Regional Report

Strategic Regional Environmental and Baseline Assessment for the Beetaloo Sub-basin

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NORTHERN TERRITORY GOVERNMENT

Disclaimer

This Regional Report was prepared to provide an overview of information and data collected during the Strategic Regional Environmental and Baseline Assessment for the Beetaloo Sub-basin. The Regional Report is intended as a summary only and the reader should refer to the baseline study reports for more detail on specific subjects. While all reasonable efforts have been made to ensure that the contents of the Regional Report are factually correct, the Northern Territory of Australia does not accept responsibility for the accuracy or completeness of the contents. The Northern Territory of Australia shall not be liable for any claim or loss arising in connection with this Regional Report, or any information contained within it, or in respect of any person or party's use of the SREBA Regional Report for the Beetaloo Sub-basin.

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Cover image: Eucalypt woodland in the northern Beetaloo region (source: Northern Territory Government).

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List of abbreviations and acronyms

Acronym	Full form
ABS	Australian Bureau of Statistics
ADWG	Australian Drinking Water Guidelines
AEMS	Autonomous Emission Monitoring Station
AET	Actual evapotranspiration
AHD	Australian Height Datum
ALA	Atlas of Living Australia
ALT	Aboriginal Land Trust
ASC	Australian Soil Classification system
ASRIS	Australian Soil Resource Information System
ATSI	Aboriginal and/or Torres Strait Islander
AWRA	Australian Water Resource Assessment
bGL	Below ground level
BAM	Beta attenuation monitor
BoM	Bureau of Meteorology
BRRG	Beetaloo Regional Reference Group
BTEX	Benzene, toluene, ethylbenzene and xylenes
BVG	Broad vegetation group
CLA	Cambrian Limestone Aquifer
CLUSTER	Clustering using group-average linkage (a multivariate analysis routine)
CMRSET	CSIRO MODIS ReScaled EvapoTranspiration
CO1	Cytochrome oxidase subunit 1 gene
COPD	Chronic obstructive pulmonary disease
CPW	Camera Photo Warehouse version 4
DAWE	Department of Agriculture, Water and the Environment (previous Commonwealth department)
DBH	Diameter at breast height
dbRDA	Distance-based redundancy analysis
DCMC	Department of Chief Minister and Cabinet (Northern Territory)
DDG	Dust deposition gauge
DEA	Digital Earth Australia
DEM-h	Hydrologically-enforced Digital Elevation Model
DEPWS	Department of Environment Parks and Water Security (Northern Territory)
DistLM	Distance-based multivariate multiple regression
DR	Daly-Roper
eDNA	Environmental DNA

Acronym	Full form
EFTF	Exploring for the Future program, led by Geoscience Australia
EMP	Environment management plan (specifically as required under the Petroleum (Environment) Regulations 2016
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
ESD	Ecologically sustainable development
ET	Evapotranspiration
FEFLOW	Modelling software for groundwater flow
GBA	Geological and Bioregional Assessment program
GDE	Groundwater-dependent ecosystem
GISERA	Gas Industry Social and Environmental Research Alliance
GLM	Generalised linear model
HEC-RAS	Hydrologic Engineering Center River Analysis System
HSU	Hydrostratigraphic units
IBRA	Interim Biogeographic Regionalisation of Australia
LDAR	Leak, detection and repair
mAHD	Australian Height Datum
MIKE	Modelling software for water systems
NAM	Nedbor Afstromnings Model
NCGRT	National Centre for Groundwater Research and Training
NDVI	Normalized difference vegetation index
NEPM	National Environment Protection Measure
NLC	Northern Land Council
NT EPA	Northern Territory Environment Protection Agency
NT	Northern Territory
NVIS	National Vegetation Information System
OBIA	Object-based image analysis
OZCAM	Online Zoological Collections of Australian Museums
PET	Potential evapotranspiration
PM10	Particulate matter 10 micrometres
PM2.5	Particulate matter 2.5 micrometres
PWC	Power and Water Corporation (Northern Territory)
RCP	Representative concentration pathway
RoWRA	Roper River Water Resource Assessment
rRNA	Ribosomal ribonucleic acid
SA1	Statistical Area 1
SA2	Statistical Area 2
SAL	Suburb and locality, geographical boundaries used in the Australian Bureau of Statistics census data

Acronym	Full form
SCE	Social, cultural and economic
SDM	Species Distribution Model
SEEBASE	Structurally enhanced depth-to-basement model that defines the 3D geometry of sub-surface basin systems
SIMPROF	Similarity profile routine
SoCS	Sites of Conservation Significance
SREBA	Strategic Regional Environmental and Baseline Assessment
SRTM	Shuttle radar topography mission
STI	Sexually-transmitted infections
TDS	Total dissolved solids
TLA	Thawed layer aquifer
TN	Total nitrogen
TPWC Act	*Territory Parks and Wildlife Conservation Act 1976* (Northern Territory)
VOC	Volatile organic compound
VSD	Vegetation Site Database
WAP	Water Allocation Plan
WRD	Water Resources Division (Northern Territory Department of Environment, Parks and Water Security)

1. Executive summary

1.1. Background

The Strategic Regional Environmental and Baseline Assessment (SREBA) for the Beetaloo Sub-basin has been undertaken following the recommendations of the Scientific Inquiry into Hydraulic Fracturing in the Northern Territory (the Inquiry). The purpose of the SREBA is to provide the information necessary for appropriate decisions to be made about the development of any onshore shale gas industry in the Beetaloo region, including assessment of water and biodiversity resources, to inform land-use planning, and the collection of baseline data to provide a reference point for ongoing monitoring.

The SREBA includes baseline studies in six domains:

- Water Quality and Quantity
- Aquatic Ecosystems
- Terrestrial Ecosystems
- Methane and Greenhouse Gas
- Environmental Health
- Social, Cultural and Economic.

The content of these studies was defined in the SREBA Framework and Scopes of Work for each domain, which build on the guidance provided in the Final Report of the Inquiry. The SREBA studies also incorporate information from other studies in the Beetaloo region subsequent to the Inquiry, notably the Australian Government's Geological and Bioregional Assessment (GBA) Program.

This Regional Report provides a summary and synthesis of the SREBA baseline studies, which are described in detail in technical Baseline Reports for each domain. All of the data and information collected and collated for the SREBA are publicly accessible through the SREBA Data Catalogue and web portal.

1.2. Study area

The Beetaloo Sub-basin is a geological entity that incorporates the deep Mesoproterozoic sedimentary rock formations that are prospective for petroleum resources and covers a surface area of approximately 28,000 km^2. Recent exploration drilling and geophysical results indicate an eastern extension of similar gas-supporting geology, referred to as the 'eastern depocentre', and this was included in the SREBA study area.

Many of the SREBA baseline studies considered a geographic area larger than the Beetaloo Sub-basin itself, in order to provide a regional context. This broader region, generally referred to as the 'study area', covers an area of 86,400 km^2. The boundary of some of the groundwater studies was larger again, in order to reflect the up and down gradient areas of the two significant groundwater flow systems in Cambrian Limestone Aquifers that feed into the Roper River and Flora River. The Social, Cultural and Economic (SCE) studies included communities outside the biophysical study area as these are likely to be affected by the development of an onshore gas industry.

The Beetaloo study area extends from north of Mataranka to Elliott in the south, and from east of Top Springs on the Buchanan Highway to west of Cape Crawford on the Carpentaria Highway. The region has a hot, semi-arid, seasonal climate with a pronounced north-south rainfall gradient. The Sub-basin falls almost entirely within a biogeographic region known as the Sturt Plateau, while the larger study area overlaps the margins of other biogeographic regions to the north (Daly Basin), east (Gulf Fall and Uplands) and south (Barkly Tablelands). The Sturt Plateau is comprised mostly of broad, gently undulating plains of neutral sandy red and yellow earths on laterised Cretaceous sediments, with extensive drainage basins with heavier soils. Vegetation across the Sturt Plateau includes extensive eucalypt woodlands, large areas of Lancewood and Bullwaddy thickets and woodlands, and tussock grasslands on heavy clay soils. The flora and fauna show more tropical elements in the northern areas and more arid elements in the south.

The study area spans parts of the catchments of the Daly, Roper, Limmen-Bight, MacArthur and Victoria-Wiso drainage systems. Surface drainage in most of the region is weakly developed and most surface water features are ephemeral, particularly within the Sub-basin. However, groundwater flow from aquifers under the study area support perennial flows in the Roper and Flora rivers, and there are a number of springs around the western, northern and eastern margins of the study area. There are also some significant perennial and intermittent water bodies in the study area, most notably Longreach Waterhole and Lake Woods near the southern boundary. The study area is underlain by a number of groundwater systems, the most important of which is the Cambrian Limestone Aquifer (CLA), a multilayered system that covers a vast area and includes the Daly, Wiso and Georgina geological basins. The CLA is the main source of groundwater for extractive use in the region, including stock and domestic use. Baseflow from this aquifer sustains perennial flows in the Roper and Flora rivers, and supports groundwater-dependent ecosystems such as those in Elsey National Park near Mataranka.

Land use within the region is mainly beef cattle production and traditional Aboriginal uses. Perpetual pastoral leases cover most of the study area, which also contains parts of fourteen Indigenous estates. The region is sparsely populated, with only two small towns (Mataranka and Elliott), and one large Aboriginal community (Jilkminggan) located on the margins of the study area. In 2021, the total census population in the region was around 1100. There is a higher proportion of Aboriginal people and young people in the communities in the Beetaloo region, compared to the Northern Territory and Australia as a whole.

1.3. Water quality and quantity

There is now a very large body of data and research findings relating to water resources in the Beetaloo Region and, in particular, to the groundwater resources in the Cambrian Limestone Aquifer. Scientific understanding has increased greatly in the past decade and since the Inquiry, partly due to the SREBA but also through the GBA program, GISERA and other research projects. While deeper aquifers are less well known, this is not a barrier to sustainable water allocation as these are likely to be used only by the gas industry, and to a limited extent.

1.3.1. Groundwater

A sound conceptual understanding of the geology and hydrostratigraphy of the Sub-basin has been developed, and this is very important for minimising any risks from hydraulic fracturing. The CLA is generally isolated from deeper aquifers by extensive aquitards (basalts and the Cox Formation), but there are restricted areas where it is potentially in contact with deeper aquifers. There are few areas where there is potential for active connection between deep (gas-bearing) and shallow formations, but one area (Hot Springs Valley, which is not part of the CLA) has been identified where faulting may provide a connection between the Beetaloo Sub-basin to the surface.

While there is vertical structuring within the CLA, a precautionary approach is to assume a high degree of connectivity throughout the CLA and its sub-units. However, two primary regional groundwater flow systems within the CLA overlying the Beetaloo Sub-basin have been identified that are separated by the Birdum Fault and which discharge into the Roper and Flora River discharge zones. This understanding, in addition to variations in climate and recharge rates, form the basis for delineating boundaries of water allocation plans relating to the groundwater resources.

Groundwater levels have been measured in bores across the water study area and the groundwater height, and depth to groundwater, mapped. The regional groundwater level is deep below the surface over most of the Beetaloo Sub-basin (up to > 100 m below ground level) and is overlain by a thick layer of Cretaceous sediment, but becomes shallow close to the northern discharge areas (Roper and Flora rivers), on the margins of the Cambrian basins where there is outcropping CLA, and beneath some of the large ephemeral surface water bodies to the south of the Beetaloo region such as Lake Woods and the Barkly lakes.

Groundwater velocities have been modelled and are low (< 0.1 m/year) across most of the CLA and all of the Beetaloo Sub-basin. Even considering limitations in this modelling, it is unlikely that groundwater flow velocities exceed 1 m/year over the Beetaloo Sub-basin because the hydraulic gradients are not sufficient to drive greater velocities. Higher groundwater velocities (> 10 m/year) occur very close to groundwater discharge areas.

Groundwater monitoring bores in the region show three common groundwater level fluctuation patterns. A seasonal recharge response occurs in the northern part of the study area (Daly Basin), mostly beyond the northern extent of the Beetaloo Sub-basin. Episodic recharge, with limited groundwater level variation across multiple years until there is a wet season with sufficiently intense rainfall to induce recharge, occur in areas of relatively thin Cretaceous sediments and where point sources of recharge (e.g. sinkholes) are abundant, including the northern margin of the Sub-basin. Gradual storage change trends are characterised by slow groundwater level fluctuations that occur over years to decades, and this is the most common trend across the Beetaloo Sub-basin where there is limited seasonal recharge or point sources of recharge. The longest groundwater level records in the region — spanning approximately 20 years — show a prolonged period of increasing groundwater levels, indicating some degree of slow diffuse recharge.

Recharge into the CLA in the northern part of the region occurs primarily through direct recharge where Cretaceous sediments are thin (less than 30 m) and where the Lower CLA outcrops near the surface, and is likely aided by numerous karstic sinkholes. The dominant form of recharge in the southern area of the CLA occurs where surface water channels into pseudo-karst, ephemeral drainage lines (such as Western Creek, Newcastle Creek) and lakes (such as Lake Woods and Barkly lakes), particularly where surface water persists in drainage terminus features. Mountain-front recharge also occurs along the flanks of the Ashburton Ranges.

Estimates of recharge for the region have been obtained from four methods, the most quantitatively accurate (and most conservative) using the Daly Roper (DR2 2020) model. This model is constructed specifically for the region, supported by the most current conceptualisation of the entire connected water resource, and calibrated to observed groundwater levels and river discharges. This provides estimates of annual average and median wet season recharge for the four water allocation planning management areas relevant to the SREBA area. The northern (Tindall Limestone) areas receive substantial and regular seasonal recharge.

The CLA overlying the Beetaloo Sub-basin has two main discharge areas at the Flora River and Roper River, near the communities of Djarrung and Mataranka. At these locations, the Lower CLA outcrops at or close to the surface and discharge occurs through springs (e.g. Bitter Springs, Rainbow Spring and Fig Tree Spring), in diffuse discharge along riverbeds (e.g. Elsey Creek, Roper River) and by evapotranspiration, including through groundwater-dependent vegetation.

Environmental tracer studies support the assumption that groundwater discharge at the Roper River discharge area is overwhelmingly derived from the CLA. Multiple lines of evidence indicate that groundwater discharge at the Roper River is mostly sourced from groundwater originating relatively close to the river. Groundwater originating from deeper formations or from areas of the CLA flowpath further to the south (overlying the Beetaloo Sub-basin) are likely only a very minor portion of the total discharge at the Roper River. Mechanisms at the Flora River discharge area are mostly the same as at the Roper River.

There are some other springs around the margin of the study area at which groundwater discharge occurs, but not all of these springs are sourced from the CLA. Notably, the series of springs in Hot Springs Valley on Tanumbirini Station are likely sourced from deeper Mesoproterozoic formations. Springs and groundwater discharge areas also occur around the locality of Top Springs to the west of the Beetaloo Sub-basin; these appear to be sourced from a localised flow system that captures recharge within the nearby catchment area or from shallow perched aquifers that are separate from the regional CLA.

A large dataset of groundwater quality data has been compiled from across the SREBA (and extended water study) region. This provides a broad-scale overview of water quality trends across the CLA, and is an important baseline for ongoing monitoring of water quality associated with onshore gas development.

1.3.2. Surface water

There are no perennially flowing waterways overlying the Beetaloo Sub-basin because there are no groundwater discharge areas, due to the depth of the regional water table. However, some long-lasting waterbodies may be maintained by localised perched groundwater systems that exist above, and are separate from, the regional water table. Numerous waterholes, some permanent, are documented throughout the SREBA study area, while some terminus features including lakes and swamps may persist well into the dry season, or even over multiple years after wet seasons with significant rainfall.

1.3.3. Water modelling

The Daly-Roper model (DR) is a coupled numerical surface water-groundwater flow model that covers the portion of the CLA that is connected to the major drainage systems of the Daly and Roper River, and was mostly recently updated in 2020 ('DR2'). Peer review of DR2 found the model classification to be Class 2-3 and also noted that DR2 (2020) was a "leading example of best practice". Based on the data and improved knowledge arising from the SREBA, the water model will be updated to DR3 for use in future water planning and licencing in this region.

The scope and quality of the data and understanding of the water resources in the Beetaloo region documented for the SREBA provide a robust scientific base for the development or refinement of water allocation plans, which ensure sustainable limits to groundwater extraction.

1.4. Aquatic ecosystems

Systematic biodiversity surveys and regional mapping have greatly increased knowledge of the aquatic ecosystems in the Beetaloo region.

1.4.1. Surface aquatic ecosystems

Surface aquatic ecosystem in the SREBA area have been mapped using satellite imagery and a range of other data sources. These cover 12% of the study area, the majority of which (90%) are floodplain systems, and the remainder palustrine (9%), riverine (1%) and lacustrine (0.01%) systems. Mapped streams have a total length of 13,787 km within the study area, of which almost 15% are classified as major streams. Twenty-two spring locations have been identified within the study area, primarily around its margins.

Mapping and field surveys identified aquatic refugia at 89 point locations across the study area, of which 37 have permanent or near-permanent surface water.

Systematic surveys at 44 sites across the study area identified 291 species of aquatic fauna, including 36 fish species; 11 species of aquatic and semi-aquatic reptile species including seven turtle species; 28 mollusc species; seven decapod species; 49 species of aquatic and semi-aquatic water bugs; 15 mayfly species; 69 species of non-biting midges (Chironomidae); and 76 species of aquatic beetles. When data from all sources are combined (including plants and frogs), a total of 400 species associated with surface water habitats were identified in the study area.

Most sites with high fish species richness occurred along the northern margin of the study area, and fish diversity in the study area centres on the perennial reaches of the upper Roper River. Parts of Western Creek hold a diverse fish fauna but are probably dependent on upstream migration from the Roper through Western Creek. Waterbodies throughout most of the study area feature a sub-set of common, widespread fish species, and species richness decreases as connectivity decreases in upstream waterholes. The spatial pattern for all aquatic species mirrors the pattern for fish, with highest diversity along the northern margin of the study area, and low total richness throughout the majority of the region. Waterbodies within the Sub-basin generally have low fish species diversity and a widespread, disturbance-tolerant invertebrate community.

Four threatened aquatic fauna species occur in the study area, the most notable being the Gulf Snapping Turtle and Largetooth Sawfish in the upper Roper River.

Multiple lines of evidence indicate that the highest conservation values for aquatic biodiversity occur in the northern margin of the study area, and largely align with the Mataranka Thermal Pools Site of Conservation Significance. Nevertheless, refugia throughout the region are important for the maintenance of aquatic biodiversity, which also requires maintaining connectivity between refugia. Waterbodies on intermittent systems in the region also have high conservation value as waterbird habitat.

1.4.2. Stygofauna

Stygofauna comprise aquatic taxa occurring in groundwater aquifers and subterranean water bodies. The SREBA completed the most detailed study of subterranean biodiversity in the NT to date, and significantly increased knowledge of stygofauna assemblages in the CLA south of Katherine.

Stygofauna were detected in 23 of the 66 groundwater bores that were sampled, and at least 28 species-level taxa were detected. The fauna is strongly dominated by crustaceans, particularly copepods and decapods. The known stygofauna of the study area now conservatively stands at 38 species-level taxa, 34 of which occur in the Tindall Limestone formation. Species accumulation curves suggest approximately 60 species occur in the study area. Only a single stygofauna species (*Parasia unguis*) was recorded in the Wiso basin, while five species were recorded from the Georgina Basin, with four of these recorded only within that Basin.

Using eDNA sampling, the shrimp *Parisia unguis* was detected in half the bores sampled and this species has a broad distribution in the CLA, including in the Georgina and Wiso Basins.

The highest diversity of stygofauna came from the Tindall Limestone in the northeast of the study area, where 26 of the 28 taxa detected during the survey were recorded. This formation also had the highest proportion of sample sites with stygofauna (73%), and all of the eight sites that had more than a single species detected.

The data suggest stygofauna are most abundant in aquifers with a relatively shallow depth to groundwater, well-developed superficial karst features, and transmissive and interconnected saturated habitat space. Annual recharge into the aquifer may be important to stygal ecosystems to maintain suitable groundwater quality and to provide primary trophic level inputs to subterranean food webs.

1.5. Terrestrial ecosystems

Regional vegetation mapping and systematic flora and fauna surveys have greatly increased knowledge of the terrestrial ecosystems in the Beetaloo region.

1.5.1. Flora and vegetation

Flora surveys contributed 15,419 new plant records for the study area. The number of plant taxa (described at least to species level) known from the study area is 1,818, with 1,093 plant taxa recorded in the Sub-basin.

Based on analysis of floristic data, plus interpretation by botanical experts, 51 vegetation communities have been described in the study region. These have been aggregated into 21 broad vegetation groups that have been mapped across the study area from remote imagery, other spatial data and data from nearly 13,000 on-ground sites.

Despite the size of the study area and the relatively high total richness of plant species occurring within it, no plants are endemic to the region, and only two threatened plant species were recorded in the study area. Four other plant species were considered significant as they have restricted ranges within their total distribution. The wetland habitat of most of these significant species reinforces the high conservation value of these restricted parts of the landscape. No geographic areas of high conservation value were identified in the region on the basis of plant biodiversity.

Disturbance was prevalent across all broad vegetation groups, despite site selection being biased towards 'best on offer' condition, and was variously associated with fire, cattle, pigs and weeds.

Environmental relationships with plant species composition in the study are complex. Overall, the latitudinal-rainfall gradient is significantly related to variation in vegetation structure, floristic composition, and with a range of species groups and habitat attributes. However, other environmental drivers such as soil type can override the influence of rainfall, and there are complex interactions between rainfall, soil type, fire and grazing regimes.

Five broad vegetation groups (comprising 25 vegetation communities) were identified as having high ecological value. Seven of the vegetation communities were identified as potential groundwater-dependent ecosystems, at varying levels of certainty. In areas mapped as potential groundwater-dependent ecosystems where depth to regional aquifers is relatively deep, vegetation may be accessing a shallower perched groundwater system.

Three broad vegetation groups predominantly occurring in the north of the study area were classified as significant vegetation and groundwater-dependent ecosystems: Monsoon forest and thicket, *Melaleuca* forests (springs, river channels) and Riparian woodland (ephemeral streams). Groundwater-dependent ecosystems (Riparian woodland and *Melaleuca* forest) are also associated with sandstones ranges and escarpments on the eastern margin of the study area, where the Sturt Plateau and Gulf Fall & Uplands bioregions converge. The Ephemeral wetland and Lignum shrubland broad vegetation groups were also identified as having high ecological value.

1.5.2. Fauna

A total of 354 vertebrate species were recorded from all surveys and incidental observations during the SREBA and GBA Program, including 14 amphibian species, 202 bird species, 39 mammal species and 99 reptile species. Including other sources, a total of 512 vertebrate species have been recorded in the study area. The ant fauna in the region is extraordinarily diverse, with 748 ant species recorded, a high proportion of which have not been previously collected.

Nine birds, one invertebrate, six mammals and four reptile species that occur in the study region are listed as threatened, and twenty species are listed as migratory under the EPBC Act. At a regional scale, the study area has relatively high total vertebrate species richness. However, no terrestrial vertebrate species are endemic to the study area.

Patterns of fauna diversity and composition relating to the latitudinal climatic gradient and landscape and habitat attributes were apparent across all fauna groups sampled. Disturbance (notably fire and grazing pressure) modifies the quality and suitability of habitat for fauna species across the landscape.

Riparian and swamp habitats have high value for bird diversity, facilitating the occurrence of more tropical bird assemblages into lower rainfall areas and the maintenance of bird diversity in the study area during dry periods. No other broad vegetation groups were identified has having notably high value for terrestrial faunal biodiversity.

Targeted surveys were undertaken for the threatened Crested Shrike-tit, Gouldian Finch, Greater Bilby, Ghost Bat and Plains Death Adder; and Northern Brushtail Possum, Mertens' Water Monitor, Mitchell's Water Monitor and Yellow-spotted Monitor were also sampled during regional surveys. Sufficient data were collated to develop spatial distribution models for the Gouldian Finch, Crested Shrike-tit, Greater Bilby and Yellow-spotted Monitor, and potential Ghost Bat roosting habitat was also mapped. There is extensive habitat for the Gouldian Finch, Crested Shrike-tit and Yellow-spotted Monitor in the Sub-basin, although likely nesting habitat for the Gouldian Finch is far more spatially restricted.

Over 7 000 records of 81 waterbird species from the study area were collated, and a total of 55 wetland sites was surveyed for waterbirds. All large-scale waterbird breeding events recorded from the study area, and the largest congregation of waterbirds, were from Lake Woods and nearby waterholes on Newcastle Creek. This area also has the highest concentrations of records of migratory shorebirds. Smaller persistent wetlands in the Newcastle Creek drainage system and on the Sturt Plateau support small-scale waterbird breeding events and are likely to be refuges for waterbird persistence during dry periods.

1.5.3. Terrestrial biodiversity values

The main terrestrial biodiversity values within the study area are:

- Sites of Conservation Significance (Mataranka Thermal Pools and Lake Woods/Longreach Waterhole)
- high value vegetation types
- important habitat for waterbirds and threatened species.

Habitats for waterbirds and other significant plant and animal species associated with aquatic environments are spatially restricted. Habitat for the threatened Crested Shrike-tit, Gouldian Finch and Common Brush-tail Possum occurs in extensive woodland communities across much of the study area, including inside the Sub-basin. In contrast, habitat for Greater Bilby and Ghost Bat occurs outside of the Sub-basin, to the south-west and north respectively.

Many of the identified threats to these biodiversity values are already present in the landscape (habitat degradation, fragmentation and loss; competition and predation; invasive plants) but could potentially be exacerbated by onshore gas development. Others key potential threats from onshore gas development are changes in surface water hydrology, reduction in groundwater availability, and contamination of surface or ground water. Additionally, predicted changes under climate change scenarios — particularly increasing number of very hot days and increasing evapotranspiration rates — may reduce the resilience of terrestrial biodiversity in the study area, particularly species with a requirement for persistent water or climate-buffering habitats.

1.6. Greenhouse gases

A series of mobile surveys across varying seasons and years using optical gas analysers has established a “pre-development” baseline for ambient methane concentrations in the Beetaloo Basin. Overall, the background methane concentrations measured within the study area were closely aligned with the Australian national reference values and seasonal changes.

The main sources of elevated methane concentrations detected during the surveys were cattle, fires and towns/fuel stations. An inventory of the estimated emission rates for each identified source and sink for the study area has been compiled.

There was no evidence from survey data of elevated methane levels associated with potential geological seep targets other than at Clints Gorge on Tanumbirini Station, where methane and ethane were recorded bubbling from hot springs. This area warrants further monitoring and investigation.

Currently the most practical and effective method of monitoring regional methane concentrations for the Beetaloo region is through periodic mobile surveys, possibly supported by targeted deployment of long-term autonomous emission monitoring stations.

1.7. Environmental health

1.7.1. Population health

A review of literature was undertaken to build understanding in relation to health issues potentially associated with onshore gas activity. The findings of the literature review were then used to identify relevant health indicators that may be applicable in the context of the demographics of the Beetaloo region, which has a higher proportion of Aboriginal people and lower median age compared to the Northern Territory and Australia. The available baseline information on relevant health indicators for the region was then reviewed.

The Mataranka SAL (Suburb and Locality; geographical boundaries used in the Australian Bureau of Statistics census data) and the Elliott SAL both have a mixed picture in terms of health conditions when compared to the Northern Territory and Australia as a whole. These SALs have a lower proportion of one or more long-term health conditions within the population, and lower levels of asthma. However, conditions commonly associated with lifestyle and behavioural factors such as diabetes and heart disease, which can be caused by smoking, poor diet, lack of exercise and high blood pressure, are more prevalent.

While the health data for the Beetaloo Sub-basin population and Statistical Area (SA2) provided by NT Health has substantial limitations, it does generally suggest that national trends in health inequalities between Aboriginal and non-Aboriginal populations are also reflected in the local community health profile. This appears to be the case for respiratory condition hospitalisations and deaths, cardiovascular condition hospitalisations and deaths, blood and immune disorder hospitalisations and deaths, neurological condition hospitalisations and sexually-transmitted infection notifications. Cases for cancers, foetal defects and adverse birth outcomes were too low to draw conclusions.

An outline monitoring plan was developed for the relevant health indicators. It was recommended that stakeholders be further engaged to refine and agree on the indicators prior to finalising an implementable monitoring plan.

1.7.2. Water quality

Existing groundwater and surface water quality data from the study area were collated, summarised and reviewed in the context of implications for human health. Analysis of groundwater data from the five main aquifer types in the study area showed:

- average pH generally ranged from lower neutral to a slightly acidic pH
- average electrical conductivity generally ranged from fresh to brackish conditions
- sulfate concentration was highest within the Upper Cambrian Limestone Aquifer and lowest in the Jamison Sandstone Aquifer
- average field and laboratory pH generally range from lower neutral to a slightly acidic pH, apart from Antrim Plateau Volcanics aquitard, which had a neutral pH
- metal concentrations were generally low and remain below the health and aesthetic guidelines across the study area
- nutrient concentrations were generally low and below the health and aesthetic guideline values across the study area, except for sulfate and chloride which exceeded health guidelines.

An environmental risk assessment was undertaken during the GBA Program of 116 chemicals associated with drilling and hydraulic fracturing operations in the Beetaloo region, of which 33 were of potentially high concern. Future groundwater monitoring programs aimed at detecting contamination from onshore gas activities should be informed by identified chemicals of potential concern.

Routine groundwater quality monitoring data from water supplies at serviced townships and Aboriginal communities within the study area shows none of these water supplies exceed Australian drinking water health guidelines, except for some aesthetic guidelines which affect palatability.

There are a variety of private entities in the study area including seven service stations and one aerodrome, but there are currently no water quality data or registered contaminated land status for any of these locations.

There are limited surface water quality data from the region, apart from field quality parameters. To improve the baseline of surface water quality analysis, it was recommended that Australian Drinking Water Health and Aesthetic guideline analytes be added to future monitoring programs. Given the potential for surface water to be used for agriculture and cultural uses by local communities, some priority locations for the future monitoring of surface water quality have been identified.

1.7.3. Soil quality

Existing information on soil types in the Beetaloo region was collated and reviewed. The dominant soil types in the region were identified and representative soil types selected for characterisation, in order to identify those soils that may be sensitive to impact or adverse effects from onshore gas activities.

Chemicals approved for use in hydraulic fracturing in the Northern Territory, as listed on the Chemical Register developed by the Northern Territory Government, were reviewed. An assessment of chemicals of concern and potential hazards to soil, such as the likelihood of transportation through the soil, was then made in order to inform the development of a risk assessment framework. Based on the soil characterisation information, risk ratings were developed for three categories of potential risk to soil from unconventional onshore gas operations; these risk ratings were then combined for an overall risk score for each soil type. These risk ratings can be spatially portrayed as a soil risk map for the study area.

Based on the soil risk assessment process, a monitoring and management plan for soils was developed. The plan is designed to provide a guide for the site-specific management and monitoring of soils with the development of unconventional onshore gas operations in the Beetaloo Sub-basin, and to assist in maintaining consistency across individual approvals and licensing processes.

1.7.4. Air quality

Five air quality monitoring stations were installed in the region as part of the Beetaloo SREBA. Monitoring will be undertaken for a period of at least 12 months, which is considered the minimum to characterise the baseline environment throughout all seasons. The following parameters are being monitored:

- deposited dust – using dust deposition gauges (DDG)
- suspended particulate matter (PM2.5, PM10) – using a real time light scattering device
- gases (NO_2, SO_2, H_2S, VOCs and aldehydes) – using passive sampling methods
- meteorological parameters (wind speed, wind direction, temperature, humidity and rainfall).

While compliance monitoring for future onshore gas activities is expected and would be the responsibility of the proponent, additional regional baseline monitoring is valuable for ensuring human health and environmental impacts are minimised and so that communities are aware of their air quality environment.

1.8. Social, cultural and economic studies

The Social, Cultural and Economic (SCE) SREBA studies draw on publicly available data from reputable sources such as the Australian Bureau of Statistics Census data, Northern Territory Government data, Medicare and Commonwealth Government data. Indicators in themselves cannot tell the full story of complex adaptive systems such as communities and so this study relied on high levels of participation by residents of the study communities, pastoralists and stakeholder groups. The SCE SREBA studies should be seen as the starting point for ongoing conversations and community involvement in planning for future development in the Beetaloo region.

The summary findings of the studies are summarised below.

- Onshore gas development is taking place in a very low trust environment. Most people interviewed have very low trust in the gas industry to adhere to best practice and very low trust in the government's ability to regulate the industry effectively. Low trust translates to calls for "careful" development, for "watchdog" mechanisms including independent oversight and inspections, and high levels of transparency and accountability. In the eyes of the people, the industry must "earn the right to self-regulate".
- Just as there is biophysical diversity, the Beetaloo basin is socially, culturally and economically diverse. Diversity is a highly valued characteristic of the region and is associated with resilience and connection. People in the Beetaloo want to preserve social, cultural and economic diversity (which is inextricably linked with ecological diversity). Some suggestions for preserving diversity in the region include through the maintenance of Aboriginal languages and culture, protection of

existing and future industries and economic opportunities, and enhanced opportunities for employment and training.

