NORTHERN TERRITORY GOVERNMENT

DEPARTMENT OF
ENVIRONMENT AND NATURAL RESOURCES

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File Ref:
TRIM No. DLR2014/0080-0001

The Hon Justice Rachel Pepper
Chair
Hydraulic Fracturing Taskforce
GPO Box 4396
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Dear Justice Pepper

RE: HYDRAULIC FRACTURING INQUIRY – INFORMATION REQUEST

In response to your information request of 8 August 2017, the Department of Environment and Natural Resources has prepared the attached Response to Request for Information.

Should you require any further clarification or information on the response please contact this office.

Yours sincerely

JOANNE TOWNSEND
Acting Chief Executive Officer

Date: 25 August 2017

RESPONSE TO REQUEST FOR INFORMATION

Request for Information by the Hydraulic Fracturing Taskforce on 8 August 2017

Information about shale basins

This refers to the collated information and data provided to the Panel in May 2017 and the map referred to as Attachment C of the Department of Environment and Natural Resources (DENR) submission to the Scientific Inquiry (May, 2017) (Attachment A refers). NT Vegetation and Land Resources information in prospective source rock areas is shown in Attachment B. A summary of current hydrological and hydrogeological knowledge in the areas mapped over prospective source rocks is provided below:

a) Northern Amadeus Basin

Vegetation Overview

The general vegetation communities of the Amadeus Basin are presented in the following table.

Vegetation Community	Area (ha)	Area %*
Eucalyptus low open woodland	16,887	1%
Eucalyptus open woodland with hummock grassland	7,314	0.2%
Acacia/mixed species low open woodland	78,979	3%
Acacia georginae low open woodland	11,788	0.4%
Acacia tall open shrubland	135,565	4%
Acacia sparse shrubland	313,707	10%
Triodia hummock grassland with tall open shrubland	817,690	26%
Triodia hummock grassland with mixed species low open woodland	1,744,581	56%

* May not balance due to rounding

Landscape Overview

A general overview of the Amadeus Basin landscapes are presented in the following table.

Landscape Class	Class description	Area (ha)	Area %*
Alluvial floodplains	Alluvial floodplains, swamps, drainage depressions and alluvial fans; sandy, silty and clay soils on quaternary alluvium	119,183	4%
Desert dunefields	Dunefields with parallel linear dunes, reticulate dunes and irregular or aligned	1,341,433	43%

	short dunes; red sands		
Desert sandplains	Level to undulating sandplains with red sands	338,243	11%
Granite plains and rises	Gently undulating to undulating plains with rises and low hills on granite, schist, gneiss (deeply weathered in places); coarse grained sandy, earthy and texture contrast soils	108,808	3%
Limestone hills	Dissected hills on Cambrian limestone and dolomite; shallow soils with rock outcrop	82,269	3%
Limestone plains and rises	Plains, rises and plateaux on weathered and unweathered cambrian limestone, dolomite, chalcedony, shale, sandstone and siltstone with associated sand sheets; sandy and earth soils	109,626	4%
Salt pans	Salt pans with waterlogged saline clays and fringing dunes	19	0.001%
Sandstone hills	Low hills, hills and stony plateaux on sandstone, siltstone, quartzite and conglomerate (deeply weathered in places); outcrop with shallow stony soils	462,634	15%
Sandstone ranges	Rugged ranges on quartzite, sandstone and conglomerate; outcrop with shallow, stony sandy soils	564,295	18%
	Total	3,126,511	

* May not balance due to rounding

Water Overview

The Amadeus Basin is a large deep sedimentary basin south of the MacDonnell Ranges. It trends east – west across the region extending to the NT/WA border. The Northern Territory Geological Survey (NTGS) has identified the Horn Valley Siltstone as a potential hydrocarbon source rock which occurs in the northern part of the Amadeus basin (refer map) mainly to the west of the Stuart Highway.

There are many aquifers hosted in the various rock types in the Northern Amadeus Basin. The most significant is the Mereenie Aquifer System (MAS) in the north-eastern part of the basin which represents the source of Alice Springs' municipal water supply. The Horn Valley Siltstone is one of the oldest Formations in the Northern Amadeus Basin and underlies most of the aquifers. However, it appears to be absent in the north-

eastern part between Pine Gap and Rocky Hill where nearly all of the groundwater usage occurs.

Exposures of the Amadeus rocks occur largely in the MacDonnell, Waterhouse and James Ranges. Most of the discharges from aquifer systems occur where the range has been disturbed by geological structures forming waterholes, seeps and springs at the 'gaps' in the ranges.

Hydrogeological knowledge across the Amadeus Basin is limited to localised areas where bores have been drilled for small water supply purposes. There has not been any overall study undertaken of aquifers in the Basin. Most of the hydrogeological studies and long term monitoring has concentrated in the MAS between Pine Gap and Rocky Hill where water supply needs have focussed.

Hydrological studies have been undertaken in the Todd River catchment around Alice Springs. The understanding of catchment behaviour and response has been necessitated by the threat of flooding in the urban area of Alice Springs and the need to develop a flood warning system.

The water quality of the northern Amadeus aquifers is variable. In parts of the system where a recharge regime occurs (ie. where aquifers are unconfined), the water quality is often potable. In deeper parts of the basin, or where there is connection with poorer quality aquifers, saline quality groundwater is available.

b) Arthur Creek Formation

Vegetation Overview

The general vegetation communities of the Arthur Creek Formation are presented in the following table.

Vegetation Community	**Area (ha)**	**Area %***
Eucalyptus low open woodland	152,288	3%
Eucalyptus low open woodland with hummock grassland	288,503	6%
Acacia/mixed species low open woodland	43,410	1%
Acacia georginae low open woodland	1,532,080	30%
Acacia tall open shrubland	150,178	3%
Acacia sparse shrubland	445,949	9%
Triodia hummock grassland with tall open shrubland	1,511,479	30%
Grassland	602,796	12%

Chenopod low sparse shrub/forbland	14,256	0.3%
Open shrubland	304,329	6%

* May not balance due to rounding

Landscape Overview

A general overview of the Arthur Creek Basin landscapes are presented in the following table.

