA), which provides a significant water resource for the pastoral industry and communities within the region. The CLA displays karstic weathering and dissolution features; where these are well developed the aquifer is highly transmissive and is capable of bore yields up to 100 l/s. The CLA is separated from the main resource targets within the Roper Group by the intervening Antrim Plateau Volcanics and Hayfield Mudstone. Thick, unweathered and undeformed basalt sequences in the Antrim Plateau Volcanics are largely impermeable and the formation is considered to represent the regional groundwater basement in the Georgina Basin. The Hayfield Mudstone comprises a thick and largely undeformed mudstone sequence up to 450 m in thickness. Where these formations are absent or thinner, along the eastern margin and in the south of the Beetaloo Basin, there is greater potential for interconnection between the Roper Group and the CLA. Other local scale aquifers occur in the basal Cretaceous sandstones and the Bukalara Sandstone. More marginal local water resources are targeted in the discrete fractured sequences of the Antrim Plateau Volcanics and the Proterozoic sequence where it outcrops along the north-east and south-west margins of the Beetaloo Basin. Generally these aquifers are only targeted where the CLA is absent. Limited information exists on the hydrogeological characteristics of the Roper Group sequence where it occurs at depth within the Beetaloo Basin. Groundwater occurrences where these formations outcrop in the McArthur Basin and information from exploration drilling suggests that the sandstone dominated sequences may behave as aquifers. Permeability in these formations is largely dependent on the development of secondary fracture derived porosity and it is likely they will only form local aquifer systems within the Beetaloo Basin.

Regional groundwater flow within the CLA in the Beetaloo Basin is separated into a western and an eastern section. The main body of the Beetaloo Basin overlies the Georgina Basin CLA, groundwater flow is to the north-west and discharges around 200 km north of the basin as spring flow in the Roper River. A small section in the west of the Beetaloo Basin overlies the Wiso Basin, regional flow within the CLA is to the north toward discharge points in the Flora and Roper Rivers. Groundwater gradients in the CLA are flat-lying (0.0001) and flow rates are in the order of metres/year. Vertical pressure gradients between the Roper Group and the CLA are not well characterised, however, exploration well formation tests indicates there is an upward pressure gradient from the Proterozoic to the CLA. Recharge to the CLA is dominated by macropore and local indirect recharge processes, including preferential flow through sink holes where the Cretaceous cover is poorly developed. Recharge rates are estimated at between 5 - 20 mm/year for all recharge mechanisms and 0.4 - 0.8 mm/year for direct infiltration (diffuse recharge). Water quality in all utilised aquifers in the Beetaloo Basin is potable, with an average groundwater conductivity range from 760 - 1780 μs/cm. Groundwater in the CLA has an ionic signature that is characteristic of carbonate and limestone aquifers and has elevated sulphate concentrations resulting from the dissolution of evaporate beds in the Anthony Lagoon Beds. The ionic signature of Roper Group Formation water has an average EC of 114000 μs/cm and is easily distinguished from groundwater in the CLA by a sodium-chloride dominant water type.

Recognised environmental dependencies associated with the Beetaloo Basin include springs in the Roper River at Elsey National Park and Red Lily/57 Mile Waterhole, both features are dependent on regional groundwater discharge from the CLA. Riparian zones along the Roper River and its tributaries including the Hodgson and Arnold Rivers also form important water dependant ecosystems. The Lake Woods wetlands are described as nationally important wetlands providing an important habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as when droughts prevail. Stock watering forms the primary groundwater extraction and accounts for over 80% of the constructed bores in the region. Small town water supplies for Daly Waters, Elliot and outstations are also significant groundwater users. Annual water use in the region is estimated at 6000 ML, of which over 90% is accounted for by stock watering.

Water allocation and licensing in the Northern Territory is regulated by the Department of Land Resource Management through the Water Act. Under the Water Allocation Plan Framework administrative areas can be declared for the purpose of managing the water within a specific area or resource. The north-west of the Beetaloo Basin falls within one such water management area, the Daly-Roper Water Control District (WCD). Bores drilled within a WCD require an extraction license unless used for stock and domestic use. Water extracted for petroleum purposes is currently exempt from the Water Act and is governed by the Petroleum Act. However, the Department of Mines and Energy recently released a set of "guiding principles" for petroleum activities, which requires water management to be consistent with requirements under the Water Act, this implies that an extraction licence is required for petroleum water supply bores drilled within the Daly-Roper WCD and for bores extracting greater than 15 l/s.

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