- There is high and widespread concern for aquatic ecosystems (including subterranean) and water sources as underpinning life and livelihoods. Most of the opposition to the industry is based on this concern.
- Many Beetaloo residents are highly committed to and/or invested in 'place'. They will not or cannot simply leave if their lifestyle changes unfavourably or if impacts become unacceptable. They feel they are disproportionately vulnerable and carry a greater burden of risk.
- Almost everyone supported development opportunities that can help facilitate the aspirations of local Aboriginal people to build greater economic self-sufficiency but designing the pathways for doing so should be community-specific and Aboriginal controlled. There was no further detail in the interviews about what processes might best facilitate a transition to Aboriginal-controlled economic development, except the need for government and industry to "come and talk to us". One known example of an Aboriginal–controlled economic development initiative is the Myuma Group of companies, established by the Traditional Owners from the Indjalandji-Dhidhanu people of Camooweal and surrounding area. They have also partnered with the University of Queensland to develop innovative industries based on the farming, harvesting and bioprocessing of spinifex grass.
- Onshore gas and any other (mining) industry development should be "balanced" and able to exist alongside existing industries. It should not detract from existing industries and regional identity, or compromise future economic opportunities. Meanings of 'minimal harm' need to be negotiated and defined.
- Most people would feel more comfortable if there were Aboriginal rangers and custodians "keeping an eye on" the condition of country and actively involved in environmental monitoring and land management. Pastoralists interviewed saw opportunities for mutual benefits and for greater collaboration and expressed a general willingness to cooperate with Aboriginal ranger groups. Some concerns raised about the concept of establishing Aboriginal ranger groups included who would fund the ranger groups (noting that industry funding could lead to rangers feeling compromised), who would be eligible to become rangers and how would they be recruited, who determines the allocation and prioritisation of tasks (for example, some pastoral stations would oppose burning of pastures).
- Many people did not feel they have been consulted adequately. There is not widespread understanding of what onshore gas development will look like or what impacts it may have for the region. It is felt that only those directly impacted have had the industry explained to them. There is a desire for more "neutral", "factual" information.
- Even some of the people who have been highly engaged feel conflicted or confused because they are hearing "two very different sides to the story". It was explained how information that can empower local people to raise their concerns or to make suggestions for how improve practices is needed. The 'Beetaloo basin' does not exist in the social data and there are no matching socio-political boundaries for coordinated management and decision-making.
- There are pockets of strong voices but no collective voice or representation of all the interests in the Beetaloo region. People in the region would like to see governance mechanisms that are "truly representative" of the interests of the region and facilitate meaningful dialogue about development opportunities and concerns.
- The importance of communication with all stakeholders was a strong and common theme — not just consultation with those directly impacted when lodging an Environmental Management Plan

or as part of other approvals processes. It was suggested that there need to be regular and openly available updates on project/s progression. There also needs to be more effort in establishing relationships with neighbours and other affected stakeholders.

- Representative organisations such as land councils, the Northern Territory Cattlemen's Association and advocacy groups play an important role disseminating information to their members and putting their interests forward. However, it is not enough to engage through these groups alone, as there can be very different experiences of, and expectations for, the onshore gas industry within the groups. There were suggestions of establishing a multi-stakeholder representative body for the Beetaloo region, and a separate cultural authority body.
- There are differences in community structures and functions, and leadership capacities, which will determine communities' abilities to respond to onshore gas development opportunities and challenges.
- Baseline trends show improvements in some areas, such as education levels and housing quality, but not in others, such as crime and alcohol-related harm. There is variation in the collection and reporting of data over time, which makes it difficult to detect consistent trends. This variation is thought to result in part from data quality issues, such as low response rates to the Census, low sample numbers make reporting at community level difficult for privacy reasons (health and crime statistics).

Not only have the SREBA SCE studies been useful for generating knowledge and establishing an understanding of community concerns in the baseline, but they have also created partnerships and relationships amongst a range of stakeholders interested in the outcomes. However, the relationships and conversation started in the SCE do not end with the completion of the reports. It is the intention that this report and the insights it brings will provide the basis for an ongoing regional monitoring framework that is seen as an ongoing learning journey rather than a destination. This journey would involve multiple stakeholders from public, private and community sectors. The monitoring program should not only deliver reliable and valid findings but should be considered independent and trusted by the community, driven by what is considered important.

The baseline and strategic assessments identified the four main themes that reflect widely held aspirations for the future and community values: safe and sustainable (and coordinated) development; strong communities; maintaining and enhancing connection to land and culture; and informed and fair local participation.

The framework for a long-term, participatory, regional social impact monitoring program is described in Section 9.7 and the SCE Baseline Report.

1.9. Emergent regional values

The strongest theme emergent from each of the baseline studies was the importance of water within the landscape. Most of the high ecological values identified during the Beetaloo SREBA baseline studies were associated with sites or ecosystems that depend on either groundwater or surface water, and this is mirrored by the importance of these water resources both culturally and economically. This emergent theme from the SREBA studies is not new or surprising, but rather the SREBA provides additional data and knowledge to more fully enunciate water-related values.

Based on the outcomes from the biophysical SREBA studies, the water-related places of the highest environmental value have been described and mapped. Areas of outstanding value are the Roper Discharge zone near Mataranka and the Lake Woods / Longreach Waterhole wetlands near Elliott. Areas of high value include the Cambrian Limestone Aquifer, and a collection of surface water ecosystems including groundwater-dependent vegetation communities and aquatic refugia scattered throughout the study area and Sub-basin. Based on the information collated during the SREBA, some recommendations for regulatory controls and ongoing monitoring are made which may further minimise the potential risks to these sites and values from onshore gas development.

There are a broad variety of values in the Beetaloo region that are not directly water-related, including ecological, cultural, social and economic values. Many of these values are at least partly captured in the concept of 'healthy' ecosystems, which are largely structurally intact, where biodiversity and ecosystems functions are maintained, and where there is access to land by traditional custodians for cultural practices. Some potential applications of the SREBA outputs to help protect these values are described.

The SCE studies provide a clear description of the emergent values and thresholds of acceptance. Through the findings and recommendations, including the regional monitoring framework, the studies detail ongoing opportunities to continue to engage and strengthen the relationships with communities potentially impacted by onshore gas development, to establish an ongoing monitoring program in the context of community concerns and aspirations and to continue to build on the knowledge base.

1.10. Application of the SREBA

1.10.1. Risk assessment

There have been two very substantial risk assessments undertaken relating to potential impacts from onshore gas resource development in the Northern Territory, and more specifically the Beetaloo Sub-basin: as a key component of the Scientific Inquiry (published in 2018), and as the final, integrative stage of the Beetaloo GBA Program (published in 2021). The SREBA does not remake those risk assessments, but rather provides additional data and understanding to address knowledge gaps or uncertainties identified during those assessments.

The GBA Program developed a novel approach using causal networks to assess the regional-scale risks of unconventional gas development in the Beetaloo region. The causal network developed for the Beetaloo Basin captures the relationships between unconventional gas resource development activities and the complex and interconnected nature of the natural environment in the assessment region. The GBA assessment identified no pathways of potentially high concern between unconventional gas resource development and water and the environment in the Beetaloo region. All potential impacts could be mitigated through compliance with existing regulatory and management controls, with a high degree of confidence. The SREBA (along with other very recent studies) has developed substantial additional data and understanding relating to the natural environment in the Beetaloo region to that available during development of the GBA impact assessment. There is considerable value in incorporating this additional data into the Beetaloo GBA causal network and further developing this as an operational tool that can be applied during the environmental impact assessment process for future onshore gas development.

1.10.2. Enhanced protection for key values

Synthesis of the data and information collected during the SREBA has identified some emergent themes and areas within the Beetaloo region of outstanding or high environmental value. Consideration of these values and the risk assessments previously undertaken for onshore gas development in this region suggest a number of measures that will strengthen the protection of these high-value areas, and increase community confidence that these values will be effectively protected. These build on regulatory measures already implemented in response to Inquiry recommendations. In general terms this includes:

- extending the boundaries of existing Reserved Blocks to capture the full extent of the two areas identified as having outstanding environmental value: Lake Woods / Longreach Waterhole and the Roper Discharge Zone
- refreshing the GBA impact assessment, incorporating the additional data available from the SREBA studies and with the outstanding and high environmental value areas, and associated values, as explicit endpoints
- amendment of the Code of Practice to exclude some activities associated with onshore gas development in the vicinity of identified areas of high environmental value, and where there is a shallow depth to groundwater within unconfined aquifers
- ensuring groundwater extraction is within sustainable limits through implementation of Water Allocation Plans (Georgina-Wiso, Mataranka Tindall Limestone and Flora)
- inclusion of representative set of sites in outstanding and high environmental value areas within the proposed Beetaloo regional monitoring program
- explicit consideration of risks to identified high-value areas in Environment Management Plans including potential for offsite, downstream impacts.

1.10.3. Regional monitoring

One of the purposes of the SREBA was the collection of baseline data to provide a reference point for ongoing monitoring. Monitoring the impact of any major onshore gas development in the Beetaloo region is essential for testing whether the previous assessment of risks was accurate, that mitigation measures and regulatory controls are effective, and to trigger and inform appropriate corrective measures if unacceptable impacts occur. While the regulatory regime for onshore gas activities has numerous requirements for project-scale monitoring, additional regional-scale monitoring is required to detect the cumulative impacts of multiple projects or indirect impacts of projects that occur distant from their footprint. The findings from each SREBA domain can be used to inform the development of a regional monitoring framework for the Beetaloo region.

1.10.4. Area-based assessment

The conventional approach to environmental assessment and regulation for onshore gas activities (as for other development proposals) is on a project-by-project basis, where a project is typically at the scale of an individual well or well pad. The Inquiry had a strong interest in the potential for regional or area-based assessment for the development of onshore gas resources in the Northern Territory, primarily because of the anticipated scale of development, use of water, and extent of infrastructure required to extract and produce the gas. The SREBA in itself satisfies many of the requirements of an area-based assessment, and provides a strong basis for any formal strategic regional assessment if that is required in the future, once the timing and scale of development is known.

1.10.5. Data management

The Beetaloo SREBA collected very large amounts of data, building on existing data from a wide variety of sources. The value of the SREBA will be maximised by ensuring these data are readily available to all potential users, including regulators, industry and the public. A data management system has been developed specifically to encompass the diverse data and information collected through the SREBA and all SREBA data and reports are publicly accessible through the SREBA Data Catalogue, except where access is restricted due to cultural sensitivities or privacy requirements.

Data collection in the Beetaloo region will not cease with the completion of the SREBA. Relevant data will continue to be collected through mandated monitoring programs, investigations associated with project-level environmental impact assessment, research projects supported by GISERA, and other activities. While the SREBA studies represent a 'snapshot' baseline at a particular time, it is important that relevant data from the Beetaloo continue to be captured and effectively curated, both to add to baseline understanding of the region and to track changes over time.

1.10.6. Recommendations

Synthesis and reporting of the SREBA studies has highlighted a number of potential measures that can maximise the value obtained from the SREBA (as well as the related work undertaken for the GBA Program), and this forms the basis for the following recommendations to be considered by the Northern Territory Government.

1. Engage with the Australian Government and CSIRO to incorporate additional data and knowledge obtained through the SREBA into the existing GBA Beetaloo causal network and to update the impact assessment, with additional endpoints, nodes and links where required.
2. In collaboration with CSIRO, develop the GBA Beetaloo causal network and user interface further as an operational tool that can be applied during the impact assessment and approval process for future onshore gas development in the Beetaloo Sub-basin.
3. Implement the measures outlined in Section 10.2 to further minimise risks to the areas identified as having outstanding and high environmental value, and increase community confidence that these values will be protected.
4. Implement a regional monitoring program, as outlined in Section 12.2, to ensure that longer-term and cumulative impacts of a gas-field scale development in the Beetaloo Sub-basin are adequately monitored and transparently reported. This would include both long-term participatory regional social impact monitoring that satisfies Recommendation 12.7 of the Inquiry, and long-term monitoring of selected biophysical indicators.
5. Maintain a data management platform and associated publicly accessible interface that captures and curates the data and information collected during the SREBA, data collected in the future through regional monitoring programs, and other relevant data (e.g. GISERA research projects, project-scale monitoring and environmental investigations).

2. Background

2.1. Scientific Inquiry

On 14 September 2016, the Chief Minister of the Northern Territory announced a moratorium on hydraulic fracturing of onshore shale reservoirs in the NT. On 3 December 2016, the Government announced that it had established the Scientific Inquiry into Hydraulic Fracturing of Onshore Unconventional Reservoirs and Associated Activities in the Northern Territory. The Inquiry was chaired by the Hon. Justice Rachel Pepper, a current judge of the Land and Environment Court of New South Wales. The Inquiry panel comprised of a number of eminent scientists across a range of relevant disciplines. The Terms of Reference were broad in scope but were limited to onshore shale gas (that is, for example, shale liquids and tight gas were excluded). They required the Panel to assess and determine:

- the nature and extent of the risks identified with the hydraulic fracturing of onshore shale gas reservoirs and its associated activities on the environmental (aquatic, terrestrial and atmospheric), social, cultural and economic conditions of the NT
- whether these risks can be mitigated to an acceptable level
- if they can, by what methodology or methodologies can these risks be mitigated
- whether the existing regulatory framework is sufficient to implement these methodologies and, if not, what changes must be made to it and by when.

The Panel collected and analysed the latest available evidence concerning the final list of issues, or risks, identified in consultation with the community, industry, land councils, local government, environmental groups, and government agencies. The issues were grouped into the following broad categories (or themes):

- water (quality and quantity)
- land
- air
- public health
- Aboriginal people and culture
- social impacts
- economic impacts
- regulatory reform (including land access).

The principles of ecologically sustainable development (ESD) were at the core of the Panel's analysis. The Panel used these principles to formulate values and objectives as an initial part of the risk assessment process, and to identify the mitigation measures to ensure that those objectives are achieved.

The panel implemented an extensive stakeholder engagement program that included community consultations and opportunities for the community to consult directly or indirectly with the Inquiry through community forums, public hearings, site visits, stakeholder consultations and the opportunity to make written submissions. The first round of consultations took place during March 2017 following the release of the issues paper. In July 2017, an interim report was released and was followed with a second round of consultations in August 2017. The Inquiry also conducted departmental briefings in both the Northern Territory and other jurisdictions, interstate visits and stakeholder meetings, and overseas visits and consultations.

The Inquiry handed down its Final Report to the Northern Territory Government on 27 March 2018 and, in April 2018, the Northern Territory Government accepted all 135 recommendations described in the Final Report. Details about the Inquiry and its Final Report are available at: https://frackinginquiry.nt.gov.au/inquiry-reports/final-report.

2.2. Inquiry recommendations

The Inquiry found that:

> *"… it is the Panel's opinion that, provided all of the recommendations made in this Report are adopted and implemented in their entirety, not only should the risks associated with an onshore shale gas industry be minimised to an acceptable level, in some cases they can be avoided altogether."*

A total of 135 recommendations were described in the Final Report of the Inquiry. This includes Recommendation 15.1: "*That a strategic regional environmental and baseline assessment (SREBA) be undertaken prior to the granting of any further production approvals"* in relation to onshore unconventional gas reservoirs.

The Final Report described the purpose of a SREBA as *"to provide the information necessary for appropriate decisions to be made about the development of any onshore shale gas industry in the NT, including assessment of water and biodiversity resources, to inform land-use planning, and the collection of baseline data to provide a reference point for ongoing monitoring"*.

The Final Report noted that the lack of adequate pre-development assessment and environmental baseline data was one of the largest environmental regulation and management-related issues associated with the development of the gas industry in the United States and also Queensland. The Inquiry considered adequate pre-development baseline information was important to:

- predict the magnitude of any post-development change and assess its impact
- underpin modelling of the possible impacts of any new industry
- inform site-specific quantitative risk assessments by industry and regulators
- strategically plan for the rollout of any onshore shale gas industry by industry, government, community and affected stakeholders
- identify key sensitivities in a regional context, and openly and constructively investigate and resolve issues that may arise as a result.

Additionally, an integrated, strategic and coordinated approach to data collection over large regions with multiple interest holders would help ensure consistency between datasets and maximise their value for region-wide modelling and assessment.

The Final Report also noted that there was generally poor spatial coverage of data on surface and groundwater characteristics and of both aquatic and terrestrial biodiversity in the regions of the Northern Territory most likely to be affected by any onshore unconventional gas industry.

Limited information on biodiversity assets and their location impedes the ability to properly assess the risks of any unconventional gas development (especially cumulative impacts over large areas) and reduces the ability to plan the location of infrastructure to minimise the risk of unacceptable impacts to aquatic and terrestrial biota. Consequently, the Final Report considered it essential that the key knowledge gaps identified in the Final Report be addressed prior to the granting of any further production approvals for onshore gas development.

Chapter 15 of the Final Report described the elements of a SREBA that would meet these recommendations. Other chapters and recommendations throughout the Final Report also referred to a SREBA, and a full list of recommendations relevant to the development of a SREBA is available in the SREBA Framework (see Section 2.3). In particular, Chapter 12 of the Report provides specific recommendations in relation to the requirements for, and content of, strategic social impact assessment conducted as part of a SREBA (Recommendation 12.6).

2.2.1. Purpose of the SREBA

As described in the Final Report, the SREBA is a set of studies to address knowledge gaps and establish appropriate baselines against which the potential impacts of proposed onshore gas activities may be assessed. The baselines can also assist in the design and planning of future development, particularly at a regional scale, in order to minimise impacts. It is important to recognise that the SREBA is not in itself a risk assessment process, but provides appropriate information to allow government, regulators and industry to apply robust risk assessment. The exception to this is in the social, cultural and economic domain where, in response to recommendations in the Final Report, the SREBA includes a regional strategic assessment.

The SREBA does not replace project-level impact assessment and approval processes, or the need for proponents to prepare a project-specific Environment Management Plan, Social Impact Assessment or Environmental Impact Statement as required by the relevant legislation and regulator. However, by providing comprehensive baseline information at a regional scale, a SREBA will make these processes more efficient and effective and supports both project design and the thorough assessment and management of project risks.

2.3. SREBA Framework

The Final Report of the Inquiry described the requirements and components of a SREBA in broad terms, without being prescriptive about the technical detail for each baseline study area. The Northern Territory Government subsequently developed a SREBA Framework, which describes the objectives and content of a SREBA, including information outputs, potential applications, and governance and implementation arrangements. The Framework also contains detailed technical guidance on how baseline studies should be undertaken within six domains:

- Water Quality and Quantity
- Aquatic Ecosystems
- Terrestrial Ecosystems
- Methane and Greenhouse Gas
- Environmental Health
- Social, Cultural and Economic.

In addition to the requirements for a SREBA described in the Final Report, the guidance for each domain was also informed by other relevant recommendations of the Inquiry, and legislative, regulatory and planning requirements of the Northern Territory Government relevant to the potential development of an onshore unconventional gas industry.

The Framework is available at https://depws.nt.gov.au/onshore-gas/sreba. The Framework was written to be generally applicable to a SREBA undertaken in any region of the NT, recognising that a more region-specific Scope of Works would be developed for each study domain dependent on the characteristics of the study area.

2.4. Beetaloo Sub-basin SREBA

The Northern Territory Government determined that a SREBA was required for the Beetaloo Sub-basin, which is the most prospective onshore gas basin in the Northern Territory. Scopes of Works specific to the Beetaloo SREBA were developed for each of the six study domains. These outlined the specific requirements for each study (or subcomponent) and are available at https://depws.nt.gov.au/onshore-gas/sreba.

The NT Department of Environment, Parks and Water Security (DEPWS) has the foremost subject matter expertise and relevant Northern Territory experience for the water and ecological study domains, and so led three baseline studies (with additional external expertise as required). The other study domains were contracted to external research agencies and consultants, as described in Table 2-1.

Overall program management for the SREBA, including coordination of stakeholder engagement and data management, was provided by DEPWS. Project oversight for each study domain was also provided by DEPWS, with the exception of the Social, Cultural and Economic domain, which was managed by the Department of Chief Minister and Cabinet (DCMC).

The Beetaloo Regional Reference Group (BRRG) was established by the Minister for Environment in October 2020. The BRRG was established as a consultative forum for community views and to provide guidance to the Northern Territory Government on the SREBA studies undertaken in the region. The purpose of the BRRG was to act as a liaison point for Northern Territory Government, researchers and specialists undertaking studies in the region; and to provide a mechanism for communication of results and findings from the SREBA studies to the regional community.

The BRRG met seven times since its inception, and consisted of representatives from key stakeholder groups in the region, including: Roper Gulf Regional Council, Barkly Regional Council, Katherine Town Council, the Northern Land Council, Northern Territory Farmers' Association, the Sturt Plateau Best Practice Group, Sunrise Health Services, Territory Resource Services Association and Territory Natural Resource Management.

Planning, stakeholder consultation and initial implementation of the SREBA studies was substantially hampered by the COVID pandemic, particularly in 2020 when most of the Beetaloo region was isolated within biosecurity zones. Data collection for most studies was therefore undertaken during 2021 and/or 2022. More detail on the methods and implementation of each baseline study are found in the individual baseline reports and in Sections 4 to 9 below.

Table 2-1. Lead organisation for each study domain and supporting agencies and experts.

Study Domain	Lead research agency/organisation	Supporting agencies and experts
Water Quality and Quantity	Water Resources Division, Department of Environment, Parks and Water Security	Eco Logical Tetra Tech Charles Darwin University National Centre for Groundwater Research and Training
Aquatic Ecosystems	Flora and Fauna Division, Department of Environment, Parks and Water Security	Biota Environmental Services Helix Molecular Solutions Museum and Art Gallery of the Northern Territory Fisheries Division, Department of Industry, Tourism and Trade TropWater, James Cook University Environmental Chemistry and Microbiology Unit, Charles Darwin University Diversity Arrays Technologies, Canberra Deakin Genomics Centre Dr Chris Watts, South Australian Museum Dr John Short, Bioaccess Australia Julie Hanley, Environmental Research Institute of the Supervising Scientist Dr Winston Ponder, Australian Museum
Terrestrial Ecosystems	Flora and Fauna Division, Department of Environment, Parks and Water Security	Charles Darwin University
Methane and Greenhouse Gases	Australian Resources Research Centre, CSIRO Energy	
Environmental Health: Population Health	Jacobs NT	NT Department of Health
Environmental Health: Water Quality	TetraTech-Coffey NT	
Environmental Health: Soils	TetraTech-Coffey NT	
Environmental Health: Air Quality	GHD	
Social Cultural and Economic Studies	The University of Queensland	GL Anthropology Anthropos

2.5. SREBA Regional Report

For each study domain of the SREBA for the Beetaloo Sub-basin, a baseline report (or set of reports) was prepared to present the methods, results and findings. These reports and associated data and information are available in the SREBA Data Catalogue.

The Regional Report is a synthesis of the SREBA baseline studies and their findings. This report consists of three parts.

- Part 1 describes the background to the SREBA (Section 2) and the general characteristics of the Beetaloo SREBA region, including the boundaries used for the baseline studies.
- Part 2 provides a detailed summary of each of the baseline studies in the six domains (Sections 4 to 9).
- Part 3 considers the outcomes from, and application of, the data and information collected during the SREBA. Section 10 provides a brief summary of the key findings from each domain and identifies emergent key values in the Beetaloo region. Section 11 described the previous risk assessments for the development of onshore gas in the Beetaloo region and the application of the SREBA findings to these risk assessments, while Section 12 discusses the application of the SREBA information and provides some recommendations to ensure the value of the data and information from the SREBA is maximised in the context of any future onshore gas development in the region.

2.6. SREBA data management and access

2.6.1. SREBA Data Management Strategy

The SREBA Data Management Strategy establishes efficient processes, procedures and policies for collecting, preparing, protecting and storing data, and to ensure data are accessible to end users. Baseline studies drew on a range of existing information from different sources, as well as generating new data and information. As the information will be used by different stakeholders for different purposes, users need to be confident that the data are reliable, and that the scope and limitations of the information are clearly stated.

Data collected for SREBA baseline studies used existing processes and systems where appropriate. An overlying data catalogue has been developed for the SREBA program that collates and categorises data and information from existing systems in a centralised information management system to enable the information to be managed and discoverable (Section 2.6.2).

2.6.1.1. Principles

The SREBA Data Management Strategy aligns with the Northern Territory Government principles-based approached to data governance that recognises the value of data, compliance with legislation in the protection of sensitive data and the benefits of data sharing. In line with these principles and the guidance in the SREBA Framework, the SREBA Data Management Strategy is underpinned by the following principles.

- Open access to data and information wherever possible.
- Protection of data that are culturally sensitive or commercial-in-confidence.
- Protection of privacy, including meeting the requirements of the Northern Territory *Information Act 2002*.

- Ensuring that the source and any licencing requirements of third-party data can be tracked.

2.6.1.2. Data quality

To ensure that data are accurate, reliable, robust and verifiable, the following quality assurance and quality control processes were applied.

- Application of uniform classifications to data so they are searchable and can be readily identified.
- Metadata was defined and collected; this described the data in order to facilitate the discovery, sharing and reuse of data.

2.6.1.3. Data storage and protection

Existing corporate systems, including the SREBA Data Catalogue, are the storage locations for the SREBA information and data. The DEPWS corporate system environment is a mature environment with existing defined management practises to store and protect the data; therefore, existing protocols and procedures for the protection of data were adopted by the SREBA program.

2.6.1.4. Data use and sharing

Information collected from SREBA baseline studies has been made publicly available provided this does not breach privacy and confidentiality requirements, unduly compromise regulatory or commercial activities and is not culturally sensitive. The sensitive data policy included in the SREBA Data Management Strategy outlines the procedures and steps for managing sensitive data collected during SREBA baseline studies.

Where the Northern Territory Government owns the copyright for a report, data or information, permission has been granted for public use through a Creative Commons license.

The SREBA Data Management Strategy aligns with the Open Data Statement (2019) of the Northern Territory Government (https://digitalterritory.nt.gov.au/digital-government/strategies-and-guidance/policies-standards-and-guidance/open-data), which commits to:

- make data publicly available for citizens and businesses to create value through digital innovations that will benefit the NT community and economy
- improve accountability and transparency across government
- promote public participation by encouraging feedback about open data and requests for new data
- openly publish data that do not infringe on the personal or commercial interests of others.

2.6.1.5. Sensitive data policy

Data gathered for the SREBA studies and for ongoing monitoring and evaluation will be publicly available online as long as doing so does not breach privacy, cultural or commercial confidentiality requirements. This includes consideration of protecting Aboriginal cultural and ecological knowledge, and intellectual property.

The collection and publication of data for the SREBA studies adheres to the Northern Territory's Information Privacy Principles, as described in the *Information Act 2002:* https://infocomm.nt.gov.au/privacy/ information-privacy-principles.

Metadata descriptions and records were used for the management and oversight of sensitive information, as the metadata can describe the sensitive data without directly disclosing confidential information.

This policy adopts the principles set out by the Australian Research Data Council for the publication and sharing of sensitive data (https://ardc.edu.au/resource/sensitive-data) and the standards set out by the NHMRC (https://www.nhmrc.gov.au/about-us/publications/national-statement-ethical-conduct-human-research-2007-updated-2018).

Where data need be desensitised, they will be desensitised according to the data sensitivity plans and policies for the DEPWS division responsible for curating and managing the datasets or, alternatively, in accordance with the principles of the Australian Research Data Council.

2.6.2. SREBA data storage and access

Data and information gathered for the SREBA are accessible through the SREBA Data Catalogue. The SREBA Data Catalogue contains all project outputs from the SREBA for the Beetaloo Sub-basin, including final reports, sub-project reports, project scope of works, maps and data. Some of the information is stored as files in the catalogue while other information is stored in other systems and linked to the Catalogue.

The SREBA Data Catalogue is hosted on the SREBA website and is available at:
https://depws.nt.gov.au/onshore-gas/sreba.

There are three ways to search for items in the Data Catalogue.

- Navigate from the home page into a project domain and view all items contained there.
- Search using text to view all items with the same search tag.
- Use the explorer map to view all items associated with a region.

Once a catalogue item is located, the metadata page will appear. This provides information about the item, such as the date it was published, authors and a short description. There is a link to the item on the metadata page. This link will either navigate to the system where the data are stored, or will download a file.

The Data Catalogue also contains spatial files; these require spatial software for viewing. Recommendations for suitable free software are provided on the SREBA data web page along with instructions on how to access and search the SREBA data catalogue.

2.7. Other relevant studies

While the Beetaloo SREBA was undertaken to address key knowledge gaps identified by the Scientific Inquiry, some other significant studies have occurred post-Inquiry that are relevant to the SREBA (and other Inquiry recommendations). Where appropriate, the scope of SREBA studies was designed to be complementary or additive to, rather than duplicative of, this work. Relevant data and findings from these other studies have been incorporated into the SREBA baseline reports and are referenced within them.

2.7.1. Geological and Bioregional Assessment

The Geological and Bioregional Assessment (GBA) program was a collaboration between the (then) Commonwealth Department of Agriculture, Water and the Environment (DAWE), the Bureau of

Meteorology, CSIRO and Geoscience Australia, and was to provide transparent scientific information relating to the potential impacts within regions of current or future onshore gas and coal developments.

The Beetaloo Sub-basin was selected at the completion of GBA Stage 1 (Hall *et al.* 2018), along with the Cooper Basin and Isa Superbasin, as a priority region for further detailed assessment. Stage 2 (baseline analysis) and Stage 3 (impact assessment) of the Beetaloo Sub-basin GBA were subsequently completed in 2020 (Huddlestone-Holmes *et al.* 2020) and 2021 (Huddlestone-Holmes *et al.* 2021), respectively. Reports from the Beetaloo GBA program are available at:
https://www.bioregionalassessments.gov.au/assessments/geological-and-bioregional-assessment-program/beetaloo-gba-region.

The Beetaloo GBA reports, and the technical studies and appendices that support them, are particularly important for providing a more comprehensive account than was available at the time of the Inquiry of the geology and prospectivity of unconventional gas resources of the Beetaloo Basin, and the hydrostratigraphy and hydrogeology of the region as well as groundwater recharge processes. The SREBA Water Quality and Quantity baseline study was able to use and strategically add to the studies synthesised in the GBA report.

The GBA program commissioned additional ecological data collection in the Beetaloo region (Davis 2021), which overlapped with the commencement of the SREBA for the Beetaloo. Collaboration between DEPWS and DAWE ensured that these studies were designed in a way that met the requirements of the SREBA Terrestrial and Aquatic Ecosystems baseline studies. The ecological data collected for the GBA have been incorporated into the SREBA datasets and reporting. This is reflected in the boundary used for the Beetaloo GBA 'extended region', which was agreed between GBA partners and DEPWS, and mirrors the Beetaloo SREBA 'biophysical study area', apart from the eastern extension of the latter to encompass the eastern depocentre (see Section 3).

Stage 3 of the Beetaloo GBA program undertook an assessment of the potential regional-scale impacts to water resources and Commonwealth and Northern Territory matters of environmental significance from development of unconventional gas resources. This involved developing a causal network describing the complex and interconnected nature of the natural environment and unconventional gas development activities in the Beetaloo region, and using this to assess potential impacts on water and the environment through both direct and indirect pathways. This provides a useful framework for application of baseline data and information collected by the SREBA to risk assessment and monitoring, and is discussed further in Section 11.

It is noted that the focus of the GBA Program was the natural environment and particularly matters that could be considered to be of national significance (including water resources), although some matters of Northern Territory significance were also considered. Its scope was therefore narrower than the SREBA and did not explicitly address social or cultural values or potential impacts.

2.7.2. GISERA

The Gas Industry Social and Environmental Research Alliance (GISERA) is a collaboration between CSIRO, Commonwealth, State and Territory governments, and industry, primarily regarding the petroleum industry but also other industries that have the potential to be impacted in petroleum development regions. It was established in 2011 to provide transparent, high-quality and independent scientific research to the community and industry. The research focuses on both environmental and socio-economic aspects, with an aim to support governments in decision-making for gas development projects.