Landscape Class	Class description	Area (ha)	Area %*
Alluvial floodplains	Alluvial floodplains, swamps, drainage depressions and alluvial fans; sandy, silty and clay soils on Quaternary alluvium	197,052	4%
Clay plains	Level to gently undulating clay plains (black soil plains); cracking clay soils	605,794	12%
Desert dunefields	Dunefields with parallel linear dunes, reticulate dunes and irregular or aligned short dunes; red sands	218	0.004%
Desert sandplains	Level to undulating sandplains with red sands	1,643,006	33%
Granite plains and rises	Gently undulating to undulating plains with rises and low hills on granite, schist, gneiss (deeply weathered in places); coarse grained sandy, earthy and texture contrast soils	12,307	0.2%
Lateritic plains and rises	Plains and rises associated with deeply weathered profiles (laterite) including sand sheets and other depositional products; sandy and earth soils	63,875	1%
Limestone hills	Dissected hills on Cambrian limestone and dolomite; shallow soils with rock outcrop	29,290	1%
Limestone plains and rises	Plains, rises and plateaux on weathered and unweathered Cambrian limestone, dolomite, chalcedony, shale, sandstone and siltstone with associated sand sheets; sandy and earth soils	1,307,211	26%

Sandstone hills	Low hills, hills and stony plateaux on sandstone, siltstone, quartzite and conglomerate (deeply weathered in places); outcrop with shallow stony soils	242,914	5%
Sandstone plains and rises	Plains, rises and plateaux on mostly on sandstone, siltstone, claystone, shale and some limestone; commonly shallow soils with surface stone and rock outcrop	943,300	19%
Sandstone ranges	Rugged ranges on quartzite, sandstone and conglomerate; outcrop with shallow, stony sandy soils	258	0.01%
	Total	5,045,224	

* May not balance due to rounding

Water Overview

The Arthur Creek Formation extensively underlies the pastoral region between the Sandover and Plenty Highways in Central Australia. In geological terms, it lies within the Southern Georgina Basin. In some areas of the basin, it underlies and overlies rock types that may be associated with significant groundwater resources.

Hydrogeological knowledge in the area of the Arthur Creek Formation is limited to bores drilled for stock watering purposes. However, the groundwater resources in the Western Davenport region just beyond its western extent are known to be significant.

There have been no hydrological studies undertaken in this area.

The water quality in aquifers above and below the Arthur Creek Formation are generally marginal to brackish in terms of potability for human consumption, but suitable for stock watering.

c) Beetaloo Sub-basin and surrounds

Vegetation Overview

The general vegetation communities of the Velkeri Formation are presented in the following table.

Vegetation Community	**Area (ha)**	**Area %***
Eucalyptus woodland	2,538,289	31%
Eucalyptus low woodland	2,424,202	30%
Eucalyptus low open woodland	509,350	6%

Eucalyptus low woodland with hummock grassland	52,144	0.6%
Eucalyptus low open woodland with hummock grassland	132,269	2%
Mixed species low open woodland with tussock grassland	246,373	3%
Melaleuca forest/woodland	95,515	1%
Acacia with grassland	1,578,720	20%
Shrubland	22,303	0.3%
Triodia hummock grassland	20,662	0.3%
Grassland	473,028	6%

* May not balance due to rounding

Landscape Overview

A general overview of the Velkerri Formation landscapes are presented in the following table.

Landscape Class	Class description	Area (ha)	Area %*
Alluvial floodplains	Alluvial floodplains, swamps, drainage depressions and alluvial fans; sandy, silty and clay soils on quaternary alluvium	494,775	6%
Basalt hills	Low hills and hills on basalt, agglomerate and tuff, some dolerite; mostly rock outcrop with surface stone and pockets of clayey soils	152,920	2%
Basalt plains and rises	Plains and rises on basalt, agglomerate and tuff, some dolerite; clayey soils with surface stone	354,345	4%
Clay plains	Level to gently undulating clay plains (black soil plains); cracking clay soils	824,134	10%
Desert sandplains	Level to undulating sandplains with red sands	41,968	1%
Lateritic plains and rises	Plains and rises associated with deeply weathered profiles (laterite) including sand	5,112,704	63%

	sheets and other depositional products; sandy and earth soils		
Lateritic plateaux	Plateaux, scarps and some rises on deeply weathered sediments; shallow soils with rock outcrop	221,753	3%
Limestone plains and rises	Plains, rises and plateaux on weathered and unweathered cambrian limestone, dolomite, chalcedony, shale, sandstone and siltstone with associated sand sheets; sandy and earth soils	173,148	2%
Rugged quartz sandstone plateaux and hills	Steep rocky plateaux and hills on quartz sandstone and sandstone; shallow sandy soils and rock outcrop	148,071	2%
Sandstone hills	Low hills, hills and stony plateaux on sandstone, siltstone, quartzite and conglomerate (deeply weathered in places); outcrop with shallow stony soils	70,528	1%
Sandstone plains and rises	Plains, rises and plateaux on mostly on sandstone, siltstone, claystone, shale and some limestone; commonly shallow soils with surface stone and rock outcrop	498,532	6%
	Total	8,092,878	

* May not balance due to rounding

Water Overview

The Velkerri Formation is mapped as the prospective source rock in the Beetaloo Sub-Basin and surrounding region. Overlying the Beetaloo Sub-basin are the Cambrian aged Georgina, Wiso and Daly Basins. Hydrogeologically, these basins form regionally extensive limestone aquifer systems extending from around Tipperary (northern Daly Basin), through the Wiso Basin as far south as the Tanami Desert, and the Barkly Tablelands region to the south-east. The boundaries between the Cambrian Daly, Wiso and Georgina Basins have been shaped by the underlying basement structure. The sedimentary rocks within each basin may be correlated and contain many stratigraphic similarities. The limestone formations including the Tindall Limestone in the Daly Basin, the Montejinni Limestone in the Wiso Basin and the Gum Ridge Formation in the Georgina Basin host the vast majority of the groundwater resources in the region. However, no hydrogeological distinction is made between each of the formations as they represent a single, extensive aquifer system. The discharge from these systems is known to sustain the many springs in the Katherine River in Katherine, the Flora River

in the vicinity of the National Park and the Roper River between Mataranka and Elsey homesteads respectively.