GISERA has funded a number of research projects in the Northern Territory that have been developed either partly or primarily to address knowledge gaps identified by the Scientific Inquiry, as described at https://gisera.csiro.au/state/nt/. As with the GBA program, the SREBA studies for the Beetaloo Sub basin have incorporated data and knowledge from relevant GISERA-supported studies and, in some cases, built on work initially undertaken through GISERA. Current GISERA projects will also add to the environmental understanding established through SREBA studies for the Beetaloo Sub-basin, and may contribute to, for example, the design of robust monitoring programs. Notable relevant projects include:

- Ong *et al.* (2019): *Pre-exploration measurement and monitoring of background landscape methane concentrations and fluxes in the Beetaloo Sub-basin, Northern Territory*
- Deslandes *et al.* (2019): *Environmental tracers in the Beetaloo Sub-basin*
- Wilkes *et al.* (2019): *Baseline assessment of groundwater characteristics in the Beetaloo Sub-basin, NT: Geochemistry Analysis*
- Rees *et al.* (2020): *Characterisation of the stygofauna and microbial assemblages of the Beetaloo Sub-basin, Northern Territory.*

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3. The Beetaloo SREBA region

This section briefly describes the Beetaloo region and the boundaries used for the SREBA studies. It provides orientation for the results described in subsequent sections, noting that many of the characteristics of the region are described in greater detail in the relevant baseline reports.

3.1. Boundaries

3.1.1. Beetaloo Sub-basin

The Beetaloo Sub-basin is a geological entity defined by the Northern Territory Geological Survey and is part of the greater MacArthur Basin. The Beetaloo Sub-basin is defined as the thickest preserved sequences of the Mesoproterozoic sedimentary rocks and incorporates an area of approximately 28,000 km^2 (Figure 3-1). The boundary of the Sub-basin is based on seismic data showing where the top of the Kyalla Formation (the upper layer of the Roper Group, which hosts the known petroleum resources) shallows to a depth of 400 m below the current ground surface. The Beetaloo Sub-basin is divided into eastern and western areas by the Daly Waters High.

Recent exploration drilling and geophysical results indicate an eastern extension of similar gas-supporting geology as the Beetaloo Sub-basin, referred to as the 'eastern depocentre' and shown as the black line in Figure 3-1.

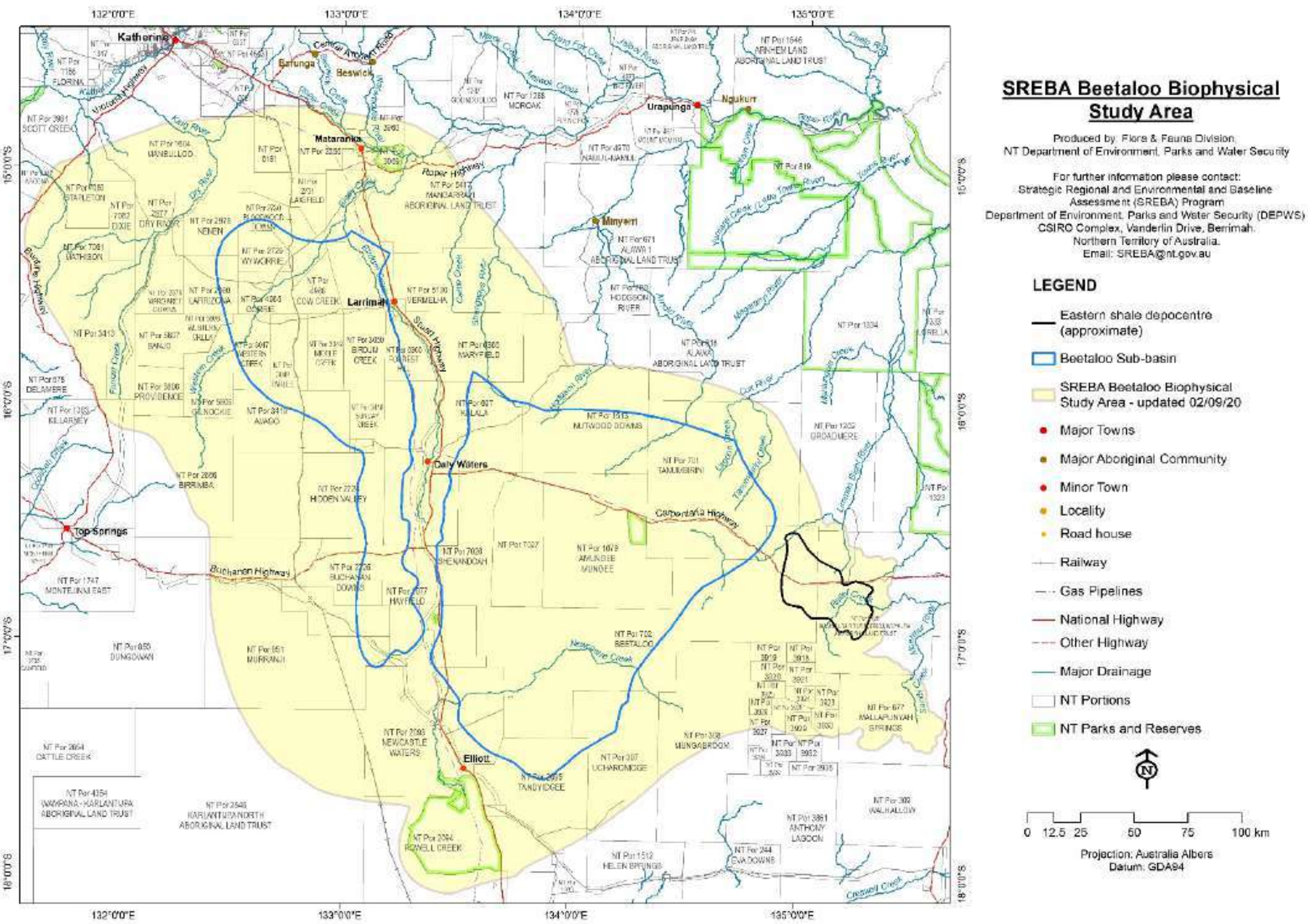

Figure 3-1: Beetaloo Sub-basin boundaries and SREBA biophysical study area.

The SREBA study area was extended to include the depocentre because this was likely to have similar environmental characteristics and was subject to similar levels of exploration activity and potential industry development timeframes as the adjacent Beetaloo Sub-basin proper.

Collectively, the boundaries described above delineate the known extent of the unconventional gas resource in the Beetaloo region, and therefore where future gas activity (wells and supporting infrastructure) would be concentrated.

3.1.2. Beetaloo SREBA biophysical study area

Many of the SREBA baseline studies considered a geographic area larger than the Beetaloo Sub-basin itself, for three reasons.

- In order to understand biophysical and ecological patterns and processes in the Sub-basin, it was necessary to place these in a broader regional context — particularly because the Sub-basin boundary has a geological basis, which is not necessarily reflected in environmental features on the surface.
- Similarly, in order to properly evaluate the significance of environmental or other values within the Sub-basin, it was necessary to consider them within a broader regional context, which is an important aspect of environmental impact assessment.
- Impacts from future onshore gas activities could conceivably extend outside the Sub-basin boundaries, so the characteristics and values of adjacent landscapes also need to be considered.

Consequently, a broader boundary was developed for the biophysical baseline studies of the SREBA, encompassing an area of 86,400 km^2. This boundary is based on:

- Interim Biogeographic Regionalisation of Australia (IBRA) region and sub-region boundaries, notably the Newcastle and Birdum sub-regions of the Sturt Plateau bioregion
- catchment boundaries, notably including Lake Woods and the internal drainage system feeding it
- the distribution of groundwater-dependent ecosystems that may feasibly be subject to impact, notably including springs and riparian ecosystems in the north-west, north and south-east of the study area, which are likely to be the surface expression of aquifers overlying the prospective gas basins
- inclusion of sufficient geographic extent to provide adequate regional context to assist the assessment of the significance of ecological values and any potential impact on them. This explains, for example, why the study boundaries are relatively expansive to the west of the Beetaloo Sub-basin study area boundary, so as to capture the regional extent of poorly known ecosystems that occur across much of the Sub-basin.

In this report and individual baseline reports, this broader area is typically referred to as the 'study area'. The 'Sub-basin' is used when referring to the smaller area comprising the geological Beetaloo Sub-basin and eastern depocenter.

The SREBA biophysical study area matches the 'extended region' referred to in the Beetaloo GBA reports, with the exception of the eastward extension around the eastern depocentre included in the SREBA studies.

3.1.3. SREBA water quality and quantity study area

The SREBA biophysical study area boundary was refined for the SREBA water quality and quantity baseline studies to more closely reflect the full extent of the Cambrian Limestone Aquifer (CLA), and the up and down gradient areas of the two significant groundwater flow systems that feed into the Roper River and Flora River. In particular, this required investigations to incorporate the full extent of the CLA in the Georgina and Wiso Basins, which extended the boundary for the water studies domain considerably further south. These boundaries are described in detail in Section 4.

3.1.4. Social, cultural and economic study area

The social, cultural and economic (SCE) studies are 'place-based' studies. This approach included the development of community profiles in selected 'communities of interest' to create a baseline of data so change can be tracked over time. These communities are not all within the SREBA Beetaloo biophysical boundary but were identified during the consultations for the Scope of Works as communities that are likely to be affected by the development of an onshore gas industry.

There were amendments made in response to further consultations with industry and stakeholder groups where it was decided that Mataranka should be prioritised over Minyerri as a community of interest. This was largely because of the potential for an increased volume of traffic through the town and associated impacts. During these consultations, it became clear that the localities of Larrimah and Daly Waters could also be potentially impacted by development and that in some respects, changes were already underway. For example, the airstrip at Daly Waters has been upgraded with a funding contribution from Origin Energy and there are plans for private development on land at Larrimah. Therefore, publicly available data was also retrieved for Larrimah and interviews were conducted in both locations.

Researchers also spoke with people in other smaller communities including Barunga, Jilkminggan, Beswick and Minyerri as people there have connection to land in the study region.

3.2. General description of the Beetaloo SREBA region

3.2.1. Location

The Beetaloo Sub-basin (28,000 km^2) and Beetaloo biophysical study area (86,400 km^2) are shown in Figure 3-1. The study area extends from north of Mataranka to Elliott in the south, and from east of Top Springs on the Buchanan Highway to west of Cape Crawford on the Carpentaria Highway. Daly Waters, which is roughly central in the SREBA area, is 235 km south-southeast of Katherine, 510 km south-southeast of Darwin, and 385 km north of Tennant Creek.

3.2.2. Climate

The region generally falls within the hot, semi-arid seasonal tropics zone of the Köppen-Geiger climate classification, with the seasonal tropical savanna zone on the northern border and arid zone on the southern border. There is a pronounced north-south rainfall gradient through the region, with mean annual rainfall of ~1200 mm in the north and ~500 mm in the south. Mean annual rainfall at Daly Waters, roughly central in the region, is 678 mm. Rainfall in the region primarily falls during the wet season (from November to April, but primarily in December to March) and average monthly rainfall is very low in the dry season (between May and October). There can be high variability among years in the timing of the transition periods between the wet and dry seasons, and the amount of rain received during the wet season. Incursion of post-cyclonic rainfall depressions can affect the seasonal timing and quantity of rainfall, and result in flooding and filling of temporary wetlands over large areas.

Average maximum and minimum temperatures are also high in the wet season and lower in the dry season, with slightly greater extremes of temperature in the southern part of the region. At Daly Waters, annual monthly maximum temperatures range between 28.9 °C (June) and 38.2 °C (Nov), and minimums between 11.9 °C (Jul) and 24.2 °C (Dec).

The GBA Stage 2 report (Huddlestone-Holmes *et al.* 2020; pp 7-12) examined predicted climate change scenarios in the Beetaloo sub-region based on the 'pessimistic' RCP8.5 scenario, comparing the 1976 to 2005 period to the 2046 to 2075 period. The predicted outcomes are summarised below, with the range in brackets giving an indication of uncertainty (10th and 90th percentile from 42 global climate models).

- Mean annual rainfall: no change (20% decrease – 10% increase).
- Mean annual potential evapotranspiration: increase (increase by 3 to 6% - 8 to 10%).
- Number of hot days (>35 °C): increase by 2 months (increase by 30 days - 3 months).

3.2.3. Geology

The geology of the study area consists of a series of stacked sedimentary basins ranging in age from Mesoproterozoic to Cretaceous with a thin Cenozoic cover. The sediment sequences are largely flat-lying and undeformed, but the Sub-basin is bounded by several prominent deformed and faulted structural highs, as well as being divided in eastern and western elements by the Daly Waters High.

The Mesoproterozoic sequence of the Beetaloo Sub-basin is comprised of stacked layers of shale and sandstone, and this sequence — specifically the Kyalla Formation and Velkerri Formation — hosts the gas plays that are the target for petroleum exploration activities in the area.

The Neoproterozoic formations overlying these are part of the Kiana Group, which is comprised of the Cox Formation and Bukalara Sandstone. The lithology of the Cox Formation is interbedded fine-grained siltstone, shale and minor sandstone, which suggests that it acts as an extensive regional aquitard that separates the deeper aquifers from the Cambrian sequence.

The Cambrian formations include the Antrim Plateau Volcanics (another regional aquitard) and, above these, a series of siltstone, limestone and dolomite sequences in the Daly River/Barkly Group that collectively contain the Cambrian Limestone Aquifer.

The Cretaceous sediments are comprised of layers of sandstone, siltstone and claystone that can reach thicknesses of up to 100 m or more and extend over most of the study area, being thinnest or absent around the northern margin.

3.2.4. Landscape, soils and vegetation

The Sub-basin falls almost entirely within a physiographic region, and an IBRA bioregion, known as the Sturt Plateau. The majority of the larger study area also lies on the Sturt Plateau, but overlaps the margins of other physiographic regions and bioregions to the north (Daly Basin), east (Gulf Fall and Uplands) and south (Barkly Tablelands).

The Sturt Plateau is comprised mostly of broad, gently undulating plains of neutral sandy red and yellow earths on laterised Cretaceous sandstones, ranging in elevation from 100 to 300 m above sea level (Baker *et al.* 2005). Soils are mainly lateritic but deep sands occur in the south-west and cracking clays in the south-east.

Vegetation across the Sturt Plateau is relatively homogenous, with more tropical elements in the northern areas and more arid elements in the south. Eucalypt (*Corymbia* and *Eucalyptus*) woodlands over perennial tussock or *Triodia* grasslands occur extensively across the bioregion, although there is considerable variation in dominant tree and grass species depending on soil type and moisture regimes.

Another feature of the region is large areas of Lancewood (*Acacia shirleyi*) and Bullwaddy (*Macropteranthes keckwickii*) thickets and woodlands. Tussock grasslands on heavy clay soils extend north from the Barkly Tableland into the central south of the region.

3.2.5. Surface water

The study area spans parts of the catchments of the Daly, Roper, Limmen-Bight, MacArthur and Victoria-Wiso drainage systems. Surface drainage in most of the region is weakly developed and most surface water features are ephemeral, particularly within the Sub-basin. However, groundwater flow from aquifers under the study area support perennial flows in the Roper and Flora rivers, and there are a number of springs around the western, northern and eastern margins of the study area. There are also some significant perennial and intermittent water bodies in the study area, most notably Longreach Waterhole and Lake Woods near the southern boundary.

Most of the southern half of the study area is in the internally draining Newcastle Creek (Lake Woods) catchment. Newcastle Creek flows westwards over the central-east area of the Beetaloo Sub-basin before turning southwards to the perennial Longreach Waterhole, before ultimately discharging into Lake Woods. Lake Woods is a large, ephemeral lake located immediately south of the township of Elliott. The extent of inundation varies significantly, from being regularly dry to almost 900 km^2 during major flooding.

The majority of the northern half of the study area is located within the southern catchments of the Roper River, which ultimately discharges to the western Gulf of Carpentaria. These sub-catchments include Elsey Creek (including its headwaters of Western Creek and Birdum Creek), Strangways River (including its tributary Cattle Creek), Hodgson River, Arnold River, as well as the southernmost headwaters of the Roper River itself (Figure 3-1). Although much of the Roper River itself is perennial (fed by the significant springs and groundwater discharge areas at Mataranka), the headwaters and sub-catchments within the Beetaloo Sub-basin are all ephemeral and are not maintained by any groundwater baseflow. Ephemeral and semi-permanent waterholes occur along Western Creek and Birdum Creek and their tributaries.

The north-western portion of the study area contains the Dry River catchment — a sub-catchment of the Daly River— which ultimately discharges into the Timor Sea. Dry River is ephemeral and only flows in response to rainfall events, with no baseflow contributions from underlying aquifers.

The eastern edge of the study area contains small portions of the upper sub-catchments of the Limmen Bight River and McArthur Rivers. Notably, this includes the Lagoon Creek sub-catchment of the Limmen Bight River, which contain the springs at 'Hot Springs Valley' discussed in the Water and Greenhouse Gas Baseline reports (see Sections 4 and 7).

3.2.6. Groundwater

The study area is underlain by a number of groundwater systems, the most important of which is the Cambrian Limestone Aquifer (CLA). This is a multi-layered groundwater systems that covers a vast area and includes the Daly, Wiso and Georgina geological basins. Subunits within the CLA include the Jinduckin Formation, Anthony Lagoon Formation, Tindall Limestone, Montejinni Limestone and Gum Ridge Formations. The CLA is a highly productive aquifer that has high regional connectivity due to the development of significant fracture and karstic secondary porosity. There are two regional groundwater flow pathways in the CLA underlying the study area. The first is the Roper River Flowpath, where groundwater in the Georgina Basin flows in a north-north-westerly direction into the south-eastern Daly Basin and terminates at a major discharge zone along the Roper River and Mataranka springs. The second is the Flora River Flowpath, where groundwater flow originates from the central Wiso Basin and flows in a northerly direction into the south-western Daly Basin and terminates at its major discharge zone along the Flora River.

The CLA is the main source of groundwater for extractive use in the region, including stock and domestic use. Baseflow from this aquifer sustains perennial flows in the Roper and Flora rivers, and supports groundwater-dependent ecosystems such as those in Elsey National Park near Mataranka.

Other aquifers occur in strata both above and below the CLA. The Cretaceous sediments can host productive supplies of fresh groundwater (and are used by some pastoral bores), but this sequence is more typically unsaturated across the Beetaloo Sub-basin. Where the Cretaceous sediments host aquifers, they are usually localised perched aquifers (often seasonal) close to the ground surface. The Antrim Plateau Volcanics below the CLA can form local aquifers where the rock is fractured, but typical bore yields are low (<2 L/s) and water quality is highly variable. The Bukalara Sandstone within the deeper Neoproterozoic formations may hold a sizeable aquifer but appears to have relatively poor water quality; this could potentially be a target for water extraction by the gas industry.

3.2.7. Land use and land tenure

Land use within the region is mainly beef cattle production and traditional Aboriginal uses. Perpetual pastoral leases cover over 90% of the Sub-basin and 79% of the broader study area. Although there are 52 pastoral leases intersecting the study area, over half the total area of pastoral land is within nine pastoral properties, together making up a total area of 3.4 million hectares. There are fourteen Indigenous estates (both Northern Territory enhanced freehold land and Aboriginal Land Trusts scheduled under the *Aboriginal Land Rights (Northern Territory) Act 1976*) intersecting the study area and making up 10.5% of its total area. The three largest of these are the Karlantijpa North, Mambaliya Rrumburriya Wuyaliya and Mangarrayi Aboriginal Land Trusts.

There are three reserves managed by the Northern Territory Government in the region (Bullwaddy Conservation Reserve, Elsey National Park, and Frew Ponds Historical Reserve) and two areas on pastoral leases that are protected under conservation agreements (Lake Woods Conservation Covenant and Longreach Waterhole Protected Area). Collectively these cover 1.9% of the study area, but only Bullwaddy Conservation Reserve falls within the Beetaloo Sub-basin.

3.2.8. People

The area is sparsely populated, with only two small towns and one large Aboriginal community located in the area:

- Mataranka (384 people; 2021 Australian census data)
- Jilkminggan (263 people)
- Elliott (287 people).

Other minor settlements in the area include Newcastle Waters (122 people), Larrimah (27 people) and Daly Waters (9 people). In 2021, the total population within these settlements was 1,092, a slight increase from the 1,070 people reported in the 2016 Census.

Aboriginal Land Trusts in or near the Beetaloo Sub-basin include Wubalawun, Mangarrayi, Murranji, Alawa, Gurungu, Marlinja, Dillinya, Karlantijpa and Mambaliya Rrumburriya Wuyaliya.

Publicly available population and health census data that represent various communities identified in the Beetaloo SREBA study area are presented in Table 3-1. Statistics for the Northern Territory and Australia are provided as regional and national comparators.

There is a high proportion of Aboriginal people in the communities in the Beetaloo region, particularly in Elliott, compared to the Northern Territory and Australia as a whole. There is also a younger population compared to the regional and national demographic, with Elliott, Jilkminggan and Newcastle Waters all having a median age of below 30 years old.

There are pronounced seasonal fluctuations in the population of the region. For example in the tourist season, there can be up to an additional 300 people in the Daly Waters area. The pastoral industry sees the population increase in the dry season with mustering and other activities, which increases the non-resident population and contractor workforce.

Table 3-1. Demographic profile of communities in the Beetaloo Sub-basin. Source: Australian Bureau of Statistics, Census data (2021). * Due to the small population for this area, limited information is available.

Geographic Location	Total Population	Aboriginal people	Male	Median age	<15 years old	>65 years old
Mataranka Suburbs and Localities (SAL)	384	27.9%	54.3%	38	9.6%	15.5%
Elliott SAL	287	85.0%	48.3%	28	27.5%	7.6%
Jilkminggan SAL*	263	-	45.6%	25	-	-
Newcastle Waters SAL*	122	-	52.5%	25	-	-
Daly Waters SAL*	55	-	47.3%	33	-	-
Larrimah SAL*	27	-	66.7%	37	-	-
Northern Territory	-	26.3%	50.5%	33	21.0%	8.9%
Australia	-	3.2%	49.3%	38	15.0%	17.2%

3.3. References

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4. Water Quality and Quantity baseline studies

4.1. Background

The Water Quality and Quantity studies for the Beetaloo Sub-basin SREBA were undertaken in line with the approach set out in the SREBA Framework and the Scope of Works. In regard to the water quality and quantity domain, the SREBA Framework describes the following key elements that are required to be addressed (paraphrased for brevity), noting that the level of detail required for each element would be informed by the understanding of what is relevant for the region being investigated.

- Groundwater
  - Description and conceptualisation of the regional hydrogeology.
  - Description of the hydraulic characteristics of each aquifer, including the identification of key geological features that may control groundwater movement and connectivity.
  - Mapping of aquifer depths and properties, and potentiometric surfaces.
  - Identification of key recharge and discharge areas, and characterisation of mechanisms.
  - Quantification of recharge, discharge and groundwater flow.
  - Presentation of water quality data and how these may relate to water movement (i.e. resource extent).
  - Identification of the location and source for springs and potential groundwater-dependent ecosystems (GDEs).
  - Estimation of ecological water requirements at springs and GDEs.
- Surface water
  - Description and mapping of relevant surface water resources.
  - Presentation of available hydrographic data.
  - Description of the rainfall-runoff characteristics of catchments.
  - Quantification of flow between catchments.
  - Analysis of flood frequency for key catchments and (where possible) inundation mapping.
  - Characterisation of surface water interactions with groundwater resources and marine/estuarine environments.

The Water Resources Division (WRD) of DEPWS established an Independent Expert Panel to provide technical oversight of the development of the Scope of Work (SoW) required to address knowledge gaps for water quality and quantity in the Beetaloo Sub-basin, as per the guidance note for water in the SREBA Framework. The Independent Exper Panel's advice was subsequently incorporated into the *Beetaloo SREBA Scope of Works: Water Quality and Quantity* (DEPWS 2020), which described a suite of sub-projects for identifying and addressing key water-related knowledge gaps for the Beetaloo Sub-basin.

- Assessment of existing knowledge gaps.
- Baseline water quality and levels.
- Aquifer parameters and aquifer inter-/intra-connectivity.
- Characterisation of recharge and surface water-groundwater interactions.

- Upgrade of the coupled surface water-groundwater numerical model.
- Characterisation and mapping of surface water resources.
- Cultural water values (subsequently moved to the social, cultural and economic study domain).

These water quality and quantity sub-projects are collectively referred to as the 'SREBA Water Studies'. There is a detailed technical report for each sub-project and a summary Baseline Report for the Water Studies domain, which should be referred to for greater detail than is presented here.

4.1.1. Supporting programs

The SREBA water studies are also supported by the extensive and detailed information produced by other recent NT Government water resource assessments and Commonwealth Government research programs (GBA and GISERA) that have been undertaken since the completion of the Scientific Inquiry. Their key outputs should be referred to in conjunction with the outputs of the SREBA for the most complete understanding of the water resources overlying the Beetaloo Sub-basin. Key technical reports and publications include:

- Tickell and Bruwer (2019): Georgina Basin groundwater assessment: Daly Waters to Tennant Creek
- Yin Foo and Dilshad (2021): Water Resources Modelling of the Mataranka-Daly Waters Region: Mataranka Tindall Limestone Aquifer Water Allocation Plan Area Natural Groundwater Balance
- Evans *et al.* (2020): *Hydrogeology of the Beetaloo GBA region (Technical appendix for the Geological and Bioregional Assessment: Stage 2)*
- Orr *et al.* (2020): *Geology of the Beetaloo GBA region (Technical appendix for the Geological and Bioregional Assessment: Stage 2)*
- Huddlestone-Holmes *et al.* (2020): *Geological and environmental baseline assessment for the Beetaloo GBA region (Geological and Bioregional Assessment: Stage 2)*
- Factsheets (relevant to water in the Beetaloo Sub-basin) published in support of the final Stage 3 impact assessment:
    - Factsheet 4: *Beetaloo GBA recharge pathways – Sinkholes and their influence on recharge to aquifers*
    - Factsheet 5: *Beetaloo GBA recharge pathways – Summary*
    - Factsheet 6: *Beetaloo GBA recharge pathways – Geology of the Carpentaria Basin and Cenozoic sediments*
    - Factsheet 12: *Isotope geochemistry of aquifer rocks in the Cambrian Limestone Aquifer*
    - Factsheet 15: *Groundwater recharge across the Cambrian Limestone Aquifer*. The work presented in this factsheet was later published in more detailed form in Crosbie and Rachakonda (2021)
    - Factsheet 17: *Hydrochemistry, ^{18}O, ^{2}H and Radon time series of the Mataranka Springs*
    - Factsheet 19: *Groundwater recharge processes in the Beetaloo GBA region*
    - Factsheet 20: *Regional tracer results from the Cambrian Limestone Aquifer*
    - Factsheet 25: *Groundwater sources to the Mataranka Springs Complex*. The work presented in this factsheet was later published in more detailed form in Lamontagne *et al.* (2021).

- Huddlestone-Holmes *et al.* (2021): *Impact assessment for the Beetaloo GBA region (Geological and Bioregional Assessment: Stage 3 synthesis)*
- Deslandes *et al.* (2019): *Environmental tracers in the Beetaloo Sub-basin*
- Wilkes *et al.* (2019): *Baseline assessment of groundwater characteristics in the Beetaloo Sub-basin, NT: Geochemistry Analysis.*

4.1.1.1. NT Water Allocation Planning

The Pepper Inquiry also made recommendations for the NT Government's management of water in areas of onshore petroleum development. Recommendation 7.7 requires that Water Allocation Plans (WAPs) – the Government's primary water resource management mechanism – be developed for the Beetaloo Sub-basin region prior to the granting of any production-level groundwater extraction licences for the petroleum industry. Furthermore, Recommendation 7.8 requires that the WAPs control the rate and volume of any water extraction by petroleum companies. These recommendations are relevant to the SREBA because they require the same level of technical understanding of the identified water resources, including an understanding of how they might be impacted by future developments.

To meet the requirements of the Pepper Inquiry's recommendations, DEPWS are developing the following WAPs:

- Mataranka Tindall Limestone Aquifer (TLA) WAP (northern Beetaloo Sub-basin)
  - Relates to management of the water resources of the Roper River and the TLA in the Mataranka and Larrimah area.
- Georgina Wiso WAP (southern Beetaloo Sub-basin)
  - Relates to management of the groundwater resources of the Montejinni Limestone (Wiso Basin) and Gum Ridge Formation (Georgina Basin) underlying the southern Sturt Plateau and north-western Barkly region.
  - A draft WAP was released for public comment in late 2022 (DEPWS 2022a).
- Flora TLA WAP (northern Beetaloo Sub-basin)
  - Relates to management of the water resources of the Flora River and the TLA of the north-western Sturt Plateau.

There are advanced drafts of technical reports relating to the Flora TLA and Georgina Wiso WAP areas that have been produced in parallel with the SREBA Water Studies, and are planned for imminent release to the public:

- DEPWS (2022b): Water resources of the Flora Tindall Limestone Aquifer Water Allocation Plan area
- DEPWS (2022c): Water resources of the Wiso Basin Water Allocation Plan area
- DEPWS (2022d): Water resources of the Georgina Basin Water Allocation Plan area.

4.1.2. Beetaloo Sub-basin SREBA study area

The various boundaries of interest for the Beetaloo Sub-basin SREBA are presented in Figure 4-1a. The Beetaloo Sub-basin is a gelological entitity defined by Williams (2020) and is based on where the top of the Kyalla Formation (uppermost gas target) is greater than 400 m below ground surface. The SREBA also considered an eastern extension of the Beetaloo Sub-basin that has been defined based on recent exploration drilling and geophysical results by Empire Energy/Imperial Oil & Gas (Bruce and Garrad 2021), which is potentially prospective for gas resources but does not meet the definition of the Beetaloo Sub-basin used by Williams (2020).

A broader 'SREBA study area' was used for the biophysical baseline studies, as described in Section 3.1. The purple boundaries shown in Figure 4-1 reflect the area investigated for the SREBA Water Studies, with a 'focused' study area where the majority of investigation occurred, and an 'expanded' study area required to incorporate the up- and down-gradient areas of the two significant groundwater flow systems that feed into the Roper River and Flora River. The larger area also covers the full extent of the Cambrian Limestone Aquifer Water Allocation Plans that are in development and informed by the SREBA studies.

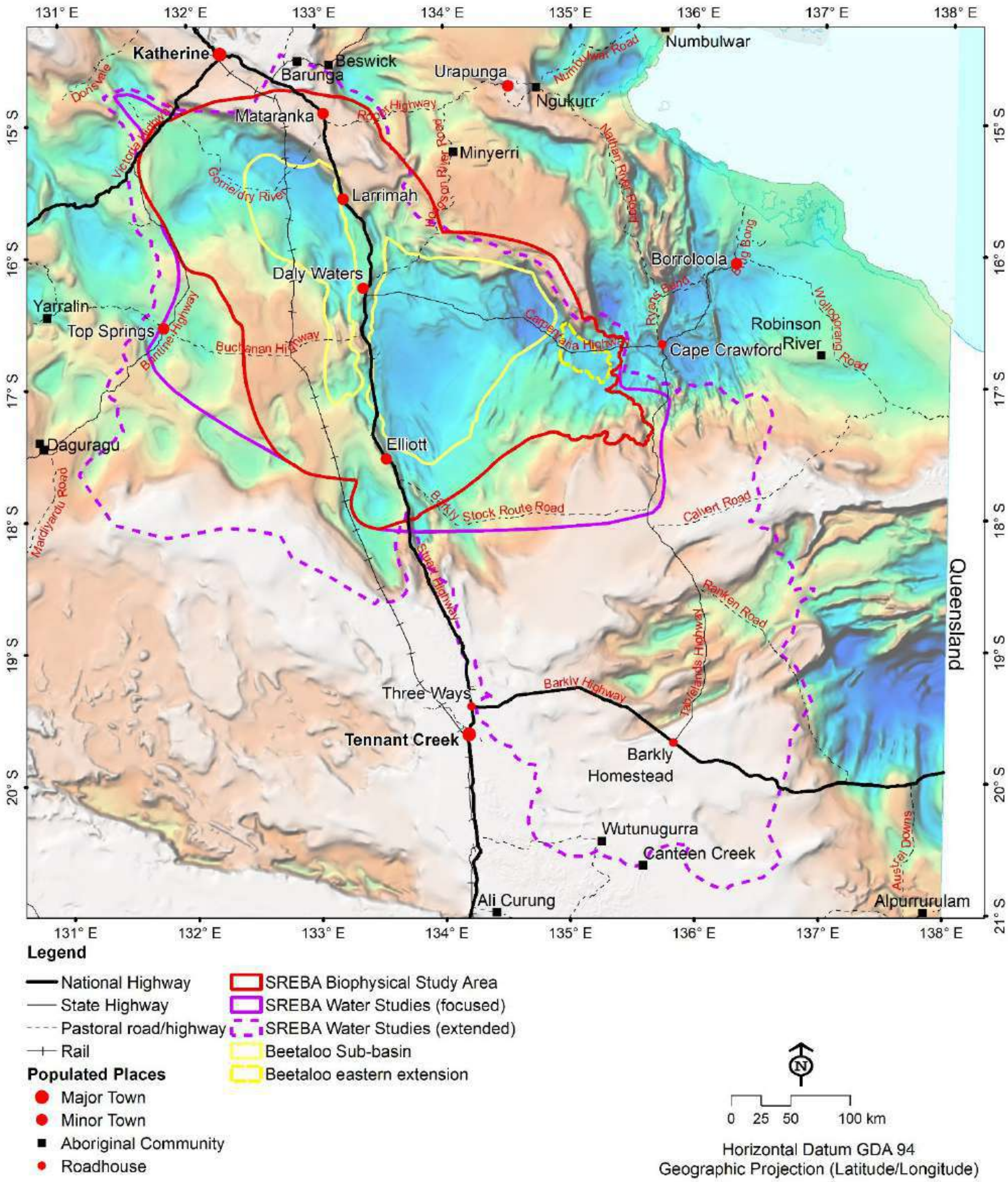

Figure 4-1a. Location of the Beetaloo Sub-basin and SREBA study area, showing the focused and extended boundary for the water studies.

4.1.3. SREBA Water Studies monitoring program

The Water Resources Division of DEPWS undertook a number of groundwater drilling and monitoring programs throughout the SREBA Water Studies, which are described in more detail in the Baseline Report. A total of 23 new monitoring and test bores were installed across across the region to complement the existing bore network (Figure 4-1b).

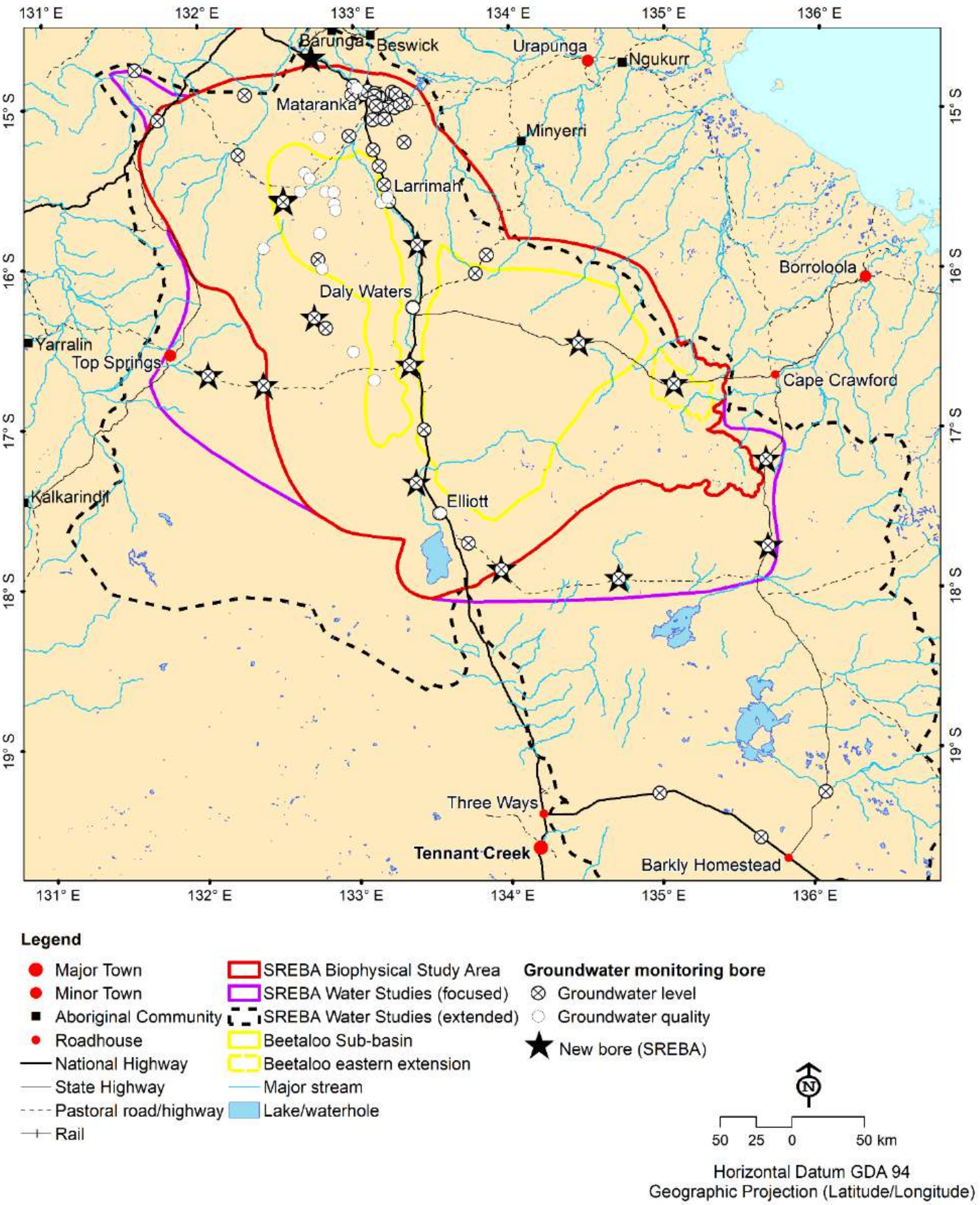

Figure 4-1b. Location of new monitoring bores and bores where additional groundwater monitoring was undertaken for SREBA.

Several monitoring events were also undertaken throughout the SREBA Water Studies program. This included installation of 30 groundwater level loggers to capture time-series groundwater level data from various aquifer systems and additional water quality sampling of 20 bores across the SREBA Water Studies region. Many of the northerly sites in Figure 4-1b have at least five years of records because they have been included in the monitoring program of the in-development Mataranka Tindall Limestone WAP.

These monitoring programs helped to increase the understanding of hydrodynamics associated with aquifers overlying the Beetaloo Sub-basin and primarily focused on:

- expanding the monitoring network for groundwater levels and quality
- improving the coverage of hydrostratigraphic data (e.g., rock samples and gamma logs)
- establishing sites for pumping tests to assess aquifer properties and hydraulic connection between primary aquifers.

4.2. Water modelling

Models represent how water flows and is stored under the ground. They do this with complex mathematical equations to simulate movement of groundwater, using well-understood principles of groundwater flow. These models allow scientists to understand (among other things) water volumes, water movement and how water systems will respond to change. The key element to a numerical model is the conceptualisation of the system.

The Daly-Roper model (DR) (Figure 4-2) is a coupled numerical surface water-groundwater flow model that covers the portion of the CLA that is connected to the major drainage systems of the Daly and Roper rivers. The DR model was developed to assess the hydrogeological system response at basin scale and to predict flow rates within the Daly River and the Roper River drainage systems, including the base flow contribution from the CLA which sustains flow during the dry season. The DR model does not incorporate the other surface water systems in the region because they only have a weak connection (if any) to the regional CLA groundwater system.

The DR model consists of two surface water flow models and a groundwater model. The surface water models use a combination of the Nedbor Afstromnings Model (NAM) rainfall-runoff model and the 1-D MIKE11 unsteady channel flow model developed by the Danish Hydrologic Institute. The MIKE11 package enables direct coupling to the finite element groundwater modelling software FEFLOW. The DR model allows groundwater discharge to enter the rivers during the dry season, when the water level in the channel falls below the groundwater level. During the dry season, springs and river flows are dependent entirely upon groundwater discharge. Wet season water levels in the channels rise above the adjacent aquifer groundwater level. Under these conditions, the DR model allows recharge into the groundwater through the riverbed.

Development of the DR model commenced in 2004 as a regional 2-dimensional groundwater model of the CLA (Knapton 2004) and has subsequently undergone multiple extensions (2008, 2009, 2012, 2015, 2018, 2020 with the next iteration due in 2023-24) and two independent peer-reviews (Middlemis 2015; 2020).

The latest review of DR2 2020 found the model classification or confidence level to be that of a Class 2-3 (where Class 3 is the highest classification) based on the criteria of the Australian Groundwater Modelling Guidelines (Barnett *et al.* 2012), and also noted that DR2 2020 was a “leading example of best practice”. A major driver for this model peer-review was the appreciation that it would be the main scientific tool used for assessing water extraction scenarios for the area that covers the Beetaloo Sub-basin.

Following the completion of the Beetaloo Sub-basin SREBA Water Studies, the DR2 model will be upgraded based on the new conceptualisations of hydrological processes and acquisition of further hydrographic data for both surface water and groundwater. The upgrade to DR3 will consist of the following general approach.

- Recalibrate the groundwater model from incremental upgrades and combine into a single unified mesh (FEFLOW).
- Update the Daly River surface model (Daly MIKE11), couple with the groundwater model and recalibrate.
- Update the Roper River surface model (Roper MIKE11), couple with the groundwater model and recalibrate.

The upgraded model will again be peer-reviewed by a hydrogeologist/groundwater modeller who is proficient with the DHI modelling software suite and has extensive knowledge of the Beetaloo Sub-basin hydrogeology.

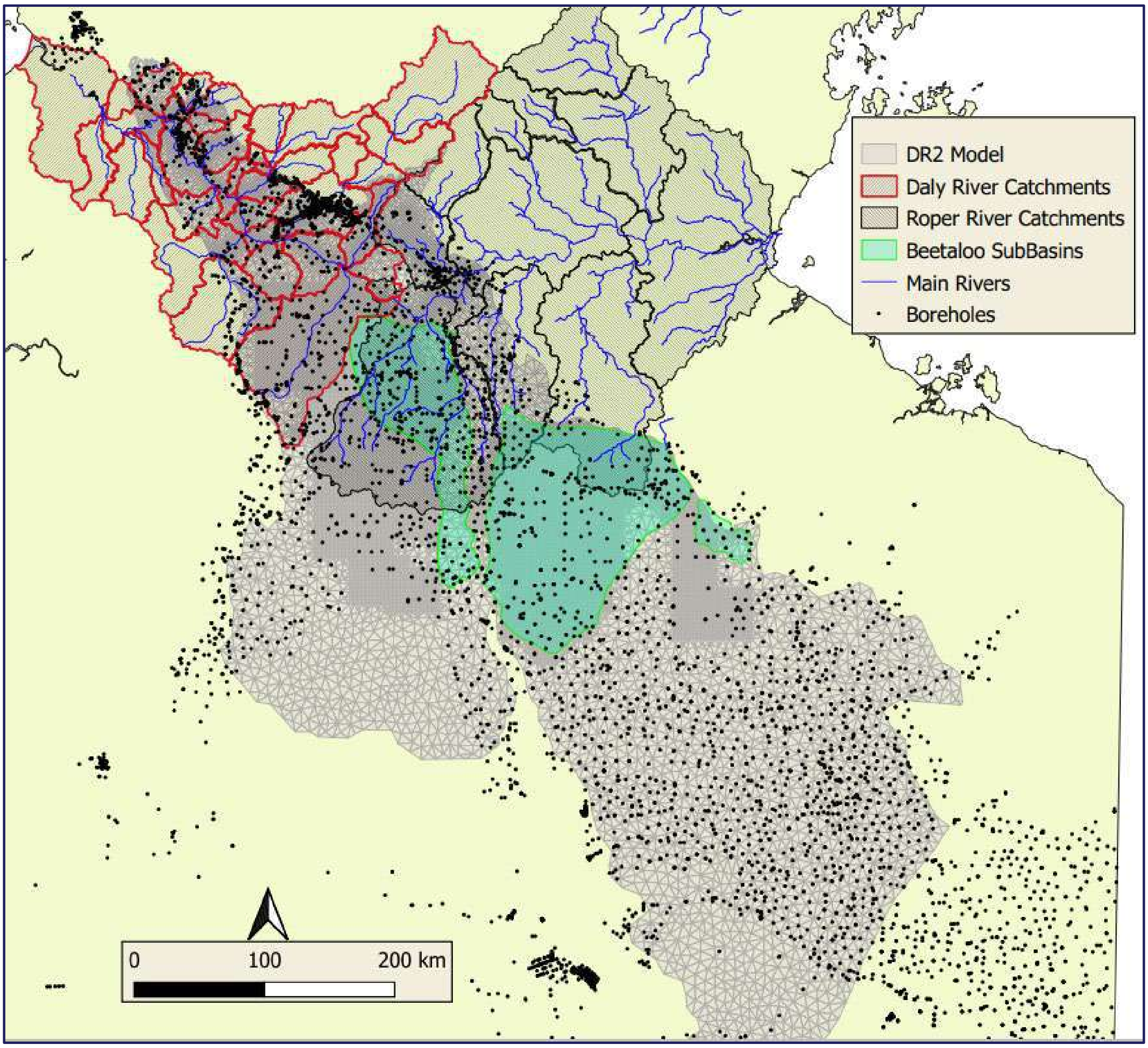

Figure 4-2. Spatial extent of the DR2 Model domain.

4.3. Groundwater

4.3.1. Geology and hydrostratigraphy

The geology of the study area consists of a series of stacked sedimentary basins ranging in age from Mesoproterozoic to Cretaceous with a thin Cenozoic cover. The sedimentary sequences of interest to the multi-layered groundwater system (i.e. the 'hydrostratigraphy') of the Beetaloo Sub-basin region are the following:

- Cretaceous (Carpentaria Basin)
- Cambrian (Daly Basin, Wiso Basin, Georgina Basin, Kalkarindji Igneous Province)
- Neoproterozoic (Kiana Group)
- Mesoproterozoic (Beetaloo Sub-basin).

The generalised hydrostratigraphy of the region is presented in Table 4-1. The stratigraphy in the eastern Beetaloo Sub-basin (Georgina Basin), which has the most complete sequence of the formations found in the region, is represented in Figure 4-3. However, the generalised stratigraphy is still mostly applicable to the western Beetaloo Sub-basin (Wiso Basin and southern Daly Basin) with the exception that the Anthony Lagoon equivalents are absent in the south and present in the north.

The hydrostratigraphic units (HSUs) intercepted by individual bores in the region are presented in Figure 4-4.

Table 4-1. Hydrostratigraphy of the SREBA Water Studies area.

Era	Period	Group	Formations	Hydrogeologic relevance
Mesozoic	Cretaceous	*Ungrouped*	Unit A-C	Variably saturated local-scale aquifer
Palaeozoic	Cambrian	Daly River/Barkly	Jinduckin Formation Anthony Lagoon Formation	Intermediate-scale aquifer and leaky aquitard
			Tindall Limestone Montejinni Limestone Gum Ridge Formation	Regional-scale aquifer
		Kalkarindji Igneous Province	Antrim Plateau Volcanics Helen Springs Volcanics Nutwood Downs Volcanics	Local-scale aquifer and aquitard
		Ungrouped	*Unnamed sandstone*	Local- to intermediate-scale aquifer
Neoproterozoic	Cryogenian	Kiana	Cox Formation	Aquitard
			Bukalara Sandstone	Intermediate- to regional-scale aquifer
Mesoproterozoic	Ectasian	Roper	Kyalla Formation	Aquitard
			Moroak Sandstone	Local- to intermediate-scale aquifer
			Velkerri Formation	Aquitard
			Bessie Creek Sandstone	Local- to intermediate-scale aquifer
			Corcoran Formation	Aquitard

Lithology key: Limestone, Dolomitic Sandstone/Siltstone, Sandstone, Shale, Igneous

Notes:

The terminology describing aquifer 'scale' is not intended to be specific but is broadly defined as:

- Local-scale = <1000 km^2 (restricted to a minor portion of a basin)
- Intermediate-scale = <20,000 km^2 (restricted within a single basin)
- Regional-scale = >20,000 km^2 (spanning multiple basins)

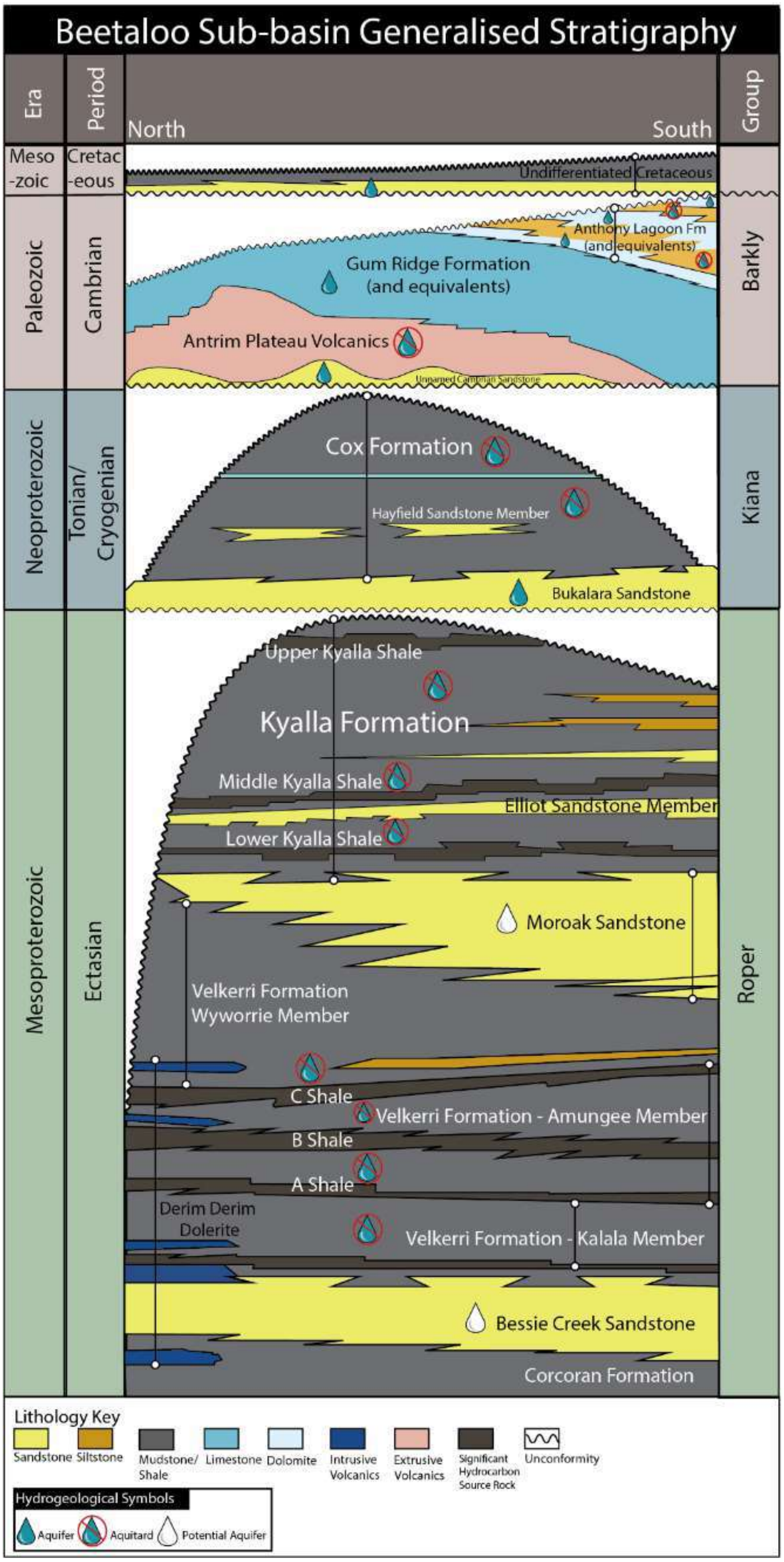

Figure 4-3. Update to the Beetaloo Sub-basin generalised stratigraphic framework, modified after Altmann *et al.* (2020) to include hydrogeological information.

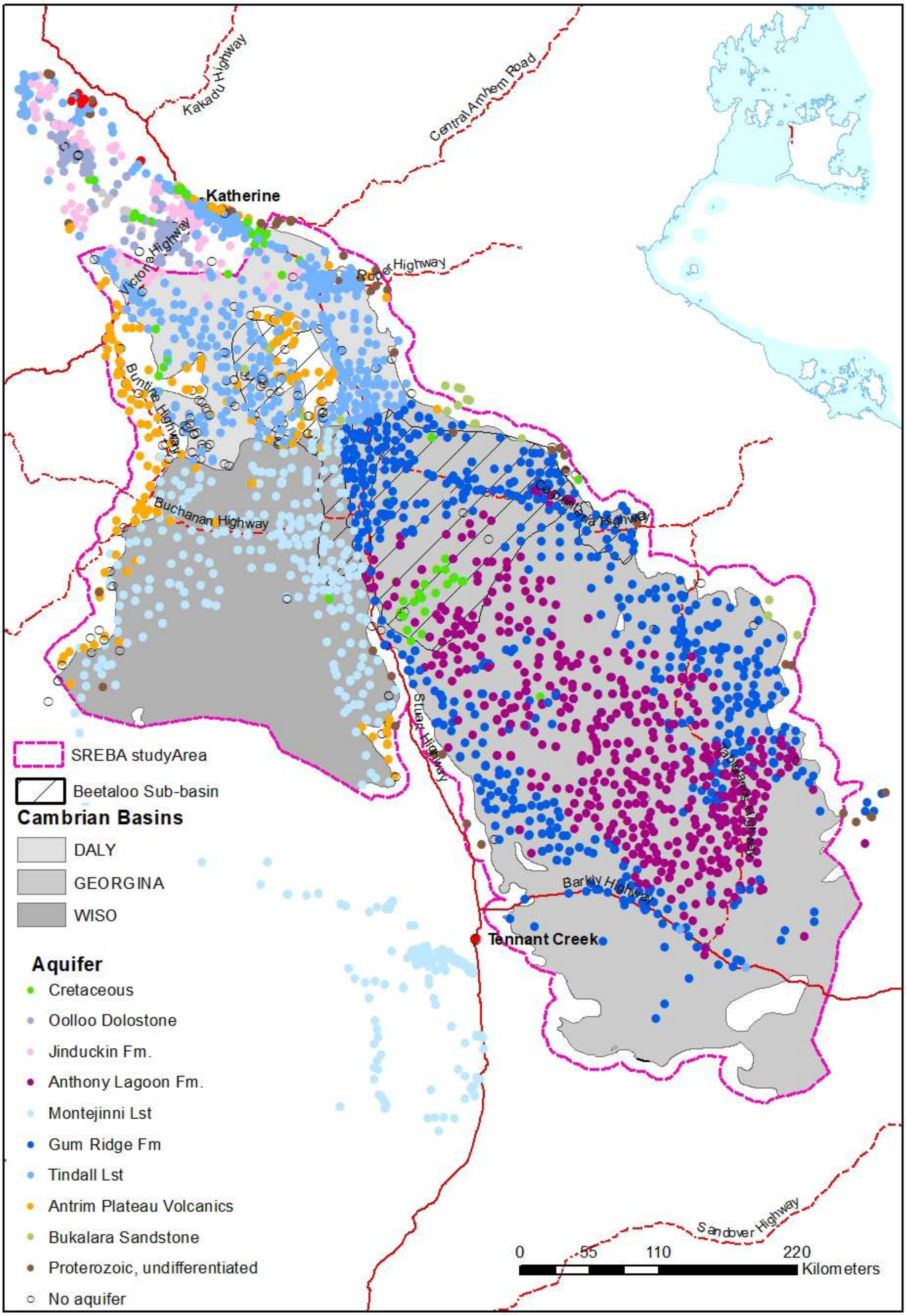

Figure 4-4. Hydrostratigraphic unit intercepted by individual bores.

The Beetaloo Sub-basin lies at depths of 1000-4000 m from the natural surface in the Mesoproterozoic (or more specifically the Velkerri Formation) and defines the gas-bearing zone. The major groundwater system (the CLA) overlies this zone at shallower depths, mostly within the top 20-400 m of the natural surface. The CLA is described in detail below, whereas the other formations are summarised briefly and the Water Quality and Quantity Baseline Report can be referred to for further information.

4.3.1.1. Cambrian Limestone Aquifer (CLA)

The regionally extensive CLA is a multi-layered groundwater system that covers a vast area (at least 200,000 km^2, and approximately six degrees latitude and longitude) and includes the Daly, Wiso and Georgina geological basins (Figure 4-5). Within these three basins, broadly equivalent formations are given different names based on geological/geographical variations that do not necessarily have any hydrogeologic distinction. As such, the term CLA is used by hydrogeologists as a simplification and as an acknowledgement that the CLA is a mostly continuous system, spanning multiple geological basins. It is noted that current data and analyses show that the 'Inacumba' aquifer has been misidentified and this concept is no longer used.

The following provides a description of the sub-units that comprise the CLA.

Upper CLA

- Dominated by siltstone but interbedded with thin karstic limestone and dolomite sequences that can host significant groundwater supplies.
- Comprised of the Jinduckin Formation (Daly Basin) and Anthony Lagoon Formation (Georgina Basin). The Hooker Creek Beds are a geological equivalent for this sequence in the Wiso Basin but there are no current records of it hosting groundwater.
- Can reach thicknesses of almost 200 m. This maximum thickness occurs approximately where Newcastle Creek runs east-west over the eastern Beetaloo Sub-basin (Figure 4-6). However, the CLA is also commonly absent or unsaturated towards the margins due to erosion.
- When present, this sequence has the potential to behave as a confining layer for the Lower CLA units, providing a barrier from interaction with the surface (i.e. inhibiting recharge and discharge). However, similar groundwater levels and chemistry are commonly observed between the Upper and Lower CLA units in the Georgina Basin, suggesting there is some degree of intra-aquifer connectivity between the Upper and Lower CLA units.
- Evaporite minerals (e.g. gypsum and some halite) are commonly found within some of the thin aquifer intervals, which can lead to groundwater being brackish and unsuitable for potable or stock water supply. However, some layers are also found to host fresh/potable water, suggesting that in many areas the aquifer intervals of the Upper CLA have poor intra-aquifer connectivity.
- The Upper CLA is not continuous across geological basin boundaries (Figure 4-6) due to significant erosion of the upper Cambrian sequence at the southern boundary of the Daly Basin (northern boundaries of the Wiso and Georgina basins). Thus, the Upper CLA is restricted to the central Daly Basin (to the south, south-east and south-west of Katherine) and Georgina Basins (east and south-east of Elliott).

Lower CLA

- Dominated by fractured and karstic limestone and dolomite lithologies that host significant fresh groundwater supplies.
- Comprised of the Tindall Limestone (Daly Basin), Montejinni Limestone (Wiso Basin) and Gum Ridge Formation (Georgina Basin).

- Can reach thicknesses of almost 400 m. The thickest sequence of the CLA typically occurs within the Georgina Basin in the area around the Carpentaria Highway, and the thinnest sequences are at the basin margins, where the underlying basalt or Proterozoic rocks outcrop. In the Wiso Basin, the Lower CLA is relatively thin due to significant erosion of both the Upper CLA unit, as well as a fair proportion of the top of the Lower CLA.
- Recent mapping and borehole correlation (DEPWS 2022e, 2022f) has identified four layers of continuous siltstone that occur throughout the Lower CLA. Observational data (chemistry and pressures) are inconclusive as to the role these layers play in limiting intra-aquifer connectivity. The current understanding of the high degree of fracturing and karstic porosity development in the CLA suggests that, until more conclusive evidence is presented to the contrary, the siltstone layers should not be considered as barriers to intra-aquifer connectivity (i.e. there is full vertical connection within the Lower CLA).
- The Lower CLA is continuous across the three Cambrian geological basin boundaries. However, there is a small area in the central Sturt Plateau (west of Larrimah; Figure 4-7) where the limestone formations of the CLA are unsaturated (i.e. they are above the water table) due to the higher elevation of the underlying basalt (Antrim Plateau Volcanics).

The CLA is a highly productive aquifer that has high regional connectivity due to the development of significant fracture and karstic secondary porosity (i.e. interconnected fractures, conduits and dissolution features). Bores targeting the CLA are commonly able to yield at least 10 L/s for extended periods and, around the Katherine region (a portion of the CLA not covered by the SREBA Water Studies), bores have been found to sustainably yield up to 100 L/s.

Mapping of the three-dimensional structure of the CLA is advanced relative to many other groundwater resources in the NT. This has been aided primarily by the distinct natural gamma signatures present in both sub-units of the sequence arsing from the interbedded siltstone (relatively high gamma count) and carbonate rock (low gamma count) lithologies. This was well-illustrated during the Sturt Plateau groundwater assessment (Yin Foo and Matthews 2000).

Downhole gamma measurements have been collected from numerous bores and exploration wells (both mineral and petroleum) and these have allowed for spatial correlations. This has been particularly beneficial for this aquifer system because, due to the karstic nature of the rock, lost circulation during drilling occurs regularly and means that accurate lithological logging is often not possible.

Downhole gamma logging is the primary tool used by the petroleum industry (as per reporting requirements) in the Beetaloo Sub-basin for instances when operators need to install multi-level monitoring bores that target both of the CLA sub-units. This method ensures that they are able to more accurately design their monitoring and production bores to prevent intra-aquifer mixing.

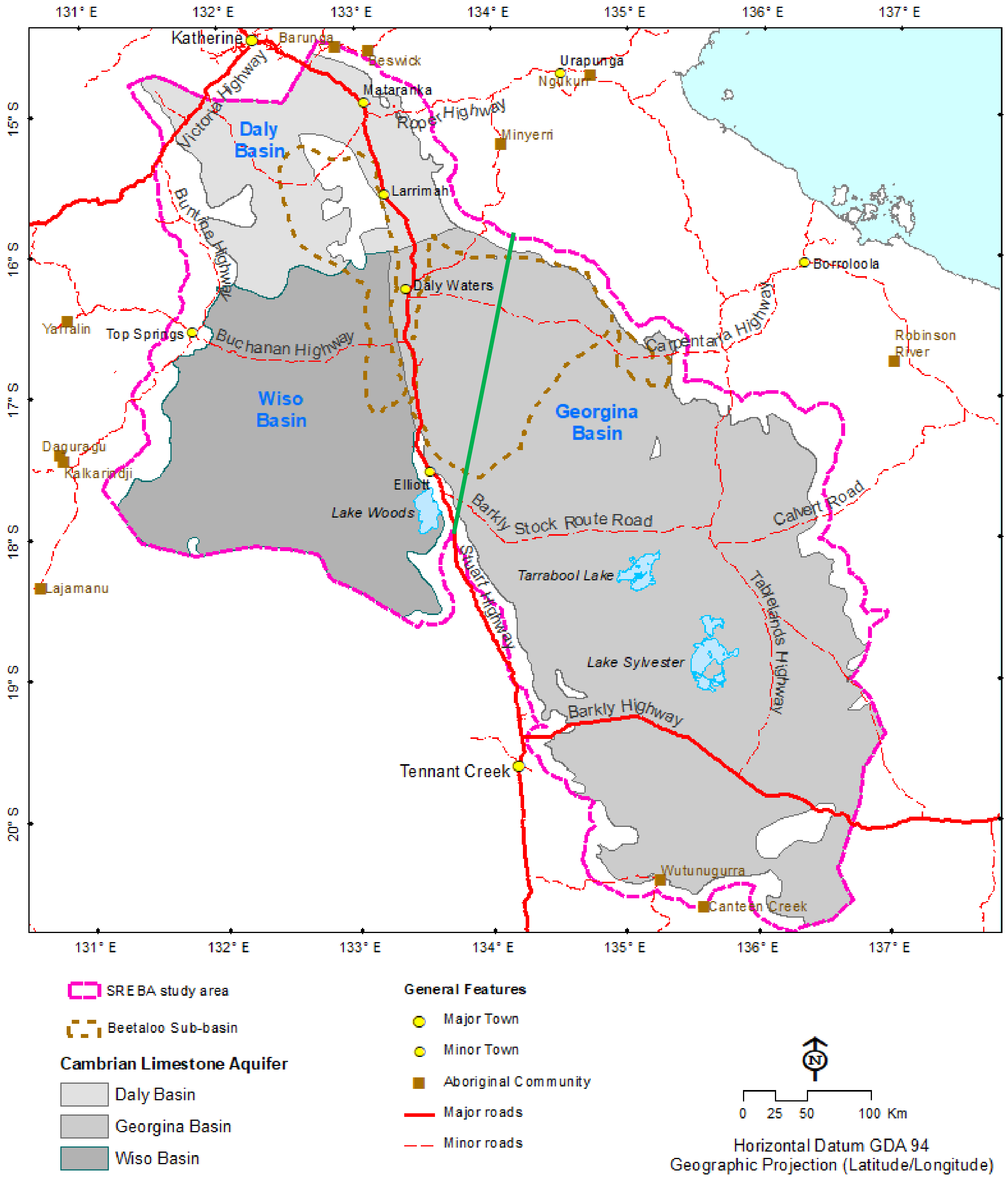

Figure 4-5. Location of the Daly, Wiso and Georgina geological basins within the SREBA Water Studies study area. Green line represents location of hydrogeologic cross-section shown in Figure 4-6.