The Beetaloo Sub-basin may be considered in two parts – east and west of the Stuart Highway. Groundwater systems hosted in the Georgina and Wiso Basin sediments respectively overlie these parts. East of the Stuart Highway, the Georgina Basin hosts two groundwater systems – an upper system within the Anthony Lagoon Formation and a lower system within the limestones of the Gum Ridge Formation. To the west of the Stuart Highway, the Wiso Basin in the Sturt Plateau region is mostly shallow and hosts a single thin aquifer in the Montejinni Limestone. Furthermore, small aquifers in the basalt and other rocks directly underlying the Cambrian limestone basins are known to exist.

The Cambrian limestone aquifers are most notable for their potentially high yielding bores. Individual bores in this region may yield in excess of 50 L/s where cavities are intersected.

In the Georgina Basin, existing water quality data is mostly represented for the upper Anthony Lagoon Formation which provides water supplies to the pastoral industry across the region. Total Dissolved Solids (TDS) levels of around 1000 mg/L are common. Dissolution of evaporate beds within this formation results in water with significant levels of sulphate and sodium chloride salts. Bores in the region that have intersected aquifers within this formation are usually less than 200m deep and are generally of low yield – however, suitable for stock watering. Higher yields are locally available. The Anthony Lagoon Formation itself hosts multiple aquifers which are thin, and may or may not be connected.

The limited water quality data from the underlying Gum Ridge Formation indicates that better quality potable water exists at depth (beneath the Anthony Lagoon Formation) with the TDS around 500 mg/L. The prospect for high yielding bores in this Formation is excellent, as existing information indicates there is aquifer development at depth associated with cavities, fractures and zones of weathering.

In the western Beetaloo Sub-basin on the Sturt Plateau, pastoral bores intersecting the Montejinni Limestone will yield low to medium supplies of good quality groundwater with TDS around 450 mg/L.

Hydrological studies have been undertaken for the two main rivers in the subject area. The information has been incorporated into a connected groundwater/surface water model of the Cambrian Limestone groundwater system/Daly and Roper River systems.

Furthermore, high flow hydrologic assessment has also been undertaken for the Daly and Roper catchments and flood forecast models have been developed for both river systems.

d) McArthur Basin

Vegetation Overview

The general vegetation communities of the McArthur Basin are presented in the following table.

Vegetation Community	Area (ha)	Area %*
Eucalyptus woodland	800,486	42%
Eucalyptus low woodland	196,177	10%
Eucalyptus low open woodland	32,875	2%
Eucalyptus low open woodland with hummock grassland	819,767	43%
Mixed species low open woodland with tussock grassland	1,360	0.07%
Melaleuca forest/woodland	31,034	2%
Acacia with grassland	4,946	0.3%
Grassland	12,650	0.7%
Littoral	8,237	0.4%

* May not balance due to rounding

Landscape Overview

A general overview of the McArthur Basin landscapes are presented in the following table.

Landscape Class	Class description	Area (ha)	Area %*
Alluvial floodplains	Alluvial floodplains, swamps, drainage depressions and alluvial fans; sandy, silty and clay soils on Quaternary alluvium	236,382	12%
Clay plains	Level to gently undulating clay plains (black soil plains); cracking clay soils	1,755	0.1%
Coastal dunes	Coastal parabolic dunefields, sandplains, beach ridges and beaches; sandy soils	93,557	5%
Lateritic plains and rises	Plains and rises associated with deeply weathered profiles (laterite) including sand sheets and other depositional products; sandy and earth soils	263,753	14%

Lateritic plateaux	Plateaux, scarps and some rises on deeply weathered sediments; shallow soils with rock outcrop	25,328	1%
Rugged quartz sandstone plateaux and hills	Steep rocky plateaux and hills on quartz sandstone and sandstone; shallow sandy soils and rock outcrop	328,513	17%
Sandstone hills	Low hills, hills and stony plateaux on sandstone, siltstone, quartzite and conglomerate (deeply weathered in places); outcrop with shallow stony soils	215,643	11%
Sandstone plains and rises	Plains, rises and plateaux on mostly on sandstone, siltstone, claystone, shale and some limestone; commonly shallow soils with surface stone and rock outcrop	738,274	39%
Tidal flats	Tidal mudflats and coastal floodplains with channels and estuaries; subject to tidal inundation; poorly drained clays and muds	4,633	0.2%
	Total	1,907,838	

* May not balance due to rounding

Water Overview

General water resource mapping has been undertaken in the region of the McArthur Basin near Borroloola. This mapping provides information regarding aquifer types, likely bore yields and water quality. It also provides indicative streamflow information.

The only detailed hydrogeological study in this region is within the vicinity of Borroloola. A groundwater assessment has been conducted for the Abner Sandstone aquifer which provides the water supply to the town of Borroloola.

A hydrologic study has been undertaken for the McArthur River catchment in order to develop a flood forecast model.

Aquifers in the McArthur Basin generally provide good quality groundwater.

e) Bonaparte Basin

Vegetation Overview

The general vegetation communities of the Bonaparte Basin vegetation communities are presented in the following table.

Vegetation Community	Area (ha)	Area %*
Eucalyptus woodland	71,960	30%
Eucalyptus low woodland	34,992	15%
Eucalyptus low open woodland with hummock grassland	1,173	0.5%
Littoral	131,820	55%

* May not balance due to rounding

Landscape Overview

A general overview of the Bonaparte Basin landscapes are presented in the following table.

Landscape Class	Class description	Area (ha)	Area %*
Alluvial floodplains	Alluvial floodplains, swamps, drainage depressions and alluvial fans; sandy, silty and clay soils on quaternary alluvium	39,172	16%
Coastal floodplains	Seasonally flooded coastal floodplains; inundated 3-6 months; poorly drained clay soils	50,491	21%
Lateritic plains and rises	Plains and rises associated with deeply weathered profiles (laterite) including sand sheets and other depositional products; sandy and earth soils	59,183	24%
Limestone plains and rises	Plains, rises and plateaux on weathered and unweathered cambrian limestone, dolomite, chalcedony, shale, sandstone and siltstone with associated sand sheets; sandy and earth soils	1,628	1%
Rugged quartz sandstone plateaux and hills	Steep rocky plateaux and hills on quartz sandstone and sandstone; shallow sandy soils and rock outcrop	3,937	2%
Tidal flats	Tidal mudflats and coastal floodplains with channels and estuaries; subject to tidal inundation; poorly drained clays and muds	90,888	37%
	Total	245,300	

* May not balance due to rounding

Water Overview

A hydrogeological study undertaken in the shallow sediments on the Keep River Plains represents the only detailed work in this area. Given a future scenario of the Keep River Plains under irrigated development, this work provided a basis for the prediction of the response of the groundwater system.