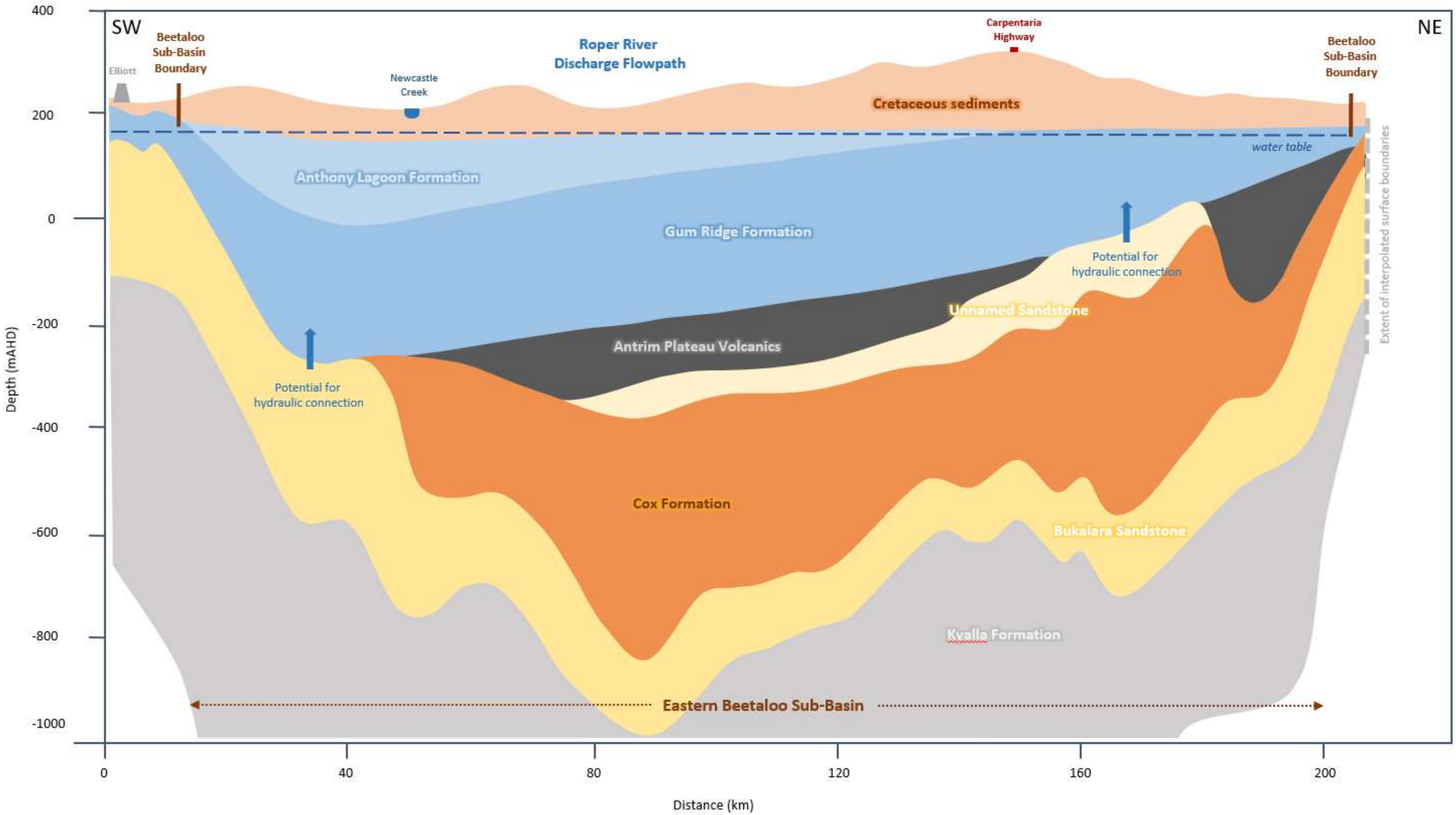

Figure 4-6. South-west to north-east hydrogeological cross-section through the eastern Beetaloo Sub-basin. Location of transect shown on Figure 4-5.

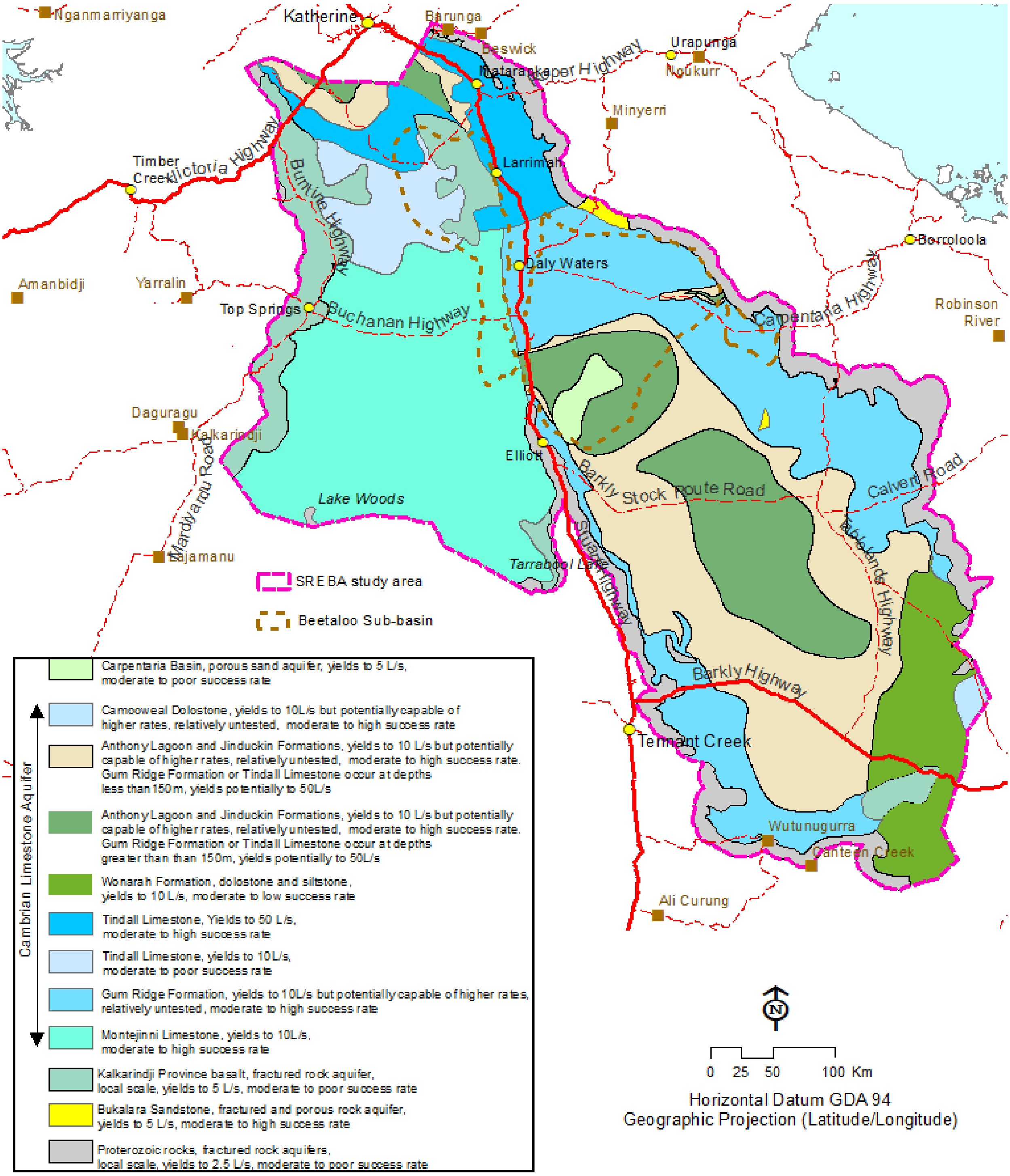

Figure 4-7. Location of the current estimate of the saturated extent of CLA formation.

4.3.1.2. Cretaceous sediments

The Carpentaria Basin extends over the majority of the SREBA Water Studies area, with small areas where it is absent occurring to the north near the Roper River and Flora River, where it is has been eroded by seasonal surface water flows. The Carpentaria Basin also does not extend much beyond the southern area of the Beetaloo Sub-basin, being broadly limited to the area north of the Barkly Stock Route. The Cretaceous sediments of this Basin are comprised of layers of sandstone, siltstone and claystone. The sequences are thinnest in the north-western area of the Beetaloo Sub-basin, ranging from being absent to almost 100 m thick in some areas, and are thickest over the central areas of the eastern Beetaloo Sub-basin, where it can reach thicknesses of almost 150 m.

The Cretaceous sediments can host productive supplies of fresh groundwater (several pastoral bores are known to utilise it for supplies), but over the Beetaloo Sub-basin this sequence is more typically found to be unsaturated. Where the Cretaceous sediments host aquifers, they are usually localised perched aquifers (often seasonal) close to the ground surface, or form aquifers at the base of the Cretaceous sequences that are an upper extension of the underlying limestone or basalt aquifers. There is significant interest in the occurrence of this sequence because of its role in both facilitating recharge (via surface drainage into laterite sinkholes or outcrops of the permeable Unit A sequence) or inhibiting recharge (where thick sequences are dominated by claystone and siltstone). These aspects of the Cretaceous sediments were investigated as part of the GBA assessments on potential recharge zones, which is discussed further in Section 4.3.4.

4.3.1.3. Other Cambrian formations

Antrim Plateau Volcanics

The Kalkarindji Igneous Province spans a large part of the north-western area of the Australian continent, and in the vicinity of the Beetaloo Sub-basin is commonly known as the Antrim Plateau Volcanics. In the SREBA Water Studies area, this basalt sequence is widespread, underlying the CLA in most places except for two areas around Larrimah and Daly Waters, and larger areas overlying the southern and eastern Beetaloo Sub-basin (Figure 4-7). In the areas where the basalt is present, it can be up to 400 m thick (but is more commonly 100-200 m), and is known to act as a regional-scale aquitard separating the underlying Neoproterozoic or Mesoproterozoic formations from the shallower CLA. However, where it is absent, there is potential for direct connection between the deeper Neoproterozoic or Mesoproterozoic aquifers (e.g. Bukalara Sandstone) and the CLA.

The basalt sequence is only known to form local aquifers where the rock is highly fractured or weathered — this is more common at its contact with other formations at the top and/or base of the sequence. Typical bore yields are low (<2 L/s) and water quality is highly variable (fresh to saline), which limits supply from this sequence for stock or domestic purposes.

Unnamed sandstone

Recent logging of petroleum exploration wells, assisted by the use of detrital zircon age distributions, has helped to differentiate an unnamed sandstone unit that can be locally found directly beneath the basalt, and unconformably overlies both formations of the Kiana Group (see below), indicating that it is likely post-Neoproterozoic. Only a small amount of information exists that can be directly attributed to the hydrogeology of the unnamed sandstone sequence. Drilling and testing undertaken during the SREBA Water Studies indicates that the sandstone can have thicknesses of at least 50 m, have high yields, poor water quality, and groundwater levels can be higher than in the CLA. The drilling results also indicate that where the unnamed sandstone directly overlies the Bukalara Sandstone, they appear to behave as one continuous aquifer.

4.3.1.4. Neoproterozoic formations

The Neoproterozoic formations overlying the Beetaloo Sub-basin are part of the Kiana Group, which is comprised of the Cox Formation and Bukalara Sandstone. These formations are widespread and commonly found in petroleum exploration drilling in the region, and are likely to be present across the entire SREBA Water Studies area. The Cox Formation and Bukalara Sandstone occur at a combined thickness of almost 600 m, with the Bukalara Sandstone typically having a thickness of less than 150 m.

The lithology of the Cox Formation is interbedded fine-grained siltstone, shale and minor sandstone, which suggests that it likely acts as an extensive regional aquitard that separates the deeper aquifers from the Cambrian sequence.

The Bukalara Sandstone is known to be a valuable local-scale aquifer where it outcrops to the north of the Georgina Basin, but its hydrogeology is less well-known in the SREBA Water Studies area. Exploration drilling and pumping tests in the western Beetaloo Sub-basin area found that the Bukalara Sandstone had good yields but relatively poor water quality. Where the Bukalara Sandstone directly underlies the CLA, a high degree of hydraulic connectivity is expected.

4.3.1.5. Mesoproterozoic formations

The Mesoproterozoic sequence of the Beetaloo Sub-basin is comprised of stacked layers of shale (Kyalla Formation, Velkerri Formation and Corcoran Formation) and sandstone (Elliott Sandstone Member, Moroak Sandstone and Bessie Creek Sandstone). This sequence – specifically the Kyalla Formation and Velkerri Formation – hosts the gas plays that are the target for petroleum exploration activities in the area.

There is very little direct hydrogeological information regarding any of the Mesoproterozoic formations of the Beetaloo Sub-basin due to their depth and limited potential for groundwater supplies. Most formations in this sequence have low potential to form aquifers, and groundwater hosted by the Mesoproterozoic formations is typically saline to hypersaline. There is low potential for connectivity between formation waters of the Mesoproterozoic sequence with the shallower Cambrian sequence.

4.3.2. Hydrodynamics, aquifer properties and inter-connectivity

The primarily focus for the SREBA Water Studies was the CLA as it is the only regional groundwater resource that is known to support significant environmental or socio-economic values. The CLA was also the primary focus of the Scientific Inquiry and all subsequent groundwater assessments. The exceptions to this are where deeper aquifers are discussed in relation to the current conceptualisation of connectivity with the CLA, and the current understanding of the only known area of surface discharge from the deep aquifers (Hot Springs Valley). For a summary of the current understanding of the hydrodynamics of the individual deeper aquifers, readers are directed to Evans *et al.* (2020), who have compiled all available groundwater investigation data as well as opportunistic data collected during petroleum exploration well drilling.

4.3.2.1. Aquifer properties

As part of the SREBA Water Studies, existing pumping test data were revisited to compile estimates of aquifer transmissivity (T), hydraulic conductivity (K) and storativity (S), as well as for a reinterpretation of tests where either intra- or inter-aquifer connectivity was tested (DEPWS 2022g). Much of the data have previously been presented as part of the numerical model development (Knapton 2020) but also form part of CSIRO's work for the Roper River Water Resource Assessment (C. Turnadge, CSIRO, pers. comm.). The latter also includes an assessment of existing pumping test data for non-CLA aquifers in the wider Roper River catchment area.

The pumping test compilation presented in DEPWS (2022g) includes a total of 178 pumping tests that can be used to estimate T and/or K, and 17 tests where storativity (S) could also be estimated (i.e. the test included drawdown data collected at an observation bore). The range in T estimates for the various CLA units spans up to four orders of magnitude, with the Upper CLA typically having a smaller range than the Lower CLA. However, this observation may be biased due to many more tests relating to the Lower CLA than the Upper CLA.

There appears to be no spatial pattern in T estimated for the CLA, which is most evident around the area around Katherine where there have been numerous tests undertaken in close proximity with markedly different estimates. This is expected given that the karstic nature of the CLA means that permeability is almost entirely dependent on the relatively random interconnectivity between narrow fractures, large conduits and/or cave-sized voids.

Bulk hydraulic parameters (i.e. representative for large portions of the regional system) have also been reviewed and estimated during the development of the numerical groundwater model for the CLA. These parameters gave the general range of 1,000-2,000 m^2/day for T and assumed storage coefficient/specific yield of 1-6% (Knapton 2020). These parameters resulted in overall good matching of modelled simulations to monitoring data across the CLA, and these are the generally accepted bulk hydraulic parameters representative of the CLA.

Estimates of storativity in the region also span orders of magnitude, with estimates of S for the Upper CLA typically being lower than those for the Lower CLA. Again, this observation should be treated cautiously because it is likely biased due to the contrast in available number of tests. However, the Upper CLA would be expected to have a lower S due to the much greater proportion of siltstone relative to karstic carbonate rock intervals.

4.3.2.2. Inter-aquifer connectivity

The CLA is potentially connected with many of the other hydrostratigraphic units (HSUs) recognised in the region and, based on current mapping, a number of general configurations are possible, both at the top and bottom of the CLA.

Most commonly, the upper CLA (or the lower CLA where the upper units are absent) is overlain by at least 50 m of Cretaceous sediment cover. Around the Roper and Flora River discharge zones to the north of the Beetaloo Sub-basin, the lower CLA outcrops to the ground surface. In areas where the Lower CLA outcrops, karstic sinkholes are common. In some areas toward the basin margin, the CLA is overlain by unsaturated formations of the upper CLA that are above the regional water table.

In most of the Beetaloo region, the CLA is underlain by basalt, which results in a barrier to connection with deeper aquifers. Where basalt is absent, the CLA can be in contact with the Cox Formation, which has the properties of a regional aquitard, or the Bukalara Sandstone, in which case there is potentially a hydraulic connection. In the rarest configuration, which likely only occurs in the area around the Daly Waters High (underlying the Stuart Highway between Elliott and Larrimah), the basalt sequence and Neoproterozoic rocks are absent, and the deeper formations are elevated, which means there is the potential for the CLA to be in direct contact with the Mesoproterozoic formations.

The HSUs that directly underlie the CLA have recently been mapped based on reinterpretation of exploration well and bore logging data, and regional geophysics (Figure 4-8). The mapping indicates that over the Beetaloo Sub-basin the CLA is mostly underlain by the basalt aquitard but that there are areas around the OT Downs Sub-basin, Beetaloo eastern extension and southern Beetaloo where the Neoproterozoic units underlie the CLA, and minor areas near Larrimah and Newcastle Waters where the Mesoproterozoic units underlie the CLA.

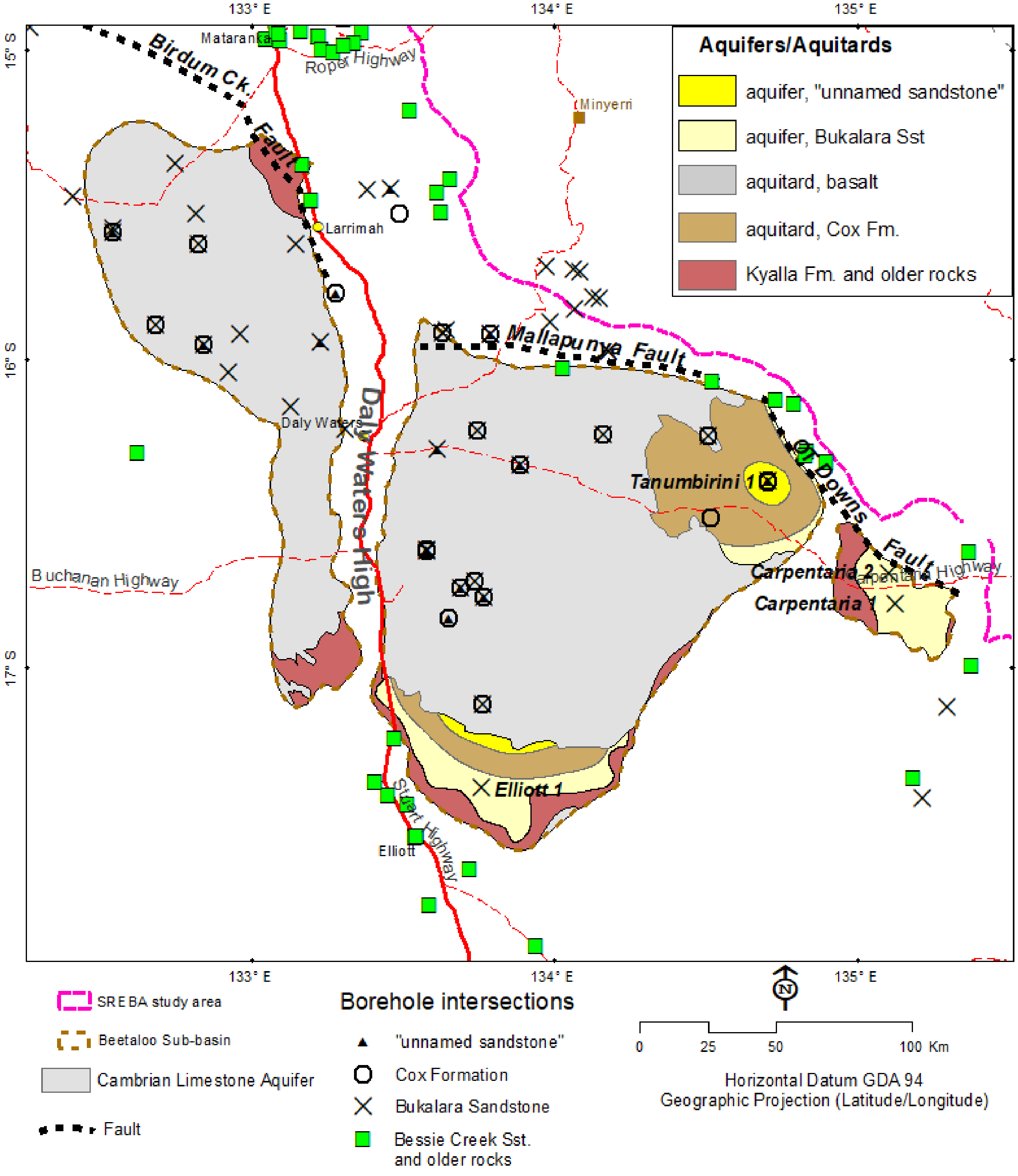

Figure 4-8. Hydrostratigraphic units directly underlying the CLA.

Evidence of potential inter-aquifer (e.g. between the CLA and deeper aquifers) and intra-aquifer (e.g. between the upper and lower units of the CLA) connectivity has also been provided by the environmental tracer investigations and reinterpretation of seismic surveys during the GBA and GISERA programs, and at a small number of sites across the wider Cambrian limestone basins (Daly, Wiso and Georgina) using pumping tests that observe pressure changes in multiple aquifers.

The environmental tracer studies undertaken by CSIRO during the GBA and GISERA studies found that helium concentrations were indicative of a flux of old water from the deeper units into the CLA and the Mataranka springs discharge area (Deslandes *et al.* 2019; Lamontagne *et al.* 2021). The origin of the elevated helium remains unclear, and lack of helium concentration data for deeper formation waters prevented the authors from estimating a potential flux into the shallower CLA. The authors postulated that the elevated helium results could be related to proximity to previously mapped structural lineaments in the underlying geology. Towards the Mataranka springs discharge area, it could also be due to connection with other Proterozoic rock underlying the CLA (but locally outcropping) that may have a groundwater source from the north of the Roper River.

CSIRO also recently developed a workflow to investigate areas where there is a higher potential for connection between pre- and post-Cambrian formations using re-interpreted geophysical data, surface water drainage features and the environmental tracer data described above (Frery *et al.* 2022). Their investigations affirmed the findings of Evans *et al.* (2020) that there are very few areas where there is potential for active connection between deep and shallow formations. However, the faulting that is responsible for the orientation of surface drainage, as well as for the springs at Hot Spring Valley (not part of the CLA), is likely to be deep-rooted and may provide a connection between the Beetaloo Sub-basin and the surface. In most other areas there is very limited evidence of active exchange between the pre- and post-Cambrian formations, but the work at least provides a better indication of where future monitoring/investigations could be targeted to further investigate this process.

Other direct observational data relating to aquifer connectivity have been obtained from pumping tests that have collected groundwater-level data from multiple aquifers. Most of these tests have collected data relevant to connection between the Upper CLA and Lower CLA (see below). One test was undertaken as part of the SREBA Water Studies to test connection between the CLA and Bukalara Sandstone aquifer in an area where the two are separated by a significant thickness of basalt (see Short 2021). The inter-aquifer connectivity test was undertaken along the north-western section of Western Creek Road (approx. 80 km west of Larrimah) and involved pumping groundwater from the Bukalara Sandstone aquifer for almost four days and observing drawdown responses in both the Bukalara Sandstone aquifer and the overlying CLA. Clear drawdown was observed at Bukalara Sandstone monitoring bores to a distance of at least 1 km, but no drawdown was observed in the overlying CLA.

This investigation provides the first field assessment that supports the conceptualisation of little to no connection between these HSUs when there is a layer of basalt present. Contrasting water chemistries at the bores at this site also provided evidence that there is negligible interaction between the Bukalara Sandstone aquifer and CLA in this area. These findings will be crucial for assessing the likely impacts of potential future groundwater extraction from the Bukalara Sandstone aquifer by the petroleum industry.

4.3.2.3. Intra-aquifer connectivity

An updated assessment of downhole geophysical logs and lithological descriptions (DEPWS 2022e, 2022f) has enabled a more robust understanding of how the layered sequences of siltstone and limestone/dolostone of the CLA occur across the region. This has also been aided by revisiting water chemistry information and historic pumping tests that have extracted from one CLA unit while collecting drawdown observations from the other (or both). Details are provided in the Baseline Report.

From these studies, a conservative and precautionary conceptualisation is recommended, and it should be assumed that there is a high degree of connectivity throughout the CLA and its sub-units. This is especially the case given its karstic nature and potential to be highly connected. The common occurrence of stygofauna across the region and between different sub-units also supports the conceptualisation of a high degree of connectivity of the CLA system (Rees *et al.* 2020; Oberprieler *et al.* 2021; Humphreys *et al.* 2022), especially in the Georgina Basin and south-eastern Daly Basin.

Another major aspect to consider in relation to intra-aquifer connectivity of the CLA is how the three-dimensional structure may act to compartmentalise regional flow systems. A major feature that has long been inferred to compartmentalise the CLA is the extensive fault known as the Birdum Fault (Yin Foo and Matthews, 2000) (Figure 4-9).

While most faults mapped in the area by seismic surveys do not appear to penetrate formations above the Roper Group (i.e. Mesoproterozoic sequence), in general all Cambrian formations are considerably deeper in the eastern Beetaloo Sub-basin compared to the west. This feature has been inferred to be due to displacement resulting from northward extension of an uplifted zone known as the Daly Waters High (Orr *et al.* 2020), which approximately follows the main drainage line of Daly Waters Creek, Birdum Creek, Durrinyan Creek, King River, and probably also extending beneath the Daly River.

The Birdum Fault is inferred to act as a barrier to flow, separating the two CLA flow systems that overlie the Beetaloo Sub-basin. This is especially likely in the area to the south-west of Mataranka, where the CLA sub-units are offset to such a degree that the Lower CLA on the southern side of the fault abuts the Upper CLA on the north side of the fault.

The degree of displacement appears to reduce to the south of Daly Waters, where there is only a minor degree of displacement in the Lower CLA sequence across the Wiso Basin/Georgina Basin boundary. There is also evidence of a connection between the Wiso Basin CLA and Georgina Basin CLA, based on similarities in water quality for a small portion of the western Wiso Basin.

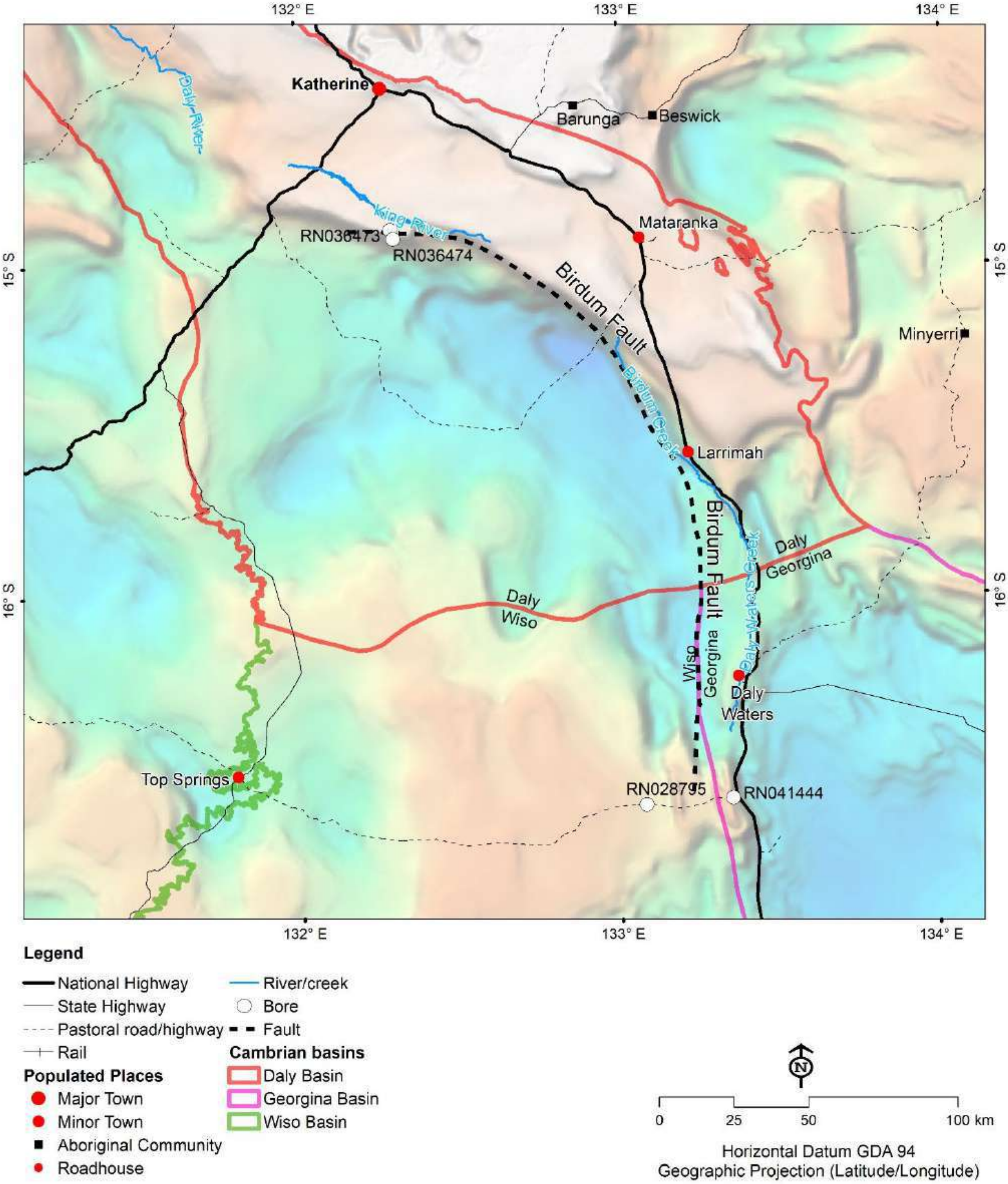

Figure 4-9. Location of the Birdum Fault.

4.3.3. Groundwater levels, flow and velocities

There are two primary regional groundwater flow systems identified for the CLA that overlie the Beetaloo Sub-basin, and they are distinguished by their major river discharge zones to the north (Figure 4-10). The first major flow system is the Roper River Flowpath, which is contained within the Georgina Basin and the south-eastern Daly Basin. Groundwater flow originates from the southern Georgina Basin, where groundwater levels can be as high as 180-200 m (relative to the Australian Height Datum (mAHD)) near the intersection of the Barkly Highway and Tablelands Highway (Figure 4-11). Groundwater then flows in a north-north-westerly direction, flowing into the south-eastern Daly Basin, where groundwater levels are approximately 140-150 mAHD. The Flora River Flowpath terminates at its major discharge zone along the Roper River and Mataranka springs, where dry season water levels of the Roper River (maintained solely by groundwater discharge) are typically 90-110 mAHD.

The second major CLA flow system overlying the Beetaloo Sub-basin is the Flora River Flowpath, which is contained within the central and northern Wiso Basin and south-western Daly Basin. Groundwater flow originates from the central Wiso Basin (northern Tanami), where groundwater levels can be as high as 160-190 m AHD beneath the Buchanan Highway, as well as from the area east of Top Springs (Figure 4-11). Groundwater then flows in a northerly direction flowing into the south-western Daly Basin, where groundwater levels are approximately 140-150 mAHD. The Flora River Flowpath terminates at its major discharge zone along the Flora River, where the Lower CLA outcrops to the surface near the community of Djarrung. Dry season water levels of the Flora River near the discharge area are typically 70-90 mAHD.

The two flow systems described above have been inferred based on multiple lines of evidence. The clearest evidence is the distribution of groundwater levels from the monitoring network (including petroleum industry data) described above. However, these data have also been supported by other lines of evidence that are less direct, including regional data relating to the basement topography (i.e. areas where formations are displaced) such as the NT SEEBASE modelling (Frogtech Geoscience 2018); regional gamma log correlations (DEPWS 2022e, 2022f); and differences in major ion chemistry across basin margins. This understanding of the CLA, in addition to variations in climate and recharge rates, also forms the basis for the delineation of the water allocation plans relating to groundwater resources of the region.

Depth to groundwater across the CLA ranges from seasonally artesian in the areas around main discharge zones close to the Roper and Flora rivers, to >100 m below ground level (mbGL) in the areas around the Buchanan Highway and Carpentaria Highway (Figure 4-12). The deeper areas of groundwater in those areas are associated with topographic highs and significant thicknesses of Cretaceous sediments. Localised areas of shallower groundwater exist around the northern discharge areas (i.e. Roper and Flora rivers); on the margins of the Cambrian basins where there is outcropping CLA (e.g. near Top Springs and south of Cape Crawford; Figure 4-5); and beneath some of the large ephemeral surface water bodies, such as Lake Woods and the Barkly lakes (Figure 4-12). The relatively shallow groundwater levels in the latter areas likely provides an indication that CLA outcrop areas and some of the large surface water bodies are potential recharge areas.