Water resource mapping undertaken for Spirit Hills and Legune Stations provides general information for this area.

No hydrological studies have been undertaken for the Keep River.

Water qualities in many aquifers within this region are affected by estuarine processes and the concentration of salts as a result of limited recharge. Where aquifers are unconfined and receive regular wet season recharge, good quality groundwater may be expected. However, aquifers near the Keep River estuary or beneath the black soils of the Keep River Plains, will likely be at least brackish and probably saline.

Recharge Rates

Sustainable Yield for the Beetaloo Sub-basin and beyond.

The Beetaloo Sub-basin and beyond are subject to the NT Water Allocation Framework. The application of the NT Water Allocation Framework is dependent on whether the resource development is located in the Top End Zone (Humid) or Arid Zone. The Beetaloo Sub-basin is located in the region of transition between the Top End and Arid Zones which presents challenges in applying the Framework.

The Department has undertaken previous work which identifies the recharge to the groundwater system between Mataranka and Daly Waters is typically evidenced as seasonally oscillating water levels and the episodic recharge regimes generally across the arid zone. In the vicinity of Mataranka, the Tindall Limestone is near surface and receives seasonal recharge through a thin veneer of alluvial or weathered sediments. Further south, an intervening layer of Cretaceous sediments exists to filter any recharge. Recharge will only occur through the shallow soil profile once the matric potential of (dry) soils is satisfied and the soil matrix becomes saturated. Generally, in the Arid Zone of the NT, the threshold equates to about 700mm in total seasonal rainfall. The average annual rainfall in the vicinity of Larrimah is 713mm.

In the area east of the Stuart Highway between Mataranka and Daly Waters, a groundwater assessment has been undertaken (ref: Bruwer and Tickell, 2015) which presents the understanding of the recharge process occurring in this region. It is based on observed groundwater level data between Katherine and Mataranka (Top End Zone), and southward to Daly Waters (Arid Zone). Monitored groundwater level data to the west of the Stuart Highway (ie. the Sturt Plateau region) indicates that the response pattern is similar from east to west across this region. This data is presented in Yin Foo and Matthews (2001).

Observed groundwater levels in the Tindall Limestone aquifer around Mataranka characterise this area as seasonally responsive. The Larrimah area is considered to be seasonally responsive but muted. The increasing levels measured since the commencement of monitoring in the late 1990's indicate accumulation in the groundwater store due to the much higher than average wet period experienced since the late 1990's.

A Water Allocation Plan is currently being developed for Tindall Limestone Aquifer in the region between the King River (north of Mataranka) and Daly Waters. This plan will define the consumptive pool for this part of the aquifer.

The value of sustainable yield for the other parts of the Beetaloo Sub-basin – the Wiso Basin to the west, and the Georgina Basin south of Daly Waters will be based on the NT Water Allocation Framework.

Recharge Estimates

Recharge estimates are made for particular study regions. The estimate will depend on the size of the area, the annual rainfall received and the overlying shallow soil and vegetation profile and Formations. The approach to estimating recharge may range from empirical methods to modelled.

Bruwer and Tickell (2015) determined an average figure of 334,500 ML/y for the Tindall Limestone extending across the region between the King River and Daly Waters. In arriving at this estimate, a number of other empirical approaches were applied. These provided figures in the same order of magnitude. A conservative measure in the lower range of estimates has been adopted as the recharge estimate for the aquifer in this region. This is considered appropriate given the current level of information available.

Yin Foo and Matthews (2001) determined the amount of recharge in the Sturt Plateau region to be in the order of 100,000 ML/y based on empirical methods. This estimate will guide licence decision making in this groundwater system.

DENR's level of assessment of the resource is considered commensurate with the low level of development and licensed water usage in the subject area. DENR has an ongoing comprehensive program of water resource monitoring in the Daly Basin extending to the northern Wiso and Georgina Basins. This provides data for an ongoing assessment and model improvement program. An adaptive management approach is facilitated within a 10 year water licensing and plan revision timeframe.

Recharge Estimate South of Daly Waters to Elliott

Knowledge of the mechanism of recharge to Georgina Basin aquifers is based on stratigraphic, water quality and environmental isotope data. Tickell, S. J. and Bruwer, Q., (2017) reports that Anthony Lagoon Formation aquifers are most likely recharged through two possible mechanisms - direct infiltration of rainfall or the infiltration of standing surface water accumulated in the shallow chain of lakes on the

Barkly Tablelands following large rainfall events. However, as monitoring data is unavailable, the quantification of recharge is not possible.

Recharge to the Gum Ridge aquifers between Daly Waters and Elliott is only possible through a 'mountain front' flow mechanism as direct infiltration through its upper surface is precluded by the confining sediments of the Anthony Lagoon Formation. Therefore, the only opportunity for recharge is through the Formation's lateral contact interface with the Lower Proterozoic sediments of the Ashburton Range which forms its western boundary. Enhanced recharge may also occur through structural features (such as faults) across the Lower Proterozoic rock. Water quality analyses and carbon dating of groundwater supports this understanding as fresher and younger groundwater occurs in the aquifer parallel to the western contact zone. There is no monitoring data and inadequate spatial data on which to assess the volume of recharge entering this aquifer system.

Faulty Wells

A hydrogeological investigation that establishes the aquifers and the depths at which they occur would be required to ensure that the production gas well is constructed to adequately seal the individual Anthony Lagoon, Gum Ridge and any other aquifers that will be intersected. Knowledge of the different water qualities intersected and stratigraphic conditions will be important factors in determining the approach to drilling, and the cement grout and casing string design.

At this present time, DENR plays no role in the regulation of Petroleum related activities. In the event that a contamination plume was detected around a well, the regulator would be involved and provide guidance as to recommended actions. DENR is not the regulator.