Note that the potentiometric surface map (Figure 4-11) and depth to groundwater map (Figure 4-12) both use a weighting system for the monitoring bores that is based on various factors such as the month of measurement, how recent the measurement was, and if the bore has been surveyed to AHD (refer to DEPWS 2022h for details).

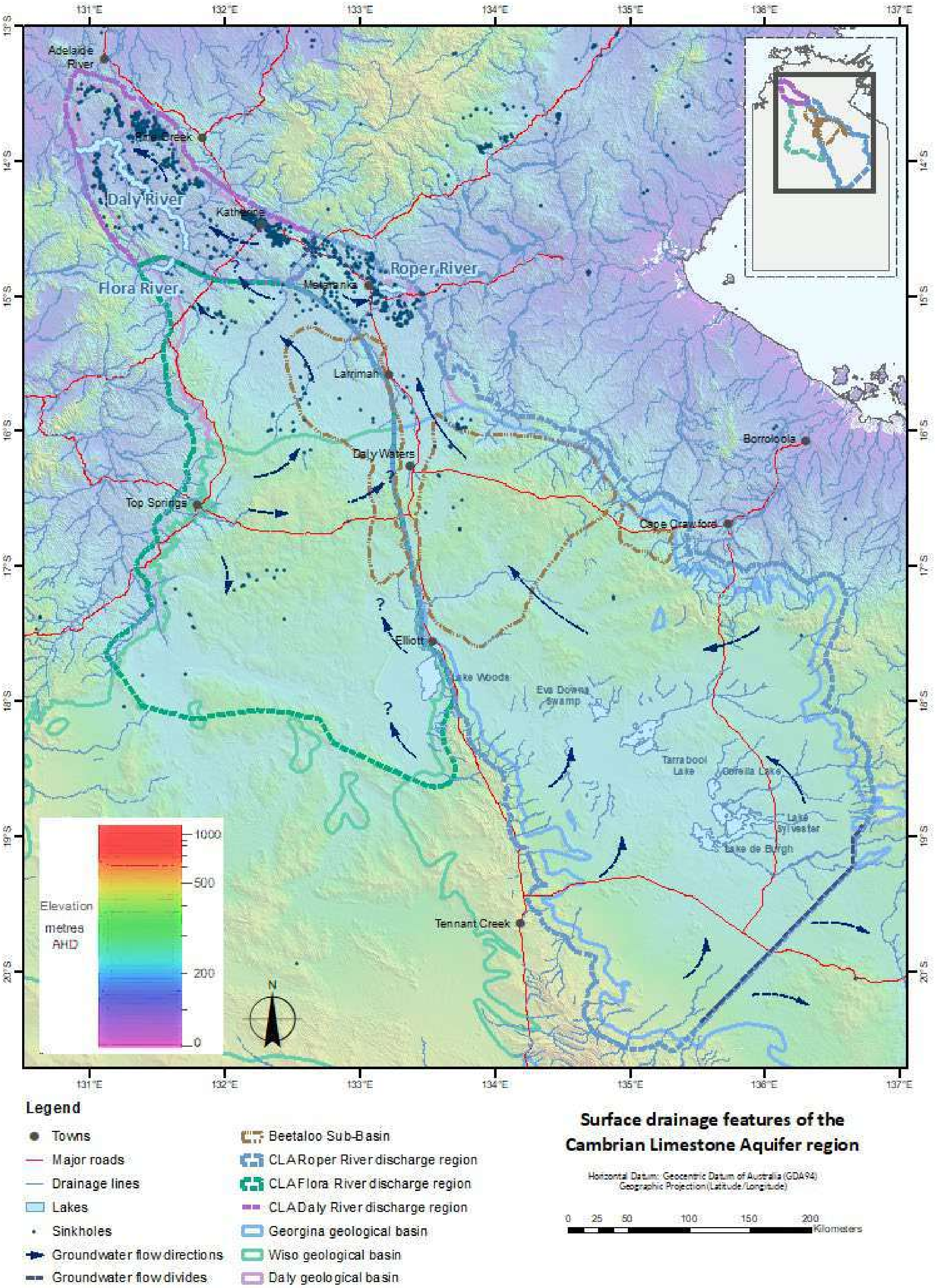

Figure 4-10. Regional topography and major groundwater flow systems of the regional CLA.

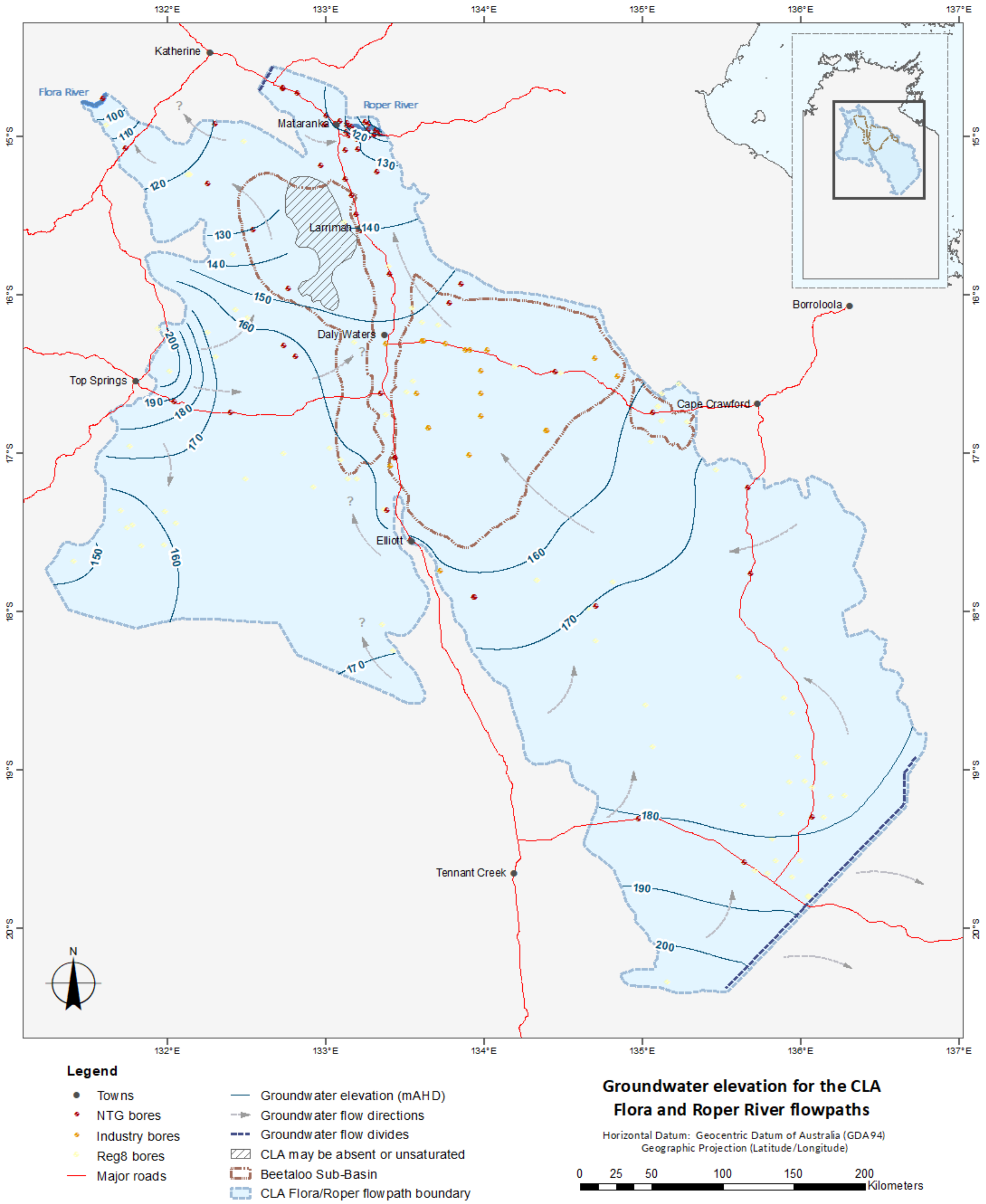

Figure 4-11. Groundwater levels of the major flow systems of the CLA overlying the Beetaloo Sub-basin.

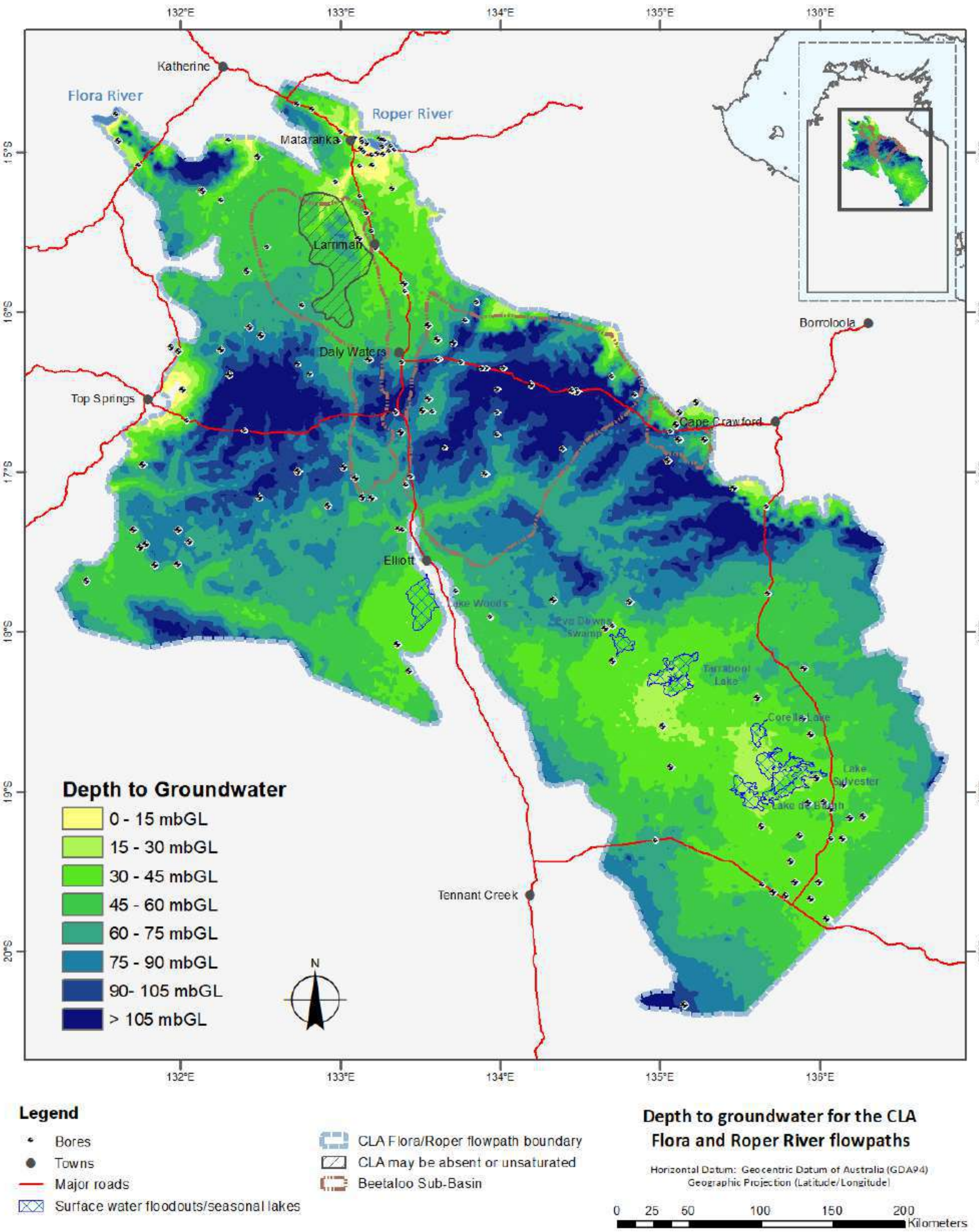

Figure 4-12. Depth to groundwater for the major flow systems of the CLA overlying the Beetaloo Sub-basin.

Estimates of groundwater velocity estimates are able to be produced by the DR2 2020 model, after calibration to some of the water level observations described above. These velocities are calculated using the modelled hydraulic gradients and an assumed aquifer porosity. An example of the velocity variations across the CLA is shown in Figure 4-13. The data represented on the map are the estimated groundwater velocity for the first layer (top most layer) of the model taken for 1 November 2021. Therefore, they represent a period where hydraulic gradients directing flow towards the discharge area are at their steepest due to water levels near the rivers reducing over the dry season.

The modelled groundwater velocities highlight key points that are described below.

- Very low velocities (< 0.1 m/year) occur across most of the CLA and all of the Beetaloo Sub-basin.
- Moderate velocities (> 1 m/year) occur near inferred recharge areas (e.g. east of Elliott/Ashburton Range, east of the Tablelands Highway) and this is due to groundwater mounding after recharge events.
- Higher groundwater velocities (>10 m/year) occur very close to (< 5 km) groundwater discharge areas.

Caution should be applied when interpreting the velocities because they are produced using an assumptions of generalised porous media flow and not based on detailed knowledge of karst networks. Modelling of such a large karstic aquifer as equivalent porous media is considered applicable for investigating water balance dynamics and pressure changes. It does, however, mean that groundwater velocities cannot account for preferential flowpaths that may facilitate higher-velocity groundwater flow at a more local scale. Regardless of the modelling limitations, it is unlikely that groundwater flow velocities exceed 1 m/year over the Beetaloo Sub-basin because the hydraulic gradients are not sufficient.

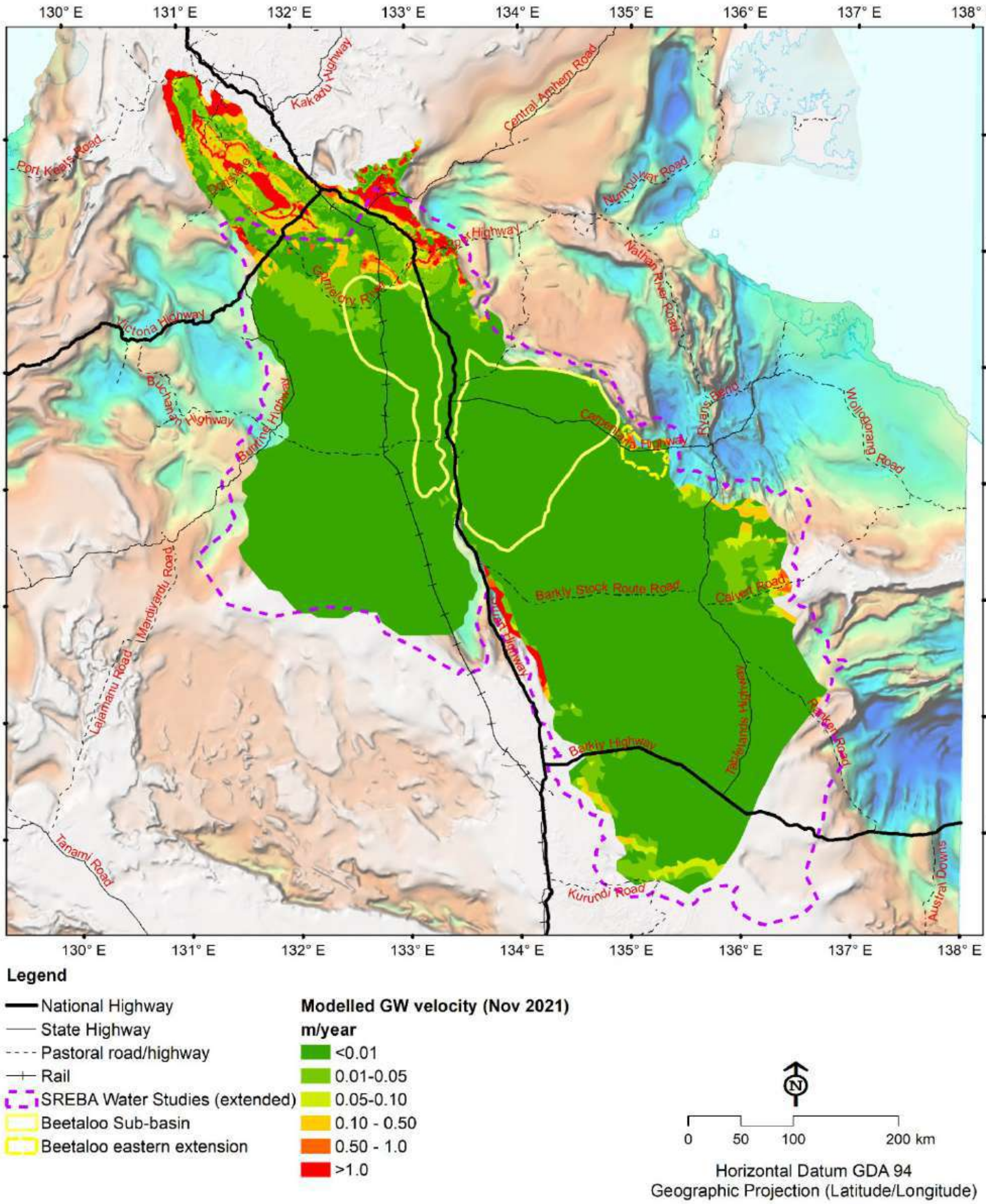

Figure 4-13. Modelled groundwater velocities (1 November 2021) of the CLA for the top-most model layer.

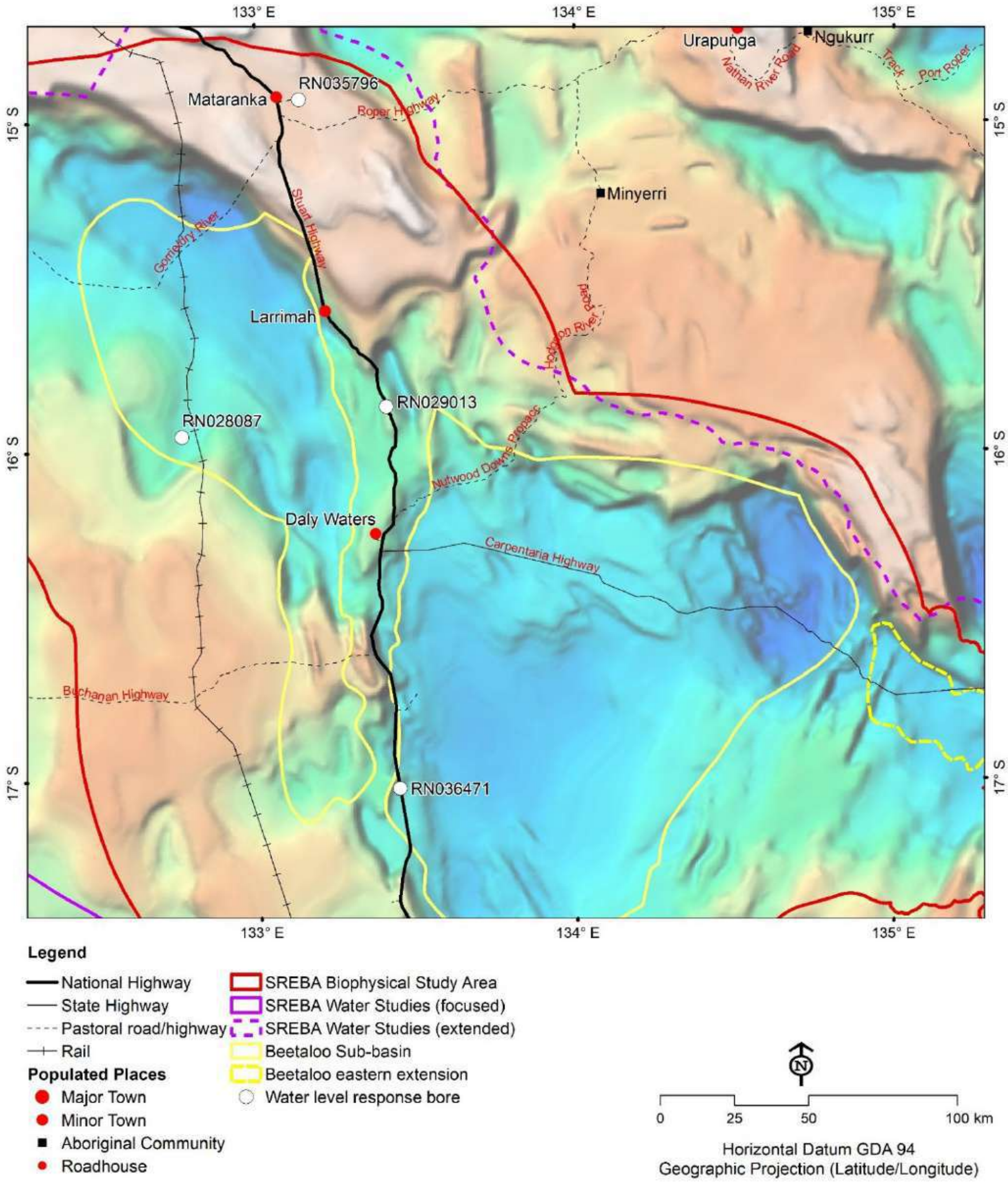

Figure 4-14. Groundwater level monitoring bores that illustrate typical CLA groundwater level trends.

Across the two main CLA flowpaths there are also distinct variations in seasonal, multi-year and long-term groundwater level fluctuations. There are three common groundwater level fluctuation responses observed in the region: seasonal, episodic and gradual storage increase. Monitoring bores used to illustrate these patterns are shown in Figure 4-14.

Seasonal trends are characterised by a seasonal response (recharge) of the aquifer in the wet season (rapid groundwater level rise) followed by discharge over the dry season (gradual groundwater level decline). The annual maximum in groundwater level is dependent on the strength of wet season rain, which can be somewhat variable but is generally reliable. The annual minimum groundwater level, however, remains fairly consistent from year to year but can show signs of overall storage gain or loss over decades.

Seasonal groundwater level fluctuation occurs in the northern part of the study area (Daly Basin) and mostly beyond the northern extent of the Beetaloo Sub-basin, where wet season rainfall is more reliable (i.e. in the Top End climate zone, as per Short and Bond (2021)) and where the Cretaceous sediments are either thin or absent, allowing for more recharge to occur. These areas are also close to the discharge zones, which is why there is an annual seasonal decline in groundwater level due to losses to the Roper River and Flora River discharge areas, as well as evapotranspiration (ET) from shallow water tables and pumping.

An example of the 'seasonal recharge' groundwater level response, observed at Mataranka near the Roper River discharge area, is shown in Figure 4-15.

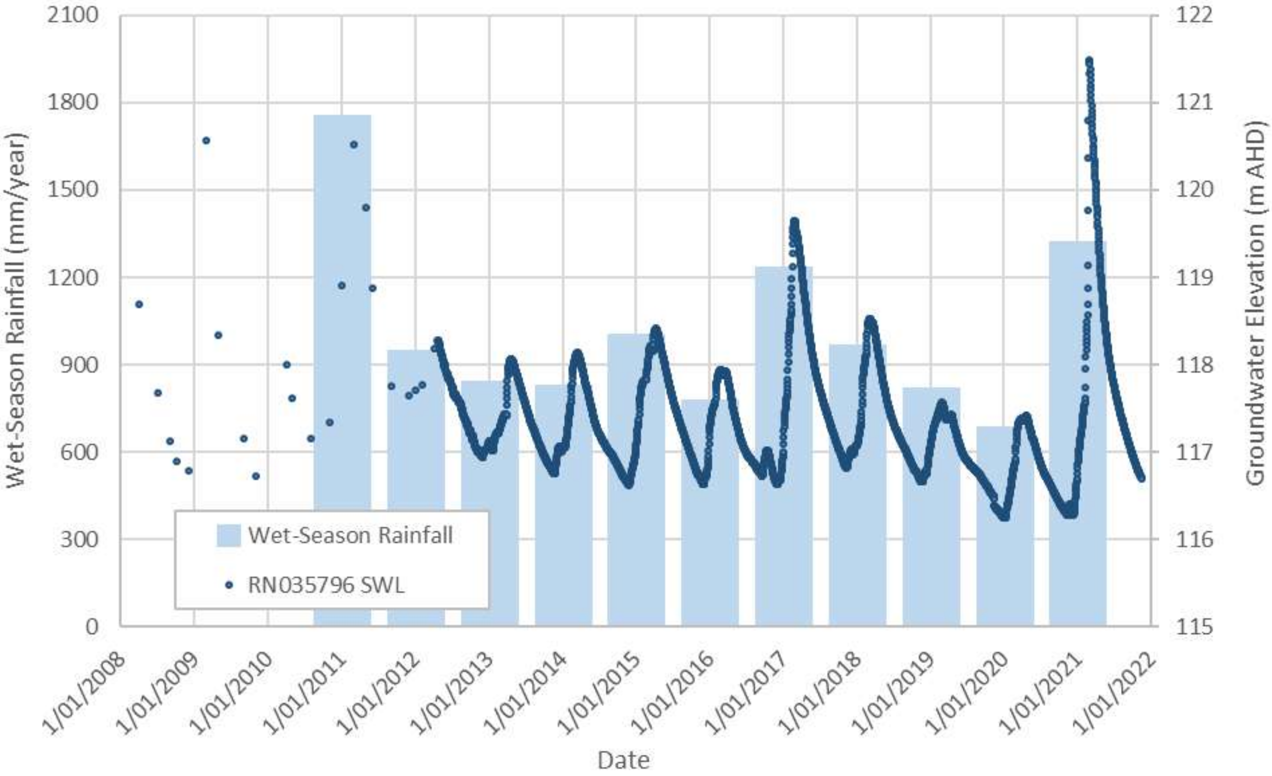

Figure 4-15. Seasonal groundwater level fluctuations recorded at RN035796 (Mataranka Homestead), near the Roper River discharge area.

Episodic trends are characterised by limited groundwater level variations across multiple years until there is a wet season with sufficiently intense rainfall to induce point sources of recharge (sinkholes and typically dry creeks) to become active. Groundwater levels peak following the high rainfall wet season; this is then followed by a relatively quick groundwater level decline as the recharge-induced pressure mound dissipates into the surrounding aquifer. Following the recharge event, the groundwater level stabilises at a higher level than prior to recharge due to the overall increase in aquifer storage.

This type of groundwater level response occurs in areas of relatively thin Cretaceous sediments and where point sources of recharge (e.g. sinkholes) are abundant. These areas also occur at the northern margin of the Arid Zone climate zone (as per Short and Bond 2021), where wet season rainfall has a much greater variability and annual average rainfall is lower overall.

An example of the 'episodic recharge' groundwater level response is shown in Figure 4-16, which shows the typical groundwater level fluctuations observed near areas with a high abundance of sinkholes.

Figure 4-16. A typical episodic groundwater level response, recorded at RN028087 (Tarlee Station).

Gradual storage change trends are characterised by slow groundwater level fluctuations that occur over years to decades. The longest groundwater level records in the region, spanning approximately 20 years, have captured a prolonged period of increasing groundwater levels. This indicates that recharge in these areas is slow and diffuse or that recharge zones are far away — more typical of Arid Zone groundwater systems (as per Short and Bond 2021).

This type of groundwater level response is the most common across the Beetaloo Sub-basin and indicates that there is limited seasonal recharge and/or few point sources of recharge. This is unsurprising given that wet season rainfall in this area is much less reliable and annual rainfall totals are much less than in the areas to the north. The Cretaceous sediments are also much thicker over the Beetaloo Sub-basin, and thus act to limit recharge even further. However, the gradual increase in groundwater levels over the last 20 years indicates that there is likely to be some degree of slow diffuse recharge that has led to an increase in overall aquifer storage occurring across this area.

An example of the 'gradual storage change' groundwater level response is shown in Figure 4-17, which shows the typical groundwater level fluctuations observed in areas of thick Cretaceous sediments and in areas far from a recharge zone.

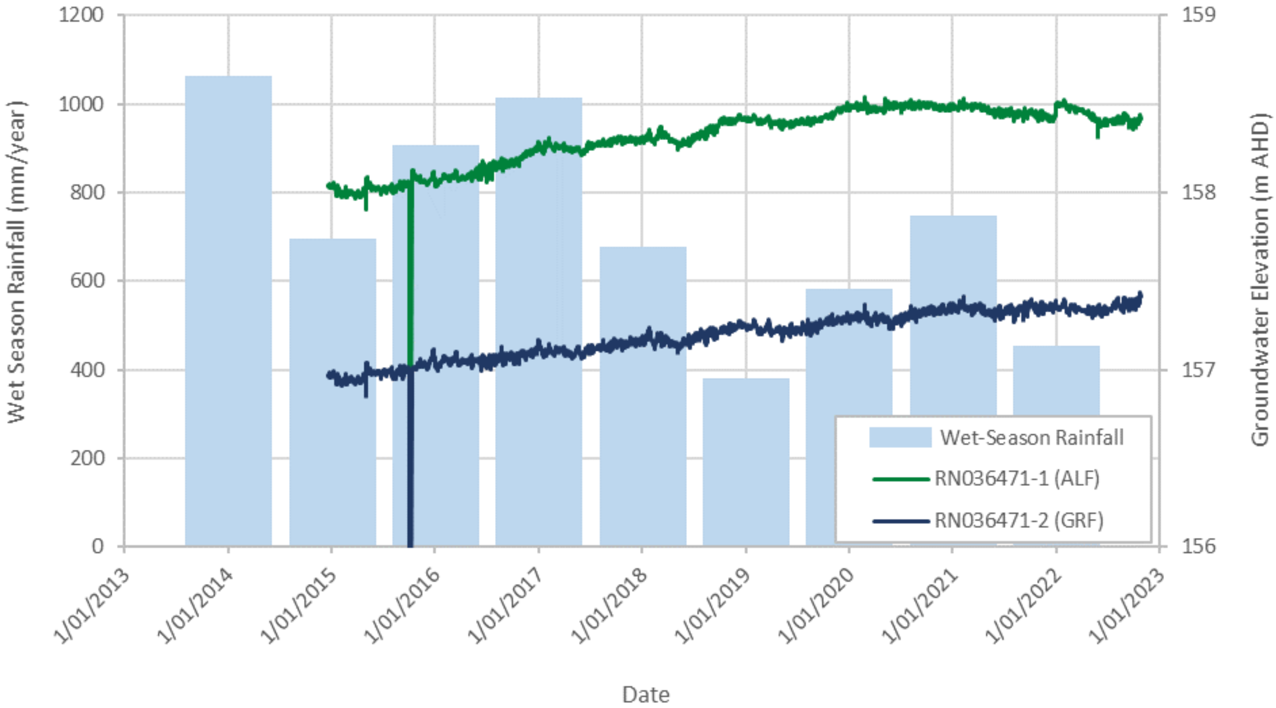

Figure 4-17. Groundwater levels recorded at RN036471 (Dunmarra) for the Gum Ridge Formation (GRF) and Anthony Lagoon Formation (ALF), illustrataig gradual storage change. The distinct reduction in water level evident in October 2015 is the pumping test undertaken at the site by DEPWS.

4.3.4. Recharge

There are four main recharge processes across the CLA:

1. **Diffuse (direct) recharge**

This is water in excess of soil moisture deficits and evapotranspiration that is added to the groundwater by vertical percolation through the unsaturated zone. This occurs episodically where Cretaceous sediments are thin (less than 30 m) and where the Lower CLA outcrops near the surface. Due to high soil moisture deficits and water-scavenging vegetation in the arid zone, diffuse recharge can be as little as 1% of precipitation (Knapton 2020; Tickell 2003).

2. **Macropore flow**

This is precipitation channelled through root casts and regolith solution tubes, with the rapidly infiltrated water having limited interaction with sediment and rocks in the unsaturated zone. This mechanism is likely widespread but is difficult to discern from diffuse recharge on a regional scale. Some of the inconsistent environmental tracer results found during the GBA and GISERA studies could be influenced by this process.

3. **Localised discrete (indirect) recharge**

This is where surface water channels into karst or pseudo-karst features such as sinkholes, dolines, ephemeral drainage lines (such as Western Creek, Newcastle Creek), lakes (such as Lake Woods and Barkly lakes) and associated floodouts. These areas are likely to be a dominant source of recharge in the southern area of the CLA, particularly in periods where surface water persists in drainage terminus features for longer durations.

4. Mountain-front recharge

This is where water infiltrates from streams originating from surrounding hilly outcrops. Mountain-front recharge occurs along the flanks of the Ashburton Ranges that generate runoff during high-intensity rainfall events and flows over the outcropping CLA.