Flood Events

In the surface water context, flow events which lie beyond an Annual Exceedance Probability (AEP) of 1 (1 in 100 years) may be defined as extreme. The surface water assessment undertaken by Gautam (2017) examined flows at three key sites with lengthy flow record in the region of the Beetaloo Basin. This work indicated that the 1% AEP for flows at G0280009 (Newcastle Creek - Stuart Highway), G9030124 (Daly Waters Creek) and G9030001 (Elsey Creek at Warlock Ponds) were 4184, 135, and 1458 m^3/s respectively. For G0280009, the two largest flows recorded were 1653 and 1649 m^3/s measured in 1974 and 1975 respectively. These flows are more frequent than 5% AEP (1 in 20 years). For G9030124, a flow of 83 m^3/s has been recorded on two occasions – 1991 and 2001. This flow has a 2% AEP (1 in 50 years). At G9030001, flows of 799 and 794 m^3/s were recorded in 1976 and 1974 respectively. These flows are less than 2% AEP (1 in 50 years).

Attachment C presents a map of the 1% AEP Flood Map for key rivers and creeks in the region overlying the Beetaloo Sub-basin (from Gautam, 2017). This indicates that for a 1 in 100 year event, flooding is largely limited to the confines of the water courses.

There have been no flood studies or surface water assessments undertaken for other areas overlying the prospective source rocks.

Groundwater Pressure

There has been no site specific modelling undertaken in the Cambrian Limestone aquifers overlying the Beetaloo Sub-basin. The karstic nature of the aquifers means that on a local scale, Darcy's law for groundwater flow is not applicable with groundwater flow following preferential pathways. However, on a regional scale, the local flow effects become less prevalent and the aquifers are considered to behave as an equivalent porous media. The mechanics of Darcian flow may then be applied.

Therefore, a modelling approach could be applied to determine the magnitude of drawdown experienced at a particular site. However, it could only be applied to sites beyond a nominal distance of greater than 500m from the site of groundwater extraction.

The issue of water quality modelling in karstic environments is problematic. Generally, without knowledge or mapping of the karstic features and structures near to the source of contamination, the immediate fate and transport of dissolved constituents is difficult to predict on a local scale. Further, study would need to be undertaken to characterise the advection, dispersion and diffusive properties of such aquifers to enable the modelled prediction of movement of a contaminant plume on a larger scale.

If it were considered that the groundwater system would revert to a natural flow condition following the completion of the groundwater extraction phase (ie. post-hydraulic fracturing), then flows will be driven by the regime of recharge. In the Georgina Basin south of Daly Waters, the rate of recharge to the Gum Ridge aquifer is extremely low (refer above) and accordingly, natural groundwater flow will occur at an extremely low rate. That is, there would be little or no movement of a contaminant plume beyond the immediate vicinity of the production gas well.

In the Anthony Lagoon aquifers, groundwater flows are highly influenced by the regime of pumping for stock water. Although groundwater movement still occurs at a very low rate (perhaps metres per year), there is likelihood of detection of a plume at some distance from the source.

In other parts of the groundwater system overlying the Beetaloo Sub-basin, the natural rate of movement is low and could be in the order of less than a metre per year.

Monitoring of a possible contaminant plume would need to occur through sampling wells in close proximity to the production gas well and target each of the aquifers and karstic feature that may be potentially contaminated.

Groundwater Dependent Ecosystems

As previously indicated (correspondence dated 22 May 2017), the Department does not have any data on potential GDEs in the area underlain by the Beetaloo basin.

Surface Expression of the Aquifers

The only known open water bodies are Lake Duggan (a perched water table) and numerous waterholes, developed on drainage features across the Sturt Plateau. These features are not connected to the Cambrian Limestone aquifers.

Studies/Surveys of Water Bodies and GDEs

Aquifers occurring in the area overlying the Beetaloo Basin are either in the Anthony Lagoon Formation or the Gum Ridge, Montejinni or Tindall Limestone systems.

Anthony Lagoon Formation exists only across the Barkly Region. The surface expression of this Formation is poor as it has a deep weathered profile and/or is covered by younger sediments. However, groundwater levels are more than 40m below ground surface. Ground surveys have only been conducted for the purpose of geological mapping and not for the detection of potential GDEs.

Exposures of the Tindall and Montejinni Limestones of the Daly and Wiso Basins respectively north of Daly Waters are rare. Both Formations are generally covered by a thick (>50m) coverage of Cretaceous aged sediments. In the area of Gorrie Station where the Cretaceous sediments are thinnest, groundwater levels are currently about 30m from surface. Outcrop surveys of these rock types have been undertaken during the hydrogeological investigations between 1997 and 2000. However, apart from the Flora and Roper Rivers, no permanent water features were located that directly connect to these aquifers. A few small springs sourced from the Montejinni Limestone occur in the headwaters of the Armstrong River on the western margin of the Wiso Basin.

Exposures of the Gum Ridge Formation of the Georgina Basin are not common. They mostly occur in the southern part of the basin. Groundwater levels are approximately 40 to 50m in this area. There will not be any spring activity as the water table is too low. Ground surveys for exposures of this Formation on the eastern and northern margins have only been conducted for geological mapping purposes. Groundwater levels in the northern basin area are approximately 80 to 100m in depth. Water table depths on the eastern margin are unknown.

Stygofauna

There have been no studies of stygofauna in the Northern Territory.

Surface Water Resources

All of the water courses in the subject area are ephemeral except in Elsey Creek below Warlock Ponds where the water table becomes shallow and is possibly expressed as a perennial pool in the river. In the lower reaches of Elsey Creek, springs emerge in the river bed and perennial flows occur downstream.

Otherwise, all other river flows (approximately 20% of the year) are event based as determined in Gautam (2017).

Strategic Development

The Territory's situation is different from other jurisdictions, such as Queensland, which is a focused on coal seam gas activities with an ongoing co-production of water and the production of large amounts of salty water, which must be treated. The gas resources in the Northern Territory are shale at depths below the ground water table. Similarly, the land holders and stakeholders have a unique composition with large pastoral leases and Aboriginal Land communally held by traditional owners. These unique characteristics warrant tailored solutions and constructs to enable future industries to gain a social licence.

The inquiry has questioned the Departments position regarding how the industry can earn a social licence – in particular mechanisms that could be introduced prior to industry commencing operation.

It is DENR's position that it is preferential to be able to prepare and plan for potential industry growth. Such preplanning provides greater certainty for industry and the community when industry growth occurs.

Processes to identify and set baselines, such as strategic assessments, are important tools for the effective management of an industry but also, critically, for transparent communication with stakeholders which underpins social licence. Ongoing scientific research and investigation provide further support the growth of industries through quality decision making and ongoing effective regulation. To that effect DENR would also argue that industry development should be matched with regulatory capacity (including inputs to regulation such as independent science and advice).

In a small jurisdiction, the introduction of measures such as the Office of Groundwater Impact Assessment has both advantages and disadvantages. Advantages include the capacity to focus and quarantine resources onto the growth industry; disadvantages include the ability to attract and maintain appropriately qualified staff, and a reliance on the data and expertise held by DENR, which would not be resourced.

Any regulatory model under consideration for the Northern Territory should reflect the industry, its risks, its land and water characteristics (including tenure). It also needs appropriate resourcing, paced to meet industry development.

References

Bruwer, Q. and Tickell, S. J., (2015). Daly Basin Groundwater Resource Assessment - North Mataranka to Daly Waters, Department of Land Resource Management, Water Resources Report Number 20/2015D

Tickell, S. J. and Bruwer, Q., (2017) Georgina Basin Groundwater Assessment - Daly Waters to Tennant Creek, Department of Environment and Natural Resources, Water Resources Report Number xx/2017D (unpublished)

Gautam, B., (2017). A Preliminary Investigation on Surface Water Flooding & Water Resources Issues within Beetaloo Catchment, Department of Environment and Natural Resources, Water Resources Report Number xx/2017D (unpublished)

Yin Foo, D and Matthews, I. (2001), Hydrogeology of the Sturt Plateau, 1:250,000 Scale Map Explanatory Notes, Department of Infrastructure, Planning and Environment, Water Resources Report Number 17/2000D

RESPONSE TO REQUEST FOR INFORMATION

Addendum to Request for Information by the Hydraulic Fracturing Taskforce on 8 August 2017 in relation to the area west of Stuart Highway adjacent to Beetaloo Sub-basin

Information about shale basins

NT Vegetation and Land Resources information in prospective source rock areas is shown in Attachment B provided to our initial response. A summary of current hydrological and hydrogeological knowledge in the areas mapped over prospective source rocks is provided below:

West of Stuart Highway adjacent to Beetaloo Sub-basin

Vegetation Overview

The general vegetation communities of the Montejinni Basin are presented in the following table.

Vegetation Community	Area (ha)	Area %
Acacia open forest	678,677	6%
Acacia tall open shrubland	25,017	0.2%
Acacia tall sparse shrubland	19,760	0.15%
Astrebla low tussock grassland	144,896	1%
Chrysopogon (mixed) low tussock grassland	151,424	1%
Chrysopogon (mixed) tussock grassland	6,884	0.06%
Corymbia low open woodland	32,708	0.3%
Corymbia low woodland	214,614	2%
Corymbia woodland	646,889	5%
Eucalyptus low open woodland	715,273	6%
Eucalyptus low woodland	239,309	2%
Eucalyptus woodland	191,734	2%
Halosarcia low open samphire shrubland	65,919	0.5%
Lysiphyllum low open woodland	34,928	0.3%

Macropteranthes tall shrubland	435,146	4%
Melaleuca open shrubland	283	0.002%
Panicum (mixed) tussock grassland	64,736	0.5%
Terminalia (mixed) low open woodland	7,887	0.07%
Triodia hummock grassland	172,250	1%
Triodia low open hummock grassland	8,013,677	68%
Not mapped	14,530	0.12%

* May not balance due to rounding

A general overview of the Montejinni Basin landscapes are presented in the following table.

Landscape Class	Class description	Area (ha)	Area %
Alluvial floodplains	Alluvial floodplains, swamps, drainage depressions and alluvial fans; sandy, silty and clay soils on Quaternary alluvium	126,687	1%
Basalt plains and rises	Plains and rises on basalt, agglomerate and tuff, some dolerite; clayey soils with surface stone	453	0.004%
Clay plains	Level to gently undulating clay plains (black soil plains); cracking clay soils	351,642	3%
Desert dunefields	Dunefields with parallel linear dunes, reticulate dunes and irregular or aligned short dunes; red sands	3,475,641	29%
Desert sandplains	Level to undulating sandplains with red sands	5,599,418	47%
Elevated plateaux surfaces	Elevated plateaux surfaces on deeply weathered sediments and associated sand sheets; sandy and earth soils	102,432	1%
Lateritic plains and rises	Plains and rises associated with deeply weathered profiles (laterite) including sand sheets and other depositional products; sandy and earth soils	1,812,964	15%
Limestone plains and rises	Plains, rises and plateaux on weathered and unweathered Cambrian limestone, dolomite, chalcedony, shale, sandstone and siltstone	333,960	3%

	with associated sand sheets; sandy and earth soils		
Sandstone hills	Low hills, hills and stony plateaux on sandstone, siltstone, quartzite and conglomerate (deeply weathered in places); outcrop with shallow stony soils	61,581	0.5%
Sandstone plains and rises	Plains, rises and plateaux on mostly on sandstone, siltstone, claystone, shale and some limestone; commonly shallow soils with surface stone and rock outcrop	11,767	0.1%
	Total	11,876,545	

* May not balance due to rounding

Water Overview

In the western Beetaloo Sub-basin on the Sturt Plateau, pastoral bores intersecting the Montejinni Limestone will yield low to medium supplies of good quality groundwater with TDS around 450 mg/L. Cretaceous aged sediments exist from surface to a depth of approximately 50m. The Montejinni Limestone may be intersected below these sediments. However, only the lower unit of the limestone is represented across this region. It overlies the undulating surface of the Cambrian aged Antrim Plateau Volcanics at approximately 70m depth. As the water table is 50 to 60m below surface, the aquifer is thin in most places, and is only prospective for water where it has infilled the troughs of the basement.

In the northern Beetaloo Basin, the layer of Cretaceous sediments thins and the Antrim Plateau Volcanics may be intersected near surface. This Formation is variably thick across the Sturt Plateau region and low yielding aquifers may develop in structural features or within its layering. The water quality is variable, however, suitable for pastoral use.

An aquifer in sandstone is known to exist at depth (between 200 and 300m) below the basalt. Moderate bore supplies (3 L/s) may be available and is suitable for stock watering. This aquifer has not been investigated in detail and therefore, knowledge of its extent, water quality variation or recharge is poor.