Sinkhole features have long been thought to act as discrete recharge features across the Cambrian basin (e.g. Evans et al. 2020; Yin Foo and Matthews 2001; Karp 2002; Karp 2005). This is because they can act as a focal point for surface runoff and, once filled with surface water, recharge is much more likely to occur. In the areas where the Lower CLA (carbonate-dominant) outcrops or is near the surface, sinkholes are formed through traditional karstic mechanisms (dissolution of the rock due to continuous infiltration of slightly acidic rainwater).

By contrast, in areas where there is thick Cretaceous cover — such as over the Beetaloo Sub-basin area — sinkholes can still be abundant but are unlikely to have formed due to dissolution of the underlying carbonate rock because of its depth. Such features are termed pseudo-karst, para-karst or laterite karst (e.g. Twidale 1987; Alkemade 1991; Grimes and Spate 2008) and are related more to physical erosion of sediments and the soil profile than to carbonate rock dissolution.

As part of the GBA Stage 3 studies, the existing NTG sinkhole dataset was used in combination with satellite imagery to infer the location of waterholes and sinkholes over the Beetaloo Basin (GBA Factsheet 4 and associated dataset). As Figure 4-18 illustrates, sinkholes are common throughout the area and the GBA and NTG mapping is only likely to have identified a subset of the total occurrence of these features in the region. Given their likely role in recharge and maintaining open water in the region, any proponents of large development projects in the area should undertake a thorough assessment of the location of sinkholes and depression features near their planned activities. This will allow for a more thorough assessment of potential impacts resulting from changes to surface water flow and/or potential point sources of contamination to the underlying aquifer.

Recharge zones were also investigated as part of the GBA Stage 3 assessment for the Beetaloo Sub-basin, which identified the zones presented in Figure 4-19 (GBA Factsheet 5). The GBA Stage 3 work primarily focused on how the Carpentaria Basin cover and point sources (sinkholes and waterholes) may affect the spatial distribution of recharge. In "Domain 1" (approximately north of Daly Waters), the Carpentaria Basin is thin (less than 40 m) and includes a relatively high proportion of sandstone. Numerous sinkholes and waterholes are present and depth to the regional water table is less than 60 m. In addition to the GBA assessment of potential recharge area directly overlying the Beetaloo Sub-basin, potential recharge areas have also been mapped across the wider CLA. This was undertaken during the SREBA and was based on recent gamma log and lithology correlations (DEPWS 2022e). This mapping is based on the assumption that recharge potential is higher where there are thinner sequences of Cretaceous sediments and/or where the Anthony Lagoon Formation (or equivalents) are not present. Thus, recharge potential is higher where the Gum Ridge Formation (or equivalents) outcrops or is covered by less than 30 m of Cretaceous sediments. These areas are shown in Figure 4-20.

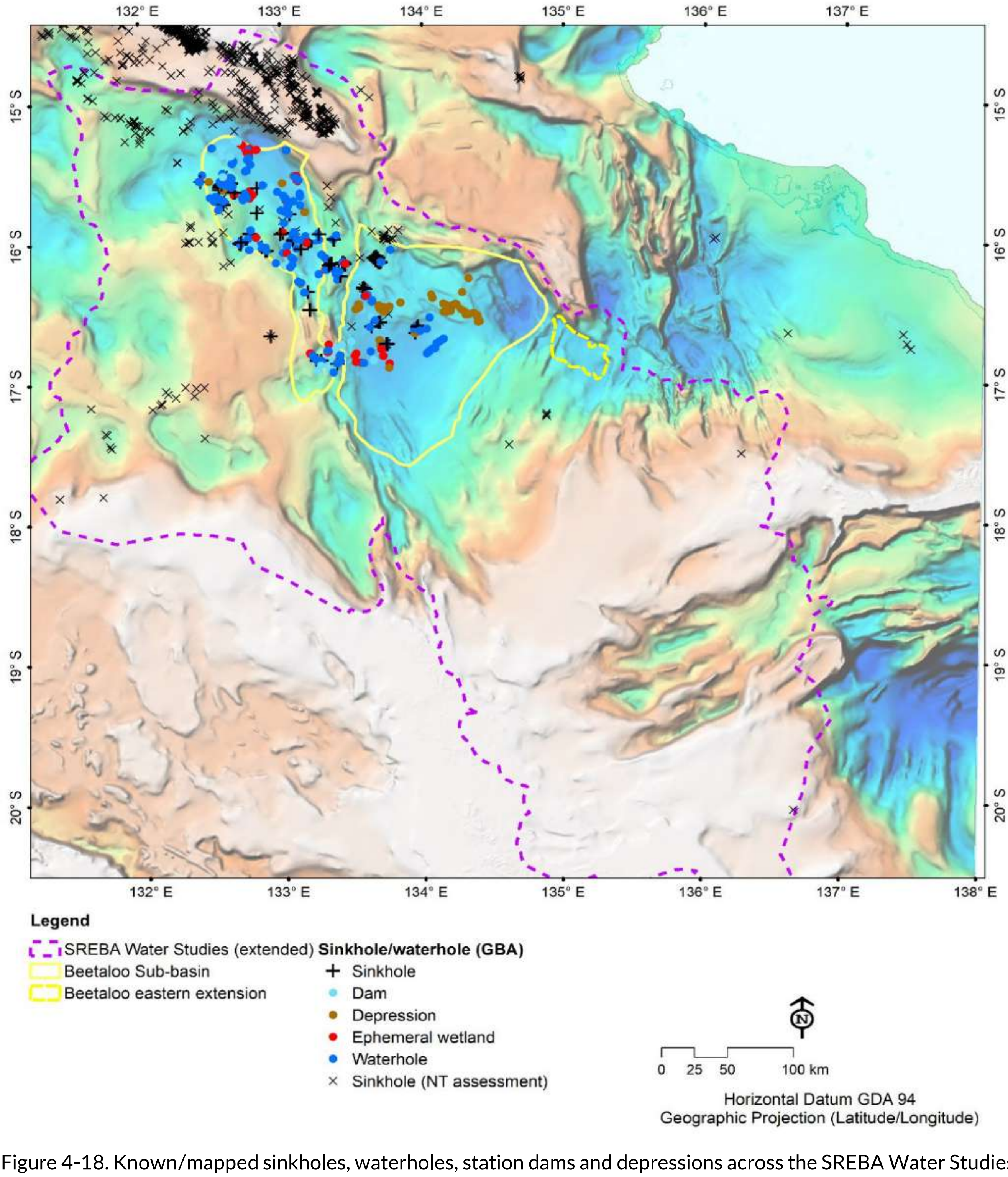

Figure 4-18. Known/mapped sinkholes, waterholes, station dams and depressions across the SREBA Water Studies area.

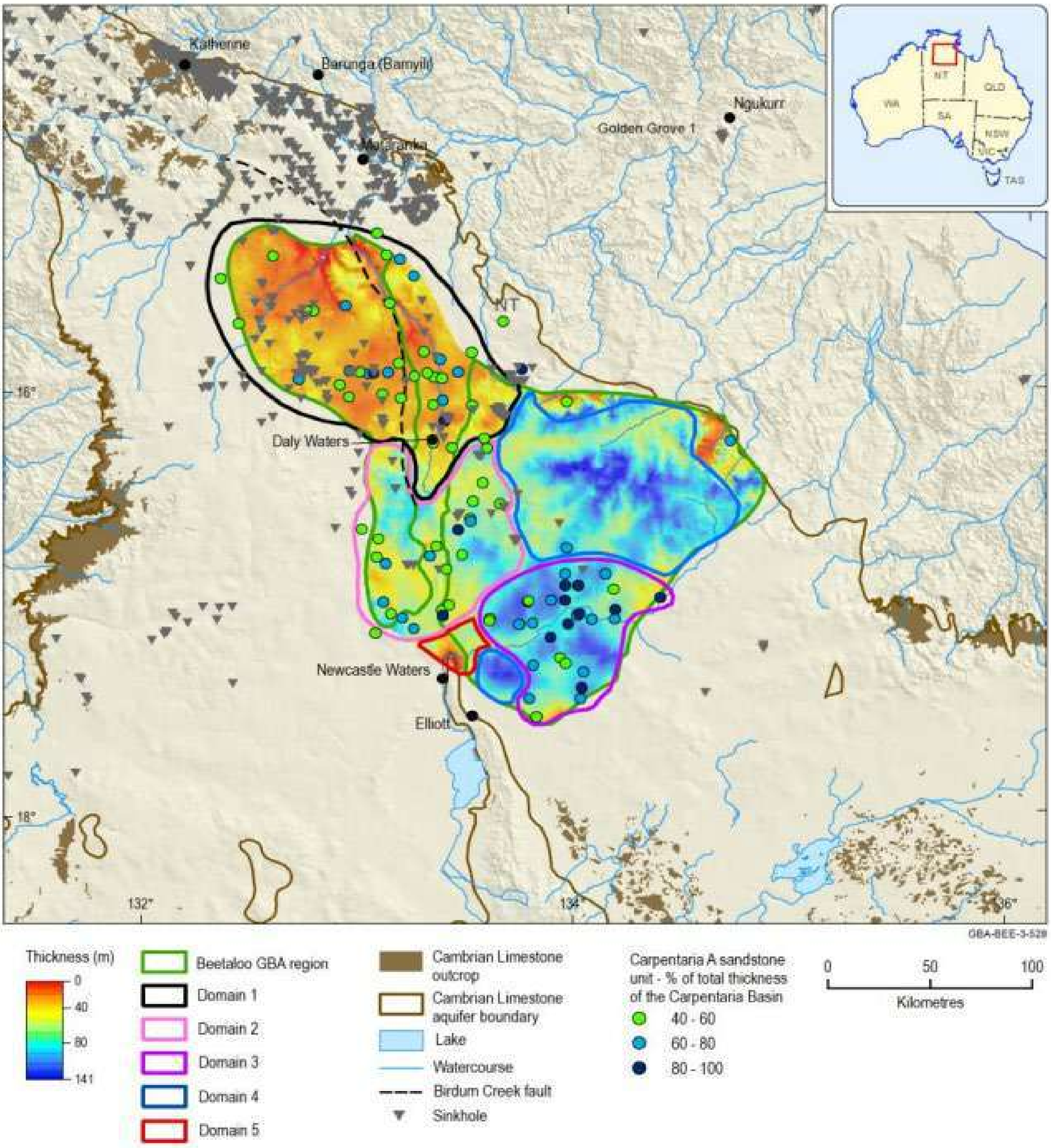

Figure 4-19. Inferred recharge domains across the Beetaloo Sub-basin (from GBA Factsheet 5: https://www.bioregionalassessments.gov.au/assessments/geological-and-bioregional-assessment-program/fact-sheets-stakeholder-engagement/fact-sheets)

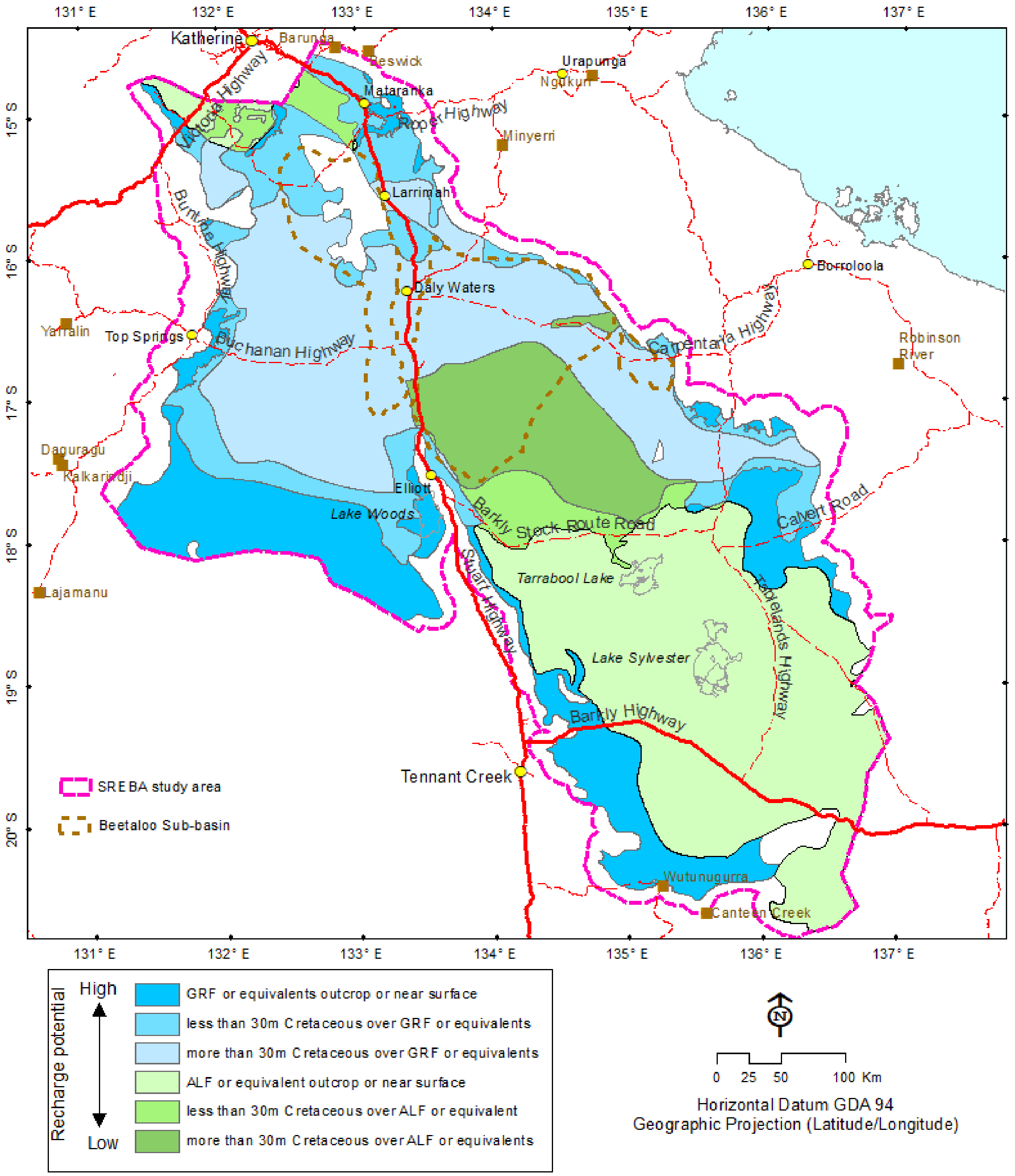

Figure 4-20. Recharge potential for the CLA based on Cretaceous sediments thickness and presence of Anthony Lagoon Formation (or equivalents).

4.3.4.1. Estimating annual recharge

Estimates of recharge for the region are obtained from four main datasets that are derived by methods that are relatively independent. The datasets include the following:

- Bureau of Meteorology's Australia-wide landscape water model (AWRA-L; Frost et al. 2013)
- CSIRO's Australia-wide recharge model (Crosbie *et al.* 2009; Crosbie *et al.* 2013)
- Chloride mass balance methods (Crosbie and Rachakonda 2021)
- Daly Roper (DR2 2020) model (Knapton 2020).

The first three methods are useful for determining recharge zones over the Beetaloo region (i.e. to predict where relatively high or low recharge rates occur spatially) and provide 'potential' estimates of recharge. However, they suffer from significant uncertainty relating to the assumptions on which they are dependent (e.g. broad-scale landscape mapping and climate fluxes, and assumptions relating to chloride dynamics and recharge mechanisms), which may or may not be applicable to this specific resource. They also typically only consider unsaturated zone processes rather than observations of actual aquifer storage change observed by groundwater levels and discharge rates.

The Daly Roper model (DR2 2020), which uses data and information collected through the SREBA Water Studies, is considered to be the most accurate in regard to the quantitative estimates of recharge rates across the Beetaloo region. This is because the model is constructed specifically for the region and is supported by the most current conceptualisation of the entire connected water resource, as well as being calibrated to observed groundwater levels and river discharges. The model is less powerful for predicting recharge locations and requires a prior understanding of the differences in recharge areas to be built into it (Knapton 2020); however, these areas are refined based on how well the model performs at replicating groundwater pressures and discharge rates.

The quantitative estimates of recharge from the DR2 model for the period 1972-2021, as they relate to the in-development WAP areas within the CLA, are presented in Table 4-2. The median values give a more useful indication of regular (i.e. occur at least 50% of the time) recharge volumes than the average, because the average, especially for the Georgina Basin, is highly skewed by a small number of very large recharge events.

The median modelled recharge rates show that there is a more regular (i.e. seasonal) recharge that occurs to the north, where wet season rains are more reliable. By contrast, the southern areas that overlie the Beetaloo Sub-basin receive much lower amounts of recharge, but they can periodically receive very large volumes, most likely when there is enough rain to cause widespread inundation of swamps, waterholes and the large inland lakes.

Notably, of the four methods, the DR2 provided the most conservative estimate of recharge.

Table 4-2. Annual wet season recharge estimates for the Beetaloo Sub-basin WAP sub-areas from the DR2 2020 model (model run to 1 November 2021).

Water allocation planning management area	Wet season average (ML/year)	Wet season median (ML/year)
Mataranka TLA	319,000	211,000
Flora TLA	261,000	119,000
Wiso Basin	48,000	4,000
Georgina Basin	608,000	600

4.3.5. Discharge

Natural groundwater discharge from the CLA to the surface is considered to be via three dominant mechanisms.

- Diffusely through riverbeds where the water table is intercepted.
- Discrete springs where geological features allow for discharge from artesian portions of the aquifer (Figure 4-21 – note that not all springs are sourced from the CLA).
- Discharge via diffuse or discrete areas of evapotranspiration (ET) where vegetation utilises groundwater or water tables are shallow.

4.3.5.1. Flora River and Roper River discharge areas

The CLA overlying the Beetaloo Sub-basin has two main discharge areas at the Flora River and Roper River, near the communities of Djarrung and Mataranka, respectively. At these locations, the Lower CLA outcrops to the surface (or subcrops close to the surface) and groundwater discharges by all three mechanisms described above. The greatest overall discharge fluxes are due to diffuse discharge along riverbeds and ET.

Groundwater discharge to the Roper River near the township of Mataranka occurs as a result of the CLA water table being intercepted by the ground surface and riverbed. Groundwater discharge occurs along the bed of the river and tributaries (e.g. Elsey Creek, Roper River) and via discrete springs (e.g. Bitter Springs, Rainbow Spring and Fig Tree Spring). In the area of Elsey National Park where the underlying basement rock subcrops at shallow depth, groundwater levels rise to above the natural ground surface. This results in shallow diffuse discharge, wetlands and, in places, water logging (Yin Foo and Dilshad 2021). These areas of shallow water table occur over a much larger area near the Roper River compared to at Flora River, and likely result in a much greater ET flux.

The recent environmental tracer studies undertaken by CSIRO as part of the GBA and GISERA programs (Deslandes *et al.* 2019; Lamontagne *et al.* 2021) have supported the long-held assumption that groundwater discharge at the Roper River discharge area is overwhelmingly derived from the CLA. However, unusually high concentrations of helium in discharging water suggests that there may also be a minor contribution from a deeper (older) groundwater source. This is not completely surprising because there are areas along the Roper River Flowpath where interaction between the CLA and deeper formations is possible (e.g. Daly Waters High). The Roper River discharge area also occurs where the basement rock is elevated and the CLA and basalt thins out, which would provide a greater opportunity for deeper sources of groundwater to interact with the surface.

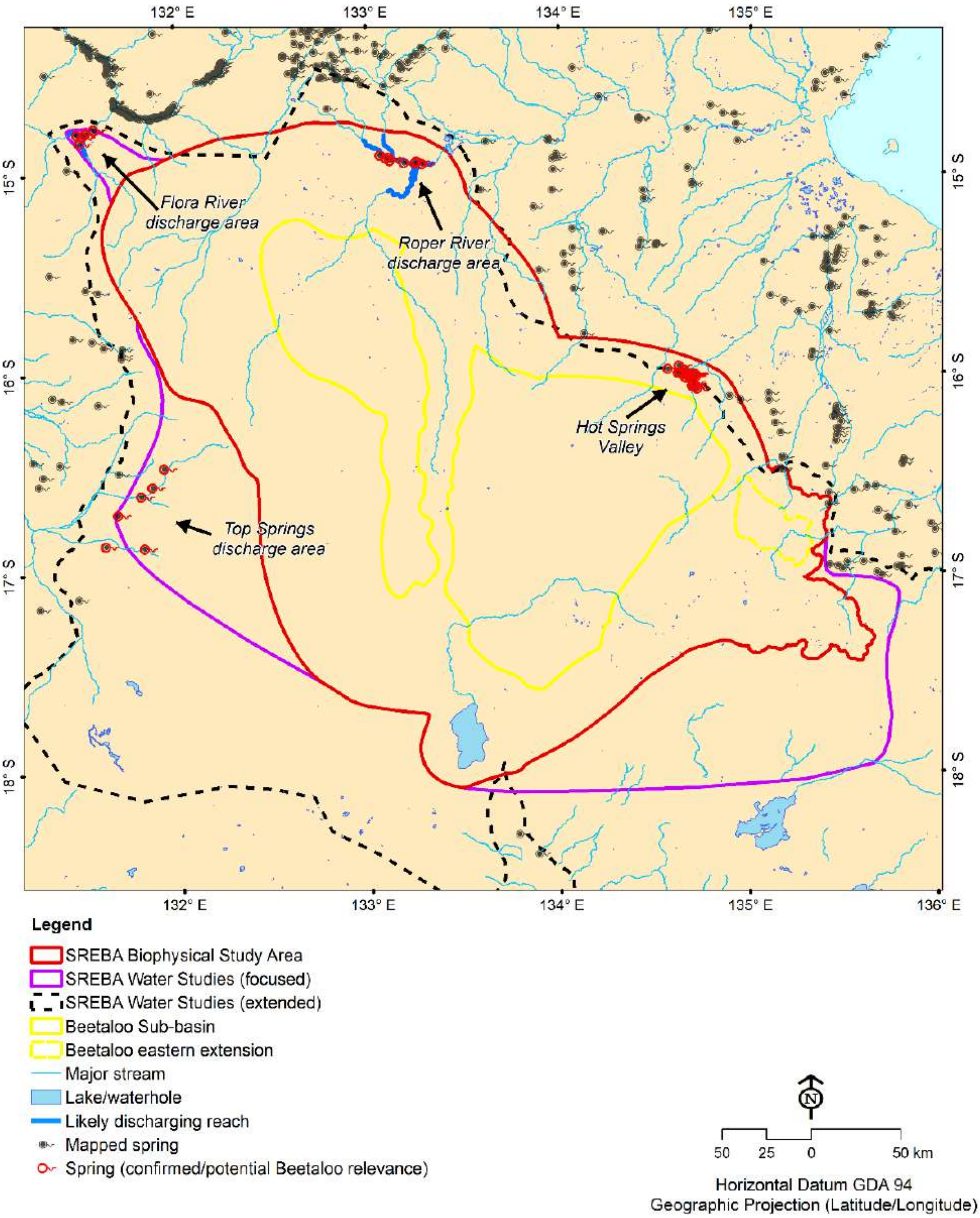

Figure 4-21. Location of groundwater springs that have a confirmed or potential relevance to activities related to the Beetaloo Sub-basin.

Another finding of the CSIRO environmental tracer work was that multiple lines of evidence (e.g. relatively 'young' discharge water and decreasing apparent groundwater ages along the flowpath) indicate that groundwater discharge at the Roper River is likely to be sourced from groundwater originating relatively close to the river. This is consistent with the understanding of recharge to the system and is also supported by groundwater modelling, which indicates that groundwater recharge within approximately 100 km of the Roper River is sufficient to support the majority of the observed discharge fluxes. Thus, groundwater originating from deeper formations or from areas of the CLA flowpath further to the south (i.e. overlying the Beetaloo Sub-basin) are likely only a very minor portion of the total discharge at the Roper River.

Mechanisms at the Flora River discharge area are mostly the same as at the Roper River. However, the Lower CLA is much thicker beneath the Flora River discharge area, and the basement formation (basalt) subcrops at a greater depth than at the Roper River discharge area. Thus, the Flora River discharge area has likely formed primarily due to progressive erosion by the main Flora River water course, to a point where the water table is incised. Groundwater discharge at the Flora River is mostly contained to the river channel, along the reach of river where the unconfined Lower CLA (Tindall Limestone) outcrops, rather than being spread out as a series of springs, wetlands and waterlogged ground like at the Roper River. The discharge along the Flora River can be categorised as a combination of diffuse and spring discharge, depending on the size and abundance of karst conduits that allow groundwater flow into the river.

As part of the SREBA Water Studies, DEPWS commissioned Charles Darwin University (CDU) to undertake an environmental tracer study of the Flora River and nearby CLA groundwater flow system (Irvine and Duvert 2022). Due to delays in land access (i.e. appropriate arrangements for access to Aboriginal and joint-managed land had not yet been negotiated by the time of writing this report), the reported study was limited to sampling groundwater from bores along the final portion of the CLA's Flora River Flowpath. However, this assessment was still able to provide useful information that expanded on the only other (limited) groundwater investigation in the area (Karp 1997) and supported the assumptions regarding the source of groundwater discharge.

Irvine and Duvert (2022) found that the majority of water discharging to the Flora River is recharged locally but that there were indications of a minor portion of groundwater with an 'older' apparent age. The authors suggested that the (potential) older groundwater source was likely the result of throughflow from up gradient areas of the Flora River Flowpath, given the depth of the basement formation, lack of significant faulting in the area and the high salinity typically associated with the deeper formation waters.

Estimated total groundwater discharge at the Flora River and Roper River discharge areas based on the gauged dry season flows (i.e. not affected by rainfall and surface inflows) for both rivers is shown in Table 4-3.

Table 4-3. River gauging and estimated groundwater discharge rates at Flora River and Roper River.

River	Gauging station	Typical dry season flow (m^3/s)	Estimated annual groundwater discharge (ML)	Time period
Flora River	G8140205	3.5–5.5	110,000–174,000	2009–2022
Roper River	G9030013	2–8	63,000–252,000	1953–2022

4.3.5.2. Other identified springs and discharge areas

In addition to the areas of CLA groundwater discharge described above, there are two other significant areas of groundwater discharge that have previously been identified through the GBA investigations as potentially interacting with the Beetaloo Sub-basin (Figure 4-21).

Hot Springs Valley

Hot Springs Valley is located to the north of the eastern Beetaloo Sub-basin on Tanumbirini Station (Figure 4-22). It is a unique groundwater discharge zone because it has the highest recorded water temperature (65 °C) of any spring in the NT (Zaar 2009; Zaar and Tickell 2022). This series of springs was identified during the GBA and GISERA programs (Evans *et al.* 2020; Frery *et al.* 2022) as an area of interest for the Beetaloo Sub-basin because the outcropping formations in the area and the likely groundwater source for these springs are the deep Mesoproterozoic formations that are part of the gas resource sequence.

Based on the recorded temperatures at the vent of Beauty Creek hot springs and the recorded Beetaloo Sub-basin formation temperatures presented in Evans *et al.* (2020), the groundwater source could be from at least 1000-1100 m bGL. Therefore, the groundwater source for the Beauty Creek hot springs is unlikely to be from the nearby outcropping Abner Sandstone but, rather, a deeper formation underlying the area. If the Beauty Creek hot springs are sourced from a relatively vertical conduit or fault, the cross-section on the 1:250,000 geological map (Paine 1963) indicates that the source formation could be the Crawford Formation, the Mainoru Formation or the Limmen Sandstone. However, without further geophysical investigation (e.g. seismic), the source of these springs remains poorly understood.

By contrast, the Lagoon Creek Gorge spring has a lower temperature (42 °C), but it is still above average ambient surface temperatures, which indicates a source that could be 200-500 m bGL. Based on the mapping of surface geology and interpreted cross-section, the Lagoon Creek springs are likely sourced from the Bessie Creek Sandstone.

During a September 2022 site visit, samples for environmental tracers (helium, carbon-14, chlorine-36, tritium, strontium isotopes and stable water isotopes) were collected from the main Beauty Creek hot spring vent to help identify potential source aquifers and discharge mechanisms. At the time of reporting, results of these tracers had not been provided by CSIRO to inform the development of this section. However, a member of the SREBA greenhouse gas baseline studies team was present during the field visit and recorded detectable concentrations of methane and ethane in the air surrounding the Beauty Creek hot spring vent when bubbles were noted to be emanating from the spring vent (Ong *et al.* 2022). Time series data for the dual hydrocarbons indicated that their concentrations were correlated, which is more indicative of a thermogenic source but does not rule out a microbial source. Ong *et al.* (2022) recommended further investigations of the gas source given the likely implications of their findings (i.e. potential interaction of the deep regional system with surface hydrology and ecosystems). Until the groundwater source and discharge mechanism at Hot Springs Valley are better conceptualised, it is recommended that a monitoring program be implemented. This program would ensure ongoing collection of baseline water quality and quantity data, in addition to relevant ecological and greenhouse gas data.

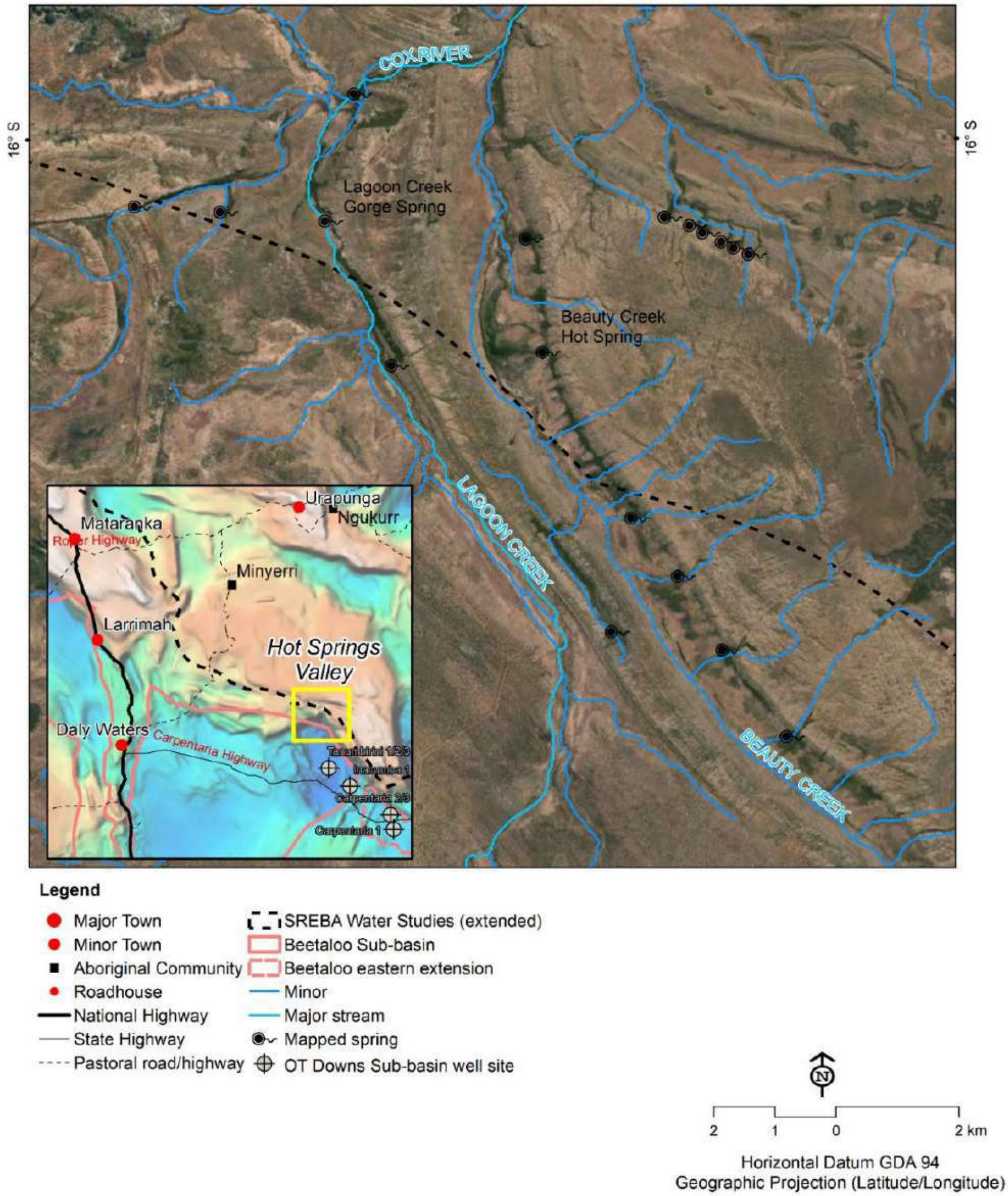

Figure 4-22. Location of mapped springs and drainage features at Hot Springs Valley.