As the northern Wiso Basin merges into the southern Daly Basin in the vicinity of Larrizona Station, the topography rises and the thickness of the Montejinni/Tindall Limestone increases with the deepening of the basin. Corresponding to the rise in topography is a thickening of Cretaceous Sediments, and the Jinduckin Formation intervenes between these sediments and the Tindall Limestone. The water table in the limestone aquifer is at over 100m in depth in this area and bore yields of over 10 L/s are recorded. The water is potable for human consumption with an electrical conductivity of approximately 700 us/cm.

Groundwater Pressure

A regional groundwater model for the limestone underlying the Sturt Plateau currently exists. However, this is only developed to the extent of recognising the existence and continuity of the Cambrian Limestone aquifer in this region. It is represented as a groundwater system in steady state which contributes flow to the Flora River and would not be suitable for simulating site specific groundwater extraction regimes.

Groundwater Dependent Ecosystems

As previously indicated (correspondence dated 22 May 2017), the Department does not have any data on potential GDEs in the area underlain by the Beetaloo basin.

Surface Expression of the Aquifers

The only known open water bodies are Lake Duggan (a perched water table) and numerous waterholes, developed on drainage features across the Sturt Plateau. These features are not connected to the Cambrian Limestone aquifers.

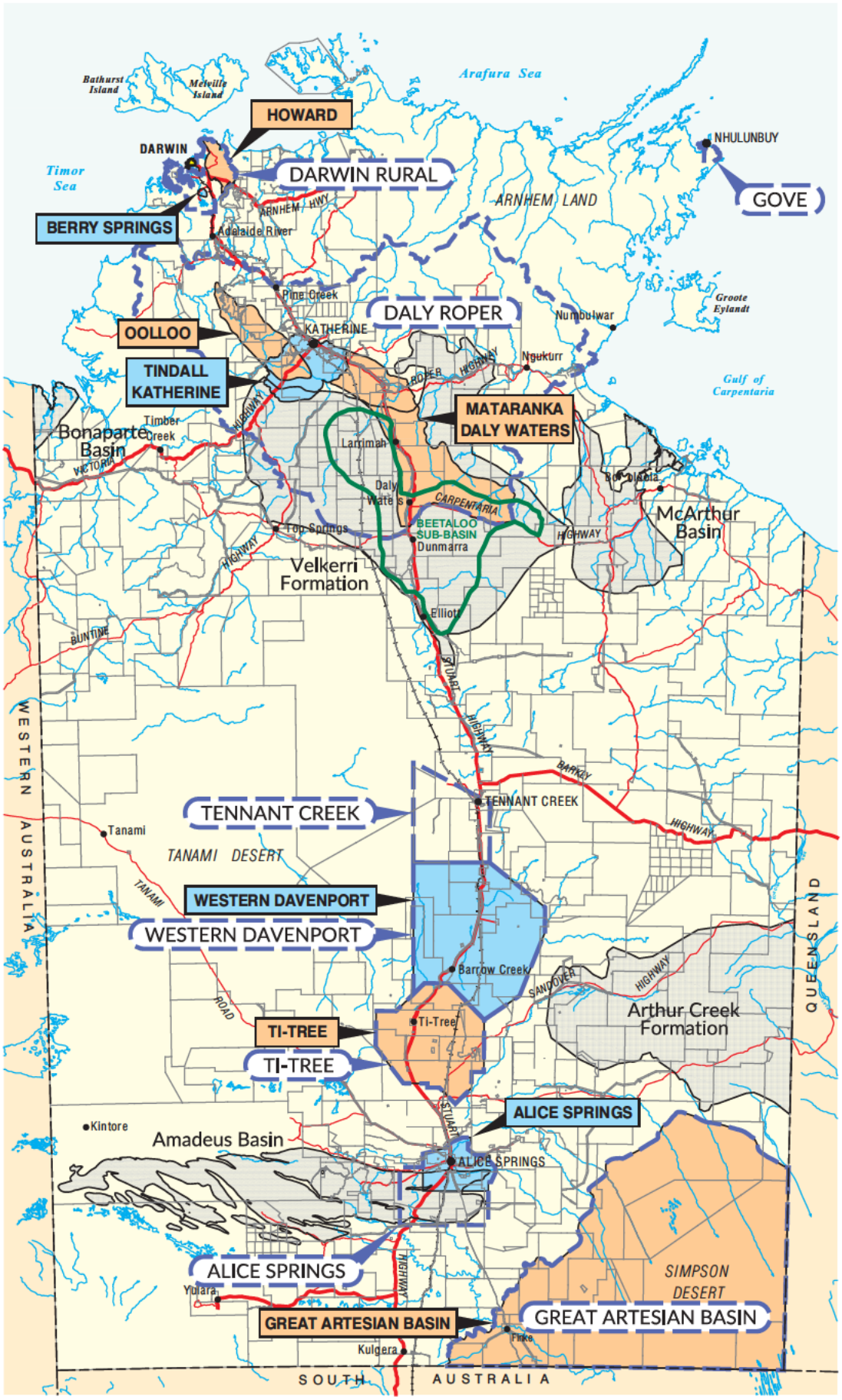
Studies/Surveys of Water Bodies and GDEs

Exposures of the Tindall and Montejinni Limestones of the Daly and Wiso Basins respectively north of Daly Waters are rare. Both Formations are generally covered by a thick (>50m) coverage of Cretaceous aged sediments. In the area of Gorrie Station where the Cretaceous sediments are thinnest, groundwater levels are currently about 30m from surface. Outcrop surveys of these rock types have been undertaken during the hydrogeological investigations between 1997 and 2000. However, apart from the Flora and Roper Rivers, no permanent water features were located that directly connect to these aquifers. A few small springs sourced from the Montejinni Limestone occur in the headwaters of the Armstrong River on the western margin of the Wiso Basin.

Stygofauna

There have been no studies of stygofauna in the Northern Territory.

NT WATER CONTROL DISTRICTS, WATER ALLOCATION AREAS, PROSPECTIVE SOURCE ROCKS & BEETALOO SUB-BASIN



NORTHERN TERRITORY OF AUSTRALIA

Water Control Districts are areas declared where there is a need for enhanced management for the sustainability of groundwater reserves and river flows.

Within a Water Control District a bore construction permit is required, water allocation plans can be developed and water extraction licences are required unless there is a specific exemption in place.

Water Allocation Plans aim to ensure the equitable sharing of available water between users, to protect the environment and ensure the long term sustainability of the water resource.

They usually occur in regions where there are competing demands for water, there is risk from water use to significant environmental values or a need to manage the whole system (surface water and groundwater resources) due to their significant inter connection.

NORTHERN TERRITORY GOVERNMENT

For further information contact:
Dept. of Environment and Natural Resources
Water Resources Division
P: 08 8999 4455
E: waterresources@nt.gov.au
Web: denr.nt.gov.au
Goyder Centre, Chung Wah Terrace
Palmerston

LEGEND

- **Water Control Districts**
- **Declared Water Allocation Plans**
- **Water Allocation Plans in Progress**
- **Beetaloo Sub Basin**
- **Prospective Source Rocks**

GENERAL FEATURES

- **Primary Road**
- **Secondary Road**
- **Railway**
- **State Border**
- **Watercourse**

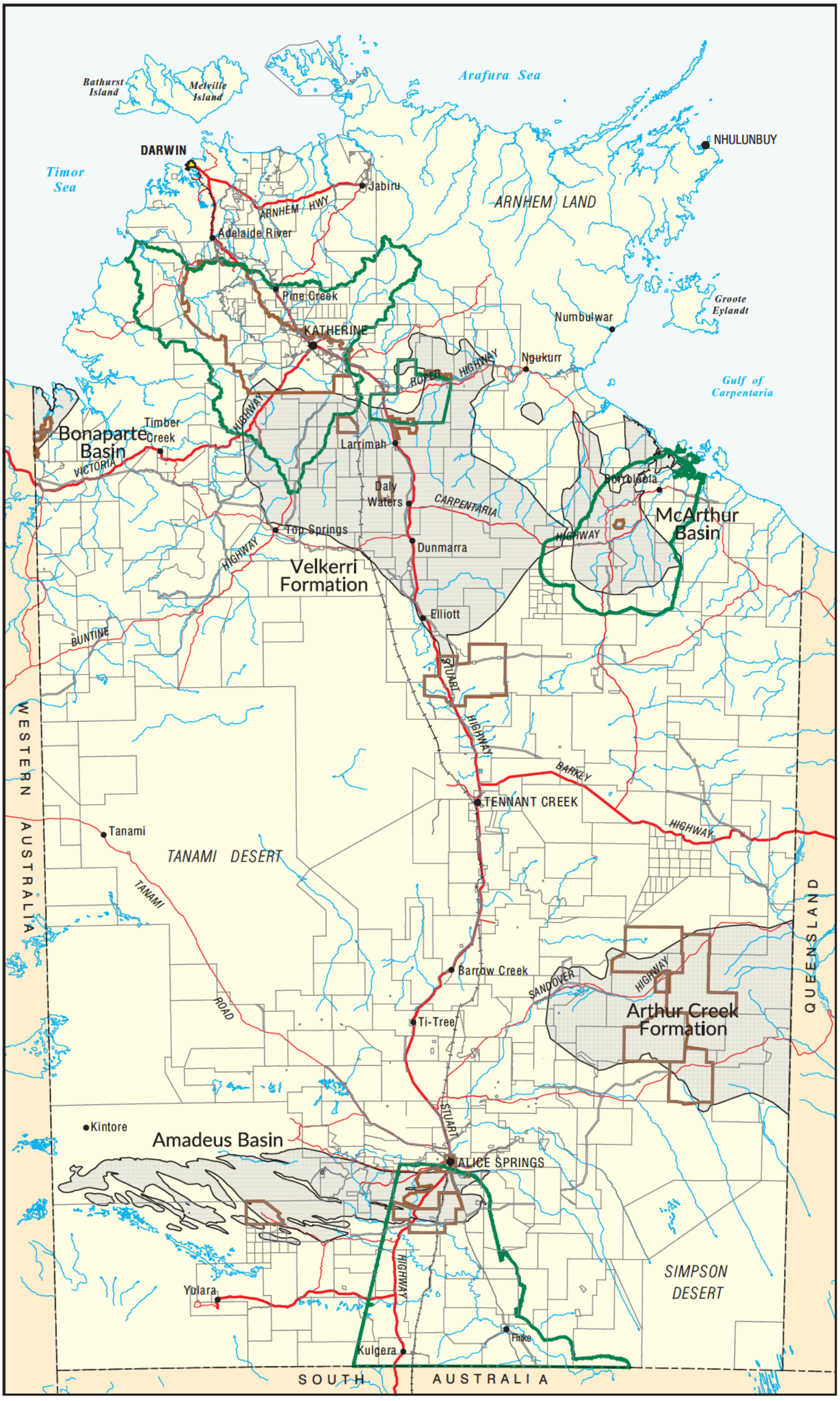
May 2017
File: NT_Water-Control-Districts-Allocation-Areas_PSR_BSB
Drawing Ref: DENR2017028

kilometres 0 100 200 300 400 kilometres

Projection Lamberts Conformal Conic
Standard Parallels 23°20'00"S & 12°40'00"S
Horizontal Datum GDA 94

GDA

NT VEGETATION & LAND RESOURCES INFORMATION IN PROSPECTIVE SOURCE ROCK AREAS



NORTHERN TERRITORY GOVERNMENT

For further information contact:
Dept. of Environment and Natural Resources
Rangeland Division
P: 08 8999 4443
Web: denr.nt.gov.au
Goyder Centre, Chung Wah Terrace
Palmerston

LEGEND

- **Broad NT wide Vegetation & Land System Mapping**
- **Medium scaled Vegetation Mapping**
- **Medium scaled Land Unit Mapping**
- **Prospective Source Rocks**

GENERAL FEATURES

- **Primary Road**
- **Secondary Road**
- **Railway**
- **State Border**
- **Watercourse**

Aug 2017
File: NT Vegetation Land-Resources-Information Prospective-Source-Rocks
Drawing Ref: DENR2017053

kilometres 0 100 200 300 400 kilometres

Projection Lamberts Conformal Conic
Standard Parallels 23°20'00"S & 12°40'00"S
Horizontal Datum GDA 94

GDA

Figure 1


N
Legend
RP_100_yr_Flood_Extent
Name
Bucket Cr
Lake Woods
Newcastle Cr
Western_Birdium_Elsey
Western_Birdium_Elsey
Bucket Cr
Newcastle Cr
Lake Woods
0 5 10 20 30 40
Kilometers