Top Springs

Springs and groundwater discharge areas are also known to occur around the locality of Top Springs (Karp 2004) to the west of the Beetaloo Sub-basin at the intersection of Buchanan Highway and Buntine Highway (Figure 4-23). The springs mostly emanate where the contact between the Lower CLA (Montejinni Limestone) and underlying basalt (Antrim Plateau Volcanics) outcrops, and they typically occur within drainage lines of the headwaters of the Victoria River (i.e. Armstrong River, Coolibah Creek and Townshend Creek).

The source of these springs is not well understood but they appear to be quite seasonal. During a field visit to the area in August 2021, standing water was observed in pools at Illawarra Spring and Lonely Spring but the water was not flowing down the watercourses of which they are a part. Also during the 2021 trip, the manager of Montejinni East Station noted that Chidbung Spring (mapped as having a Cretaceous groundwater source) had been dry for years and the other springs had gone dry recently due to a series of consecutive low wet season rainfall totals in the area.

Stream gauging of the Armstrong River near the Buntine Highway indicates that this watercourse runs dry soon after the wet season ends and is unlikely to be supported by spring discharge or diffuse groundwater discharge upstream of the gauge site. These observations do not align with what would be expected if the discharge was from a large regional-scale groundwater source such as the Flora River Flowpath of the CLA, which has been observed to have increasing water levels/storage in most areas and supports perennial springs (along the Flora River).

Even if the majority of the groundwater discharge occurring at springs around Top Springs is sourced from CLA formations, this groundwater is more likely to be sourced from a localised flow system that captures recharge within the nearby catchment area of Top Springs (i.e. within 20-30 km) or from shallow perched aquifers that are separate from the regional CLA. Groundwater elevations mapped across the Wiso Basin CLA (Figure 4-11) indicate that the groundwater system that flows over the Beetaloo Sub-basin does not have the potential to flow westward to Top Springs; rather, groundwater flow is directed eastward from Top Springs towards the Beetaloo Sub-basin. Thus, the springs in the area around Top Springs are unlikely to interact with the Beetaloo Sub-basin or to be impacted by gas industry activities.

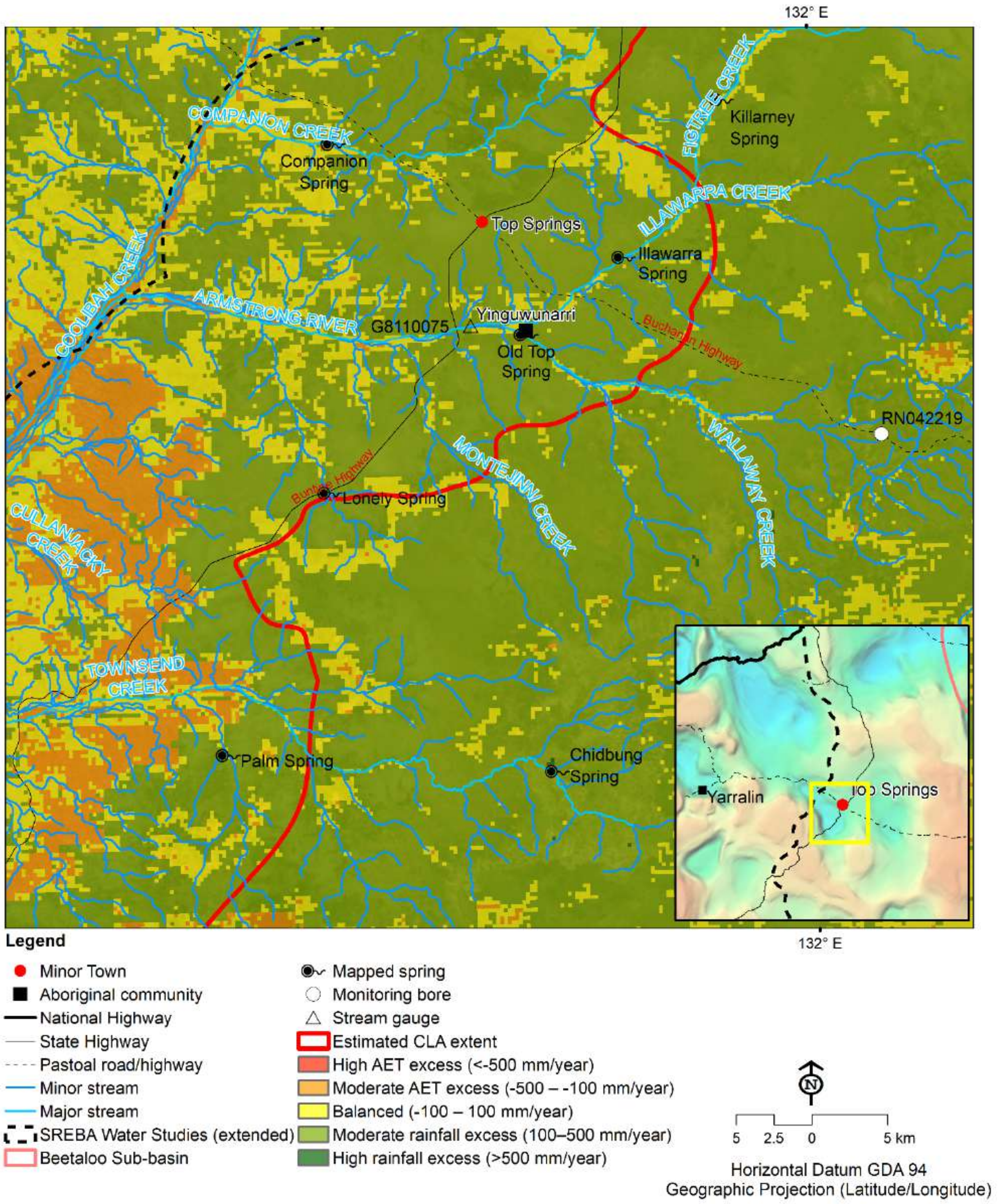

Figure 4-23. Location of mapped springs and drainage features around Top Springs.

4.3.6. Evapotranspiration

Evapotranspiration (ET) represents another major natural flux of water from the CLA. However, the relatively deep groundwater levels across the SREBA Water Studies area (Figure 4-12) mean that much of the ET across the region likely represents fluxes derived from recent rainfall, rather than being from the regional groundwater system. Groundwater-derived ET is limited to areas to the north where the water table is shallow enough for use by terrestrial vegetation (typically < 15 m bGL), or for direct evaporation where groundwater is above the 'extinction' depth (typically < 1 m), or from open water.

For the CLA, the two areas where ET is likely to occur are towards the north around the Flora River, and in the Roper River discharge areas. In these areas, ET occurs due to terrestrial vegetation water use, as well as direct evaporation from shallow water tables and from open surface water bodies. As part of the SREBA Water Studies, DEPWS commissioned investigators at CDU (Gautam *et al.* 2022) to undertake a desk-based assessment of actual ET (AET) fluxes from the CLA discharge areas based on estimates produced by CSIRO's remote sensing-derived CMRSET algorithm (CSIRO MODIS Re-scaled ET; McVicar *et al.* 2022). Here the term AET is used to distinguish from potential ET (PET), which is commonly calculated based on meteorological variables but only estimates how much ET *could* occur given an unlimited supply of water and not what *actually* occurs based on site-specific water supply constraints.

Gautam *et al.* (2022) found that AET at the Flora River and Roper River discharge areas was strongly seasonal and directly correlated with wet season rainfall. This indicates that the majority of the annual AET flux is derived from recent rainfall rather than from the CLA. However, during the middle and end of the dry season, there were still appreciable levels of AET around the two discharge areas when compared to nearby areas where AET from groundwater sources is unlikely (i.e. with different vegetation types and deeper groundwater levels). The areas of elevated AET provide insight into where vegetation is using groundwater and where there may be direct ET from waterlogged ground. This mapping indicates that AET is a greater component of discharge in the areas around Mataranka, where there are large regions of vegetated land and swampy wetland areas associated with shallow groundwater. Readers can view composite CMRSET images of Mataranka and Flora River for June-2021 on the Terrestrial Ecosystem Research Network (TERN) web portal.

The CMRSET AET estimates are also useful for assessing potential groundwater recharge and discharge zones. This is achieved by calculating the rainfall excess (rainfall minus AET) for a given location (Crosbie and Rachakonda 2021; Gautam *et al.* 2022). In areas where rainfall is in excess of AET, there is a potential for recharge or higher rates of runoff. By contrast, in areas where AET is in excess of rainfall, there is potentially a source of discharging groundwater or it could be a focus area for runoff (i.e. lakes or floodout areas). This principle was used as part of the chloride mass balance modelling by Crosbie and Rachakonda (2021) to help constrain where recharge was occurring.

For the majority of the SREBA Water Studies area, there is either a slight rainfall excess (100-500 mm/year) or an approximate balance between rainfall and AET. This indicates that large areas either have the potential to recharge the underlying CLA or to provide runoff to ephemeral surface water systems. The excess rainfall dataset also identifies the groundwater discharge zones to the north as areas where there is likely a non-rainfall source of water (i.e. groundwater or runoff), and it also clearly shows that the regional lakes are significant focus points for the region's surface water, given that they do not receive any groundwater.

An unexpected feature of the dataset is the area of moderate AET excess in the area around Top Springs. This area is beyond the western extent of the CLA and where the underlying basalt is outcropping, potentially indicating a significant groundwater discharge area for the basalt to the Victoria River catchment or a high rate of groundwater use by terrestrial vegetation.

The total AET from each of the main discharge areas at Flora River and Roper River has been estimated based on the CMRSET dataset (Table 4-4). The median AET rate estimated for November is assumed to be approximately representative of groundwater AET in the wet season (a period when estimated AET rates are dominated by rainfall and surface water flows) because November is still warm but is prior to the onset of significant rainfall and runoff.

The estimated AET fluxes highlight the difference in discharge mechanisms for the two CLA discharge areas. At Flora River, groundwater discharge is primarily due to discharge to the water course (i.e. >75%; see above) with only a minor portion discharging as ET from the surrounding landscape or from open water within the river. By contrast, ET appears to account for more than double (i.e. more than two thirds of the total discharge flux) the total flux of groundwater from the Roper River area, where groundwater discharges by AET from a much broader area of shallow groundwater and vegetation.

Note that the CMRSET estimates also include AET fluxes from open water after groundwater has discharged to the surface. Thus, the estimates include a portion of groundwater discharge already accounted for by the estimates of river discharge provided in the previous section.

Table 4-4. CMRSET estimate of AET for the CLA groundwater discharge areas at the Flora River and Roper River.

River	Median July AET (ML/month)	Median November AET (ML/month)	Estimated minimum groundwater AET (ML/year)	Time period
Flora River	2,800	4,000	43,300	2000-2022
Roper River	20,100	30,300	324,200	2000-2022

4.3.6.1. Groundwater extraction

As of December 2022, total maximum groundwater extraction licence (GWEL) entitlements from the CLA systems that overlie the Beetaloo Sub-basin are 42,900 ML/year. Licensed uses for the groundwater are a combination of agriculture (40,889 ML/year), petroleum activity (947.5 ML/year), town water supply (754.5 ML/year) and industry (309 ML/year). Note that for these totals, current entitlements across the entire Flora River and Roper River CLA flow paths are used, and this includes the entire area of the draft Georgina and Wiso WAP area (DEPWS 2022a), as well as areas to the north (Flora and Mataranka TLA) where there are larger entitlements for agriculture and industry.

Groundwater extraction for stock and domestic supplies is not licensed or metered in the region, which makes estimating this aspect of the water balance uncertain. However, it is known that groundwater is extracted for stock and domestic supply at all pastoral stations in the region (e.g. homestead supplies and stock watering), at most roadhouses and motels (potable supply and greenspace irrigation), by residents of the minor townships (e.g. non-potable uses), and potentially at Aboriginal camps and homelands. The estimated total stock and domestic groundwater extraction for the Georgina Basin and Wiso Basin is approximately 14,000 and 5,000 ML/year, respectively (DEPWS 2022a).

4.3.7. Groundwater quality

As part of the SREBA water studies, a groundwater quality dataset has been compiled from historic data as well as from data collected as part of recent Commonwealth Government programs (GBA, GISERA and EFTF), petroleum industry monitoring, and ongoing town water supply monitoring by Power and Water Corporation (PWC). To help ensure that parameters within this dataset are as consistent and reliable as possible, DEPWS commissioned the National Centre for Groundwater Research and Training (NCGRT) to undertake a review of the dataset and provide advice for interpreting its content as part of the SREBA (Shand *et al.* 2022).

The NCGRT review found that although the dataset had some significant limitations for detailed hydrogeochemical analysis due to the *ad hoc* nature and limited analytical suite of early sampling (prior to 2015), it is useful for providing a broad-scale overview of water quality trends across the primary HSU of concern (the CLA). The input from the NCGRT was also able to be used to improve the quality of the raw dataset. This provided improved confidence in the water quality data that underpin some of the conceptualisation already presented in this report, as well as a better understanding of regional processes affecting the variability in naturally occurring water quality parameters.

Groundwater data collected prior to 2015 rarely included parameters such as dissolved oxygen, metals, nutrients or petroleum hydrocarbons (including gases). However, petroleum exploration companies began measuring baseline data for these parameters prior to the Scientific Inquiry.

Specialised water quality parameters that are more specific to potential petroleum industry impacts now form the basis of the groundwater monitoring required for the industry as part of the Code of Practice (DENR & DPIR 2019), specifically the *Preliminary Guideline: Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-basin*. The water quality parameters in the Code of Practice have since been included in the sampling programs for the petroleum industry, GBA, GISERA, EFTF and the SREBA water studies. The latter program has included sampling of PWC's township borefields for an expanded analytical suite (as per the Code of Practice). The NCGRT also recommended an update of the Preliminary Guideline to improve water quality data capture.

The SREBA water study groundwater quality dataset is extensive (Figure 4-24 and Figure 4-25) and continues to grow as new data are provided by ongoing NTG and PWC monitoring programs, as well as those from petroleum exploration companies. These data provided insight into the CLA groundwater flow system, as well as establishing the baseline concentrations of key parameters for ongoing monitoring of the petroleum industry.

The SREBA water study confirmed that petroleum companies should continue to:

- conduct water quality sampling at sites prior to exploration drilling, as per current procedures but with recommended updates to Preliminary Guideline
- monitor water quality in proximity to exploration (or in future, production) wells so issues with water quality are detected quickly, as per current procedure.

The spatial variability in many general water quality parameters and the slight differences in temporal trends and variability found in some of the longest water quality time series suggests that the application of broad "one-size-fits-all" water quality triggers for the region is not advisable. Instead, site-specific triggers should be developed with an appreciation of the regional scale trends (i.e. typical ranges expected for an area and/or HSU) but based primarily on targeted sampling around a given project (i.e. well-pad impact and control monitoring bore arrays, as well as nearby third-party bores). The temporal variability of a given parameters should also not be assumed without sufficient supporting time series data.

Dissolved methane concentrations are very low in groundwater across the Beetaloo region and are typically below standard limits of reporting (e.g. <10 µg/L). However, dissolved methane concentrations of 10-500 µg/L are not uncommon and have been observed on several occasions during the GISERA, industry and SREBA water study monitoring programs. Methane stable carbon isotope ratios measured during the GISERA program (Wilkes *et al.* 2019) were found to be indicative of sub-surface microbial activity rather than due to upward leakage of the deeper thermogenic sources of gas. To date, dissolved ethane concentrations have not been observed at levels above standard laboratory limits of reporting (e.g. <10 µg/L) for any groundwater samples collected in the region.

Volatile petroleum hydrocarbons are very low and mostly below detection in groundwater samples collected across the CLA and Beetaloo Sub-basin. Given that there is no known contaminated groundwater in the SREBA water studies area, volatile petroleum hydrocarbons should be assumed to naturally be below standard reporting limits (e.g. < 1 µg/L). As such, if these types of compounds are detected during sampling programs in the area, it should immediately trigger the need for follow-up assessment.

Additional information on the human health implications of the existing water quality in the area are presented in the SREBA Environmental Health (Water Quality) Baseline Report.

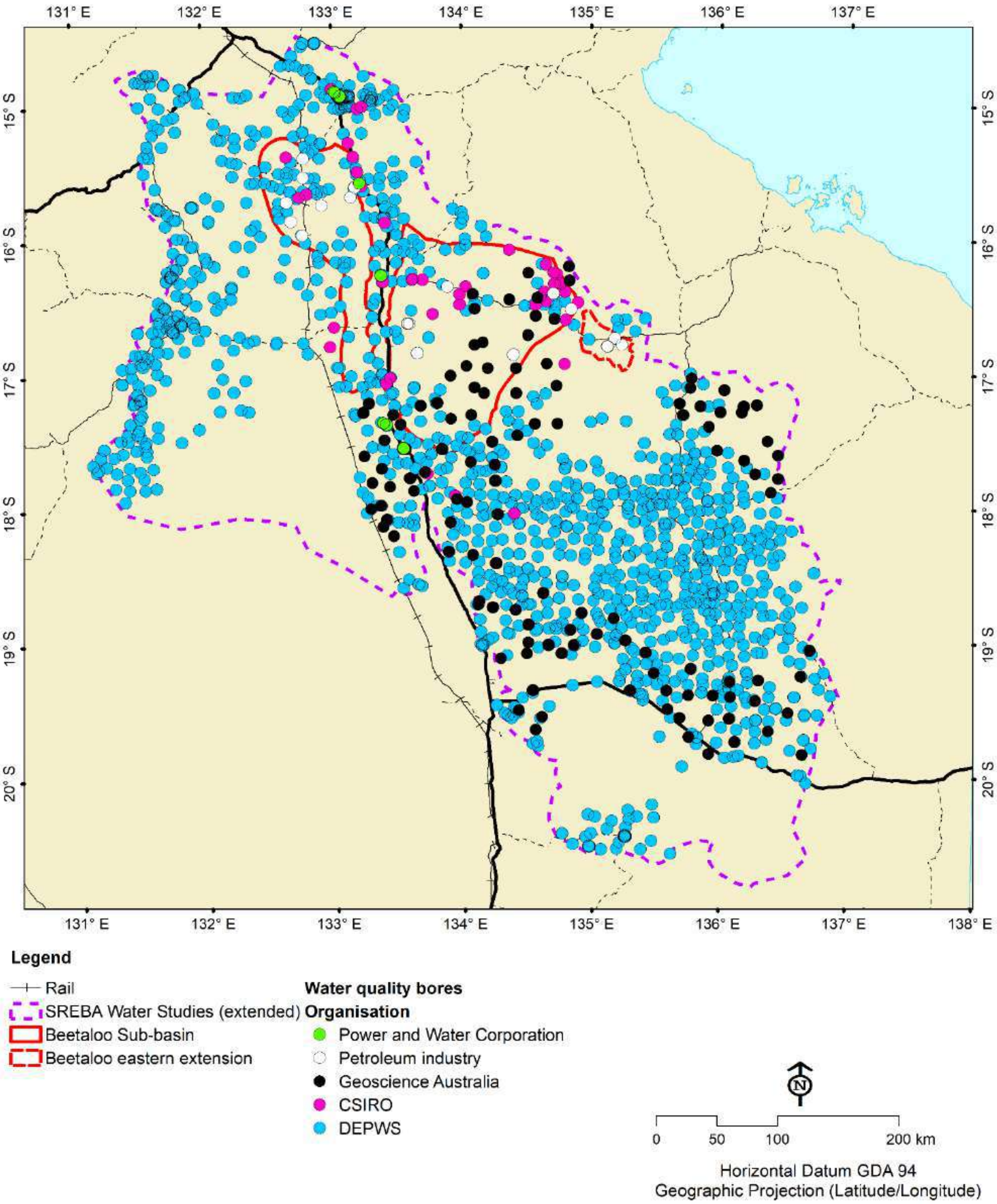

Figure 4-24. Location of bores with water quality data and source organisation.

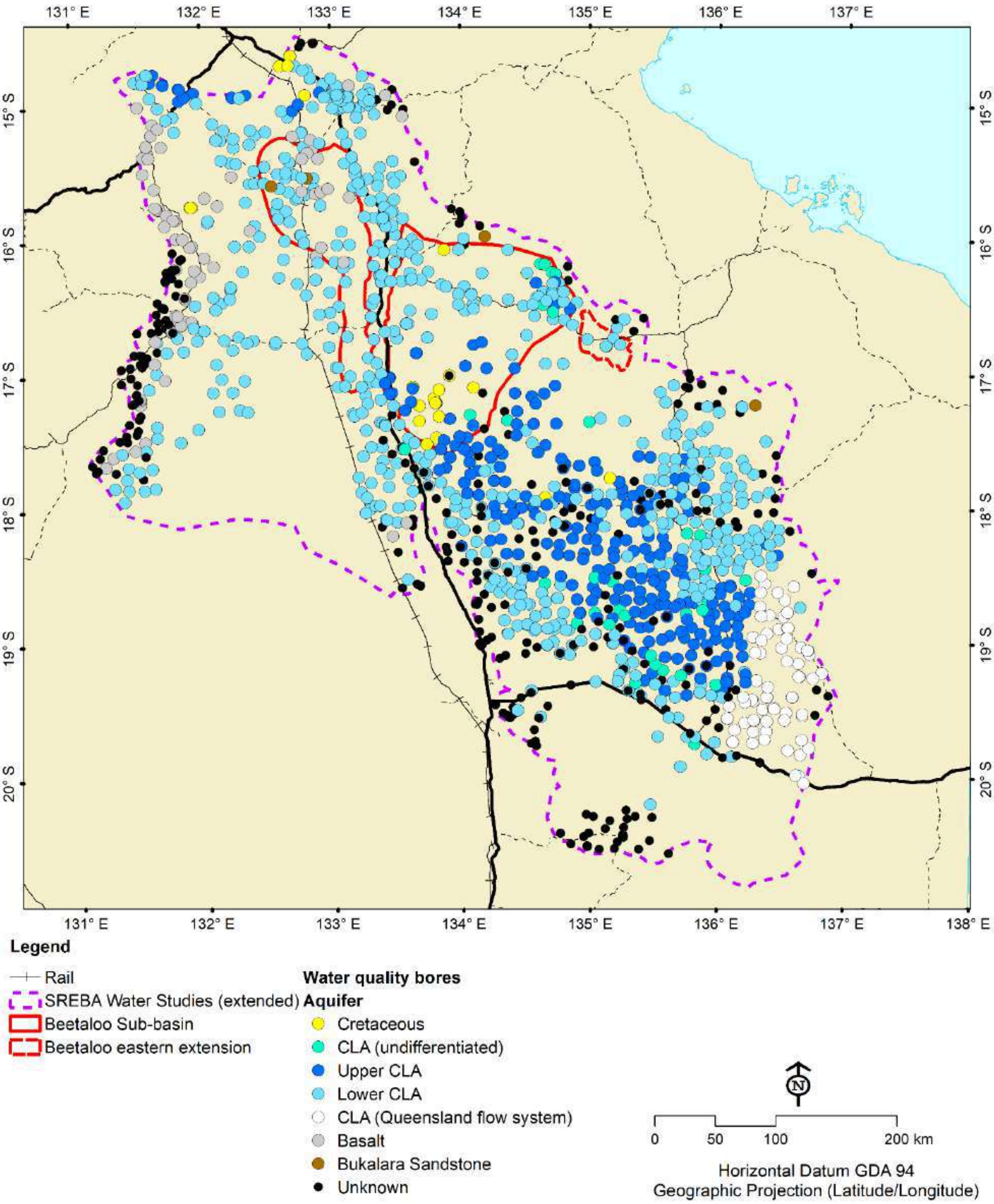

Figure 4-25. Aquifers targeted by water quality bores.

4.4. Surface water

For the SREBA water studies, assessment of surface water for the Beetaloo study area was undertaken at a mostly desktop level since potential impacts to surface water systems in the region (which are highly episodic and ephemeral) will primarily be dependent on the location of project-specific infrastructure (e.g. roads, pipelines, storage ponds and cleared areas), and these are not yet known.

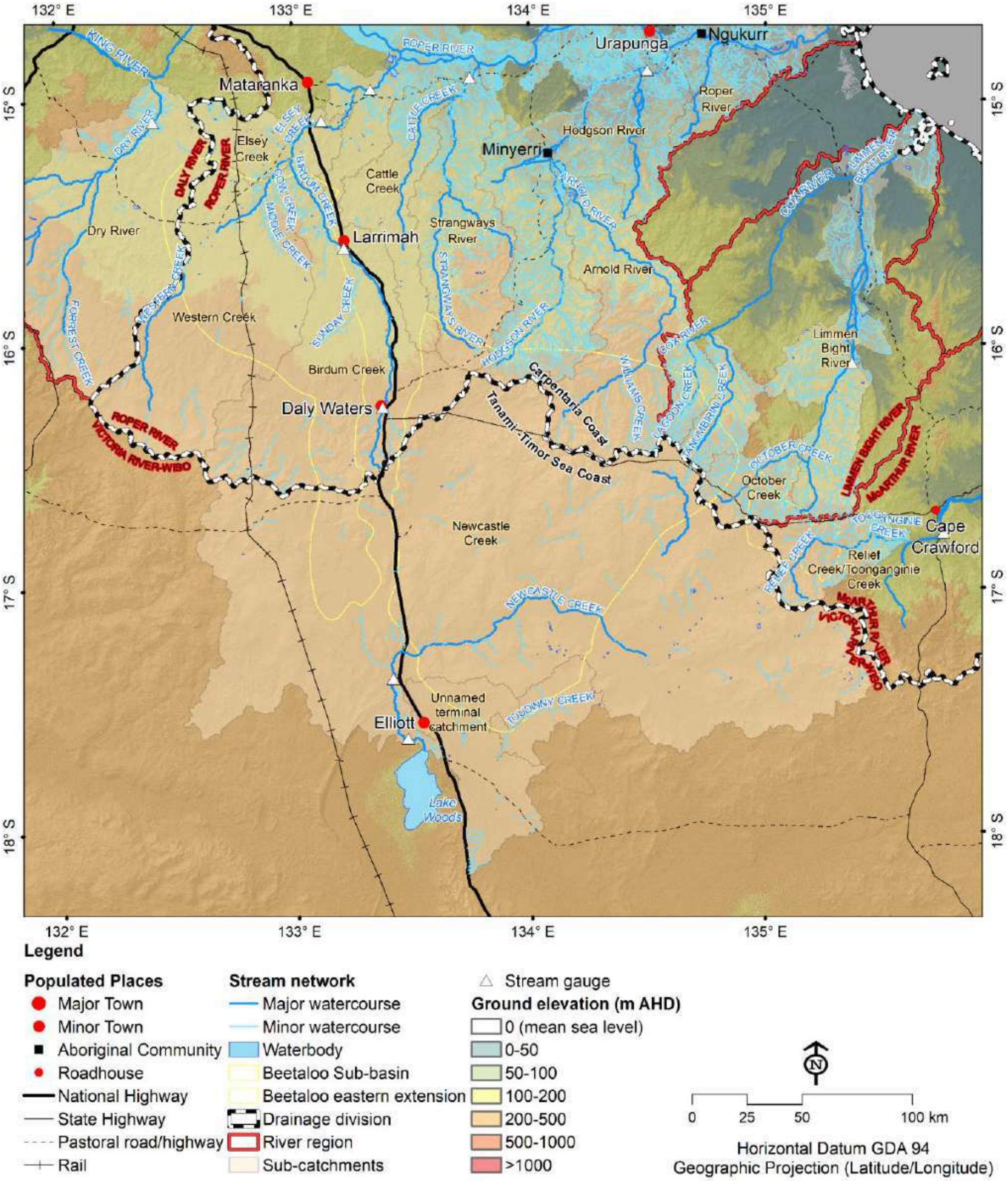

Figure 4-26. Surface water catchments, drainage network and waterbodies overlying the Beetaloo Sub-basin.

Furthermore, the generally flat topography in the area means that accurate flood modelling will require more precise topographic data than is currently available for the region (although mapping of the extent of surface water was undertaken for the Aquatic Ecosystems SREBA domain). Thus, detailed surface water studies are more appropriately undertaken by the petroleum industry during the initial impact assessment and infrastructure planning stages of individual projects, once areas of interest are more accurately defined.

The surface water catchments that overlie the Beetaloo Sub-basin include the following drainage divisions, river regions and sub-catchments (Figure 4-26).

- **Tanami-Timor Sea Coast**
  - *Daly River*
    - Dry River
  - *Victoria River-Wiso*
    - Newcastle Creek
    - Toudinny Creek
    - Unnamed terminal catchment north of Elliott
- **Carpentaria Coast**
  - *Roper River*
    - Roper River
    - Elsey Creek
    - Strangways River
    - Hodgson River
    - Arnold River
  - *Limmen Bight River*
    - Limmen Bight River
  - *McArthur River*
    - Relief Creek/Tooganginie Creek.

There are few perennially flowing waterways overlying the Beetaloo Sub-basin because there are no groundwater discharge areas due to the depth of the regional water table. However, some long-lasting waterbodies may be maintained by localised perched groundwater systems that exist above, and are separate to, the regional water table. Surface water flows coincide with the northern wet season, with monitoring stations typically recording flows commencing in December/January and rarely continuing beyond May. The relatively rapid cessation of flows after the end of wet season rainfall further demonstrates that there is no ongoing groundwater discharge or drainage from significant storage features (such as lakes and swamps) through the dry season.

Numerous waterholes, some permanent, are documented throughout the SREBA study area, while some terminus features, including lakes and swamps, may persist well into the dry season or even over multiple years after wet seasons with significant rainfall. The most significant of these waterbodies are Lake Woods and Longreach Waterhole (1-2 km upstream of Lake Woods), which are part of the Newcastle Creek catchment to the south of Newcastle Waters and Elliott.

4.4.1.1. Daly River catchment

The outermost north-western area of the Beetaloo Sub-basin underlies the Dry River catchment, which is a sub-catchment of the Daly River, with the Daly River ultimately discharging into the Timor Sea. Dry River flows in a northerly direction and terminates at its confluence with King River, approximately 50 km south of Katherine. King River ultimately discharges into the Katherine River, and the Katherine River discharges into the Daly River.

Dry River is an incised channel in a wide, flat plain and the channel width typically varies from 10 to 30 m in the upper (southern) reaches, and from 50 to 200 m in the lower (northern) reaches, with some locations extending in width to over 1 km. Channel braiding occurs along the entirety of the river, demonstrating a highly dynamic riverbed associated with sandy and loamy red earth soils. The channel and floodplain are typically shallow, being < 10 m deep.

Dry River is ephemeral and only flows in response to rainfall events, typically during the wet season months. No flows have been recorded in August or September and only once in July and October. Flows typically cease within four weeks of the last wet season rains because there are no significant storage features or groundwater discharging into Dry River. The modelled median annual discharge volume from Dry River into King River is 75,000 ML/year. However, this varies significantly from year to year with the spatial variability of wet season storms and monsoons. As such, the modelled average annual volume is more than double the median at 170,000 ML/year. The flow data collected at stream gauge site G8140011 show that Dry River has no flow for more than half the year, and that flow only exceeds 300 m^3/s for 1% of the time.

The Dry River catchment overlies the CLA and Cretaceous sediments but riverbed elevations lie well above the underlying regional water table, which means that the river receives no baseflow contributions from underlying aquifers. However, when Dry River flows during the wet season, it acts as a discrete recharge zone due to water infiltrating through the riverbed to the aquifer below. A number of sinkholes also occur throughout the catchment and a portion of overland flows are stored and 'lost' into these, infiltrating into the underlying aquifer(s) as discrete localised recharge.

4.4.1.2. Victoria River-Wiso basin

Much of the central and southern Beetaloo Sub-basin underlies an area of the Victoria River-Wiso basin that contains the Newcastle Creek (Lake Woods) catchment and two other minor endorheic (internally-draining) catchments to the east of Elliott (Figure 4-27). Newcastle Creek flows westwards over the central-east area of the Beetaloo Sub-basin before turning (almost at a right angle) southwards just to the north of the Newcastle Waters/Marlinja township. Newcastle Creek continues southward for approximately another 30 km, where it reaches the perennial Longreach Waterhole, before ultimately discharging into Lake Woods south of Elliott.

Lake Woods is a large, flat ephemeral lake located immediately south of the township of Elliott. The lake covers an area of approximately 200 km^2 but the extent of inundation varies significantly, from being regularly dry to almost 900 km^2 during major flooding. The lake receives surface runoff predominately from the Newcastle Creek catchment (approximately 19,000 km^2) but also from smaller catchments along the Ashburton Range, which borders the lake on its eastern side.

Lake Woods has no outlet, with its water being lost over time due to ET and potentially infiltration and recharge to the underlying aquifer. Water losses via ET estimated using the CMRSET dataset (McVicar *et al.* 2022) are approximately 1,226,000 ML/year for the period 2001-2021 for the area of Lake Woods and Longreach Waterhole. The greatest calendar-year total ET is estimated at 1,832,000 ML in 2011. These estimates are considered reasonable given that there is an OzFlux observation tower (used to constrain CMRSET estimates) located <100 km from the north of the lake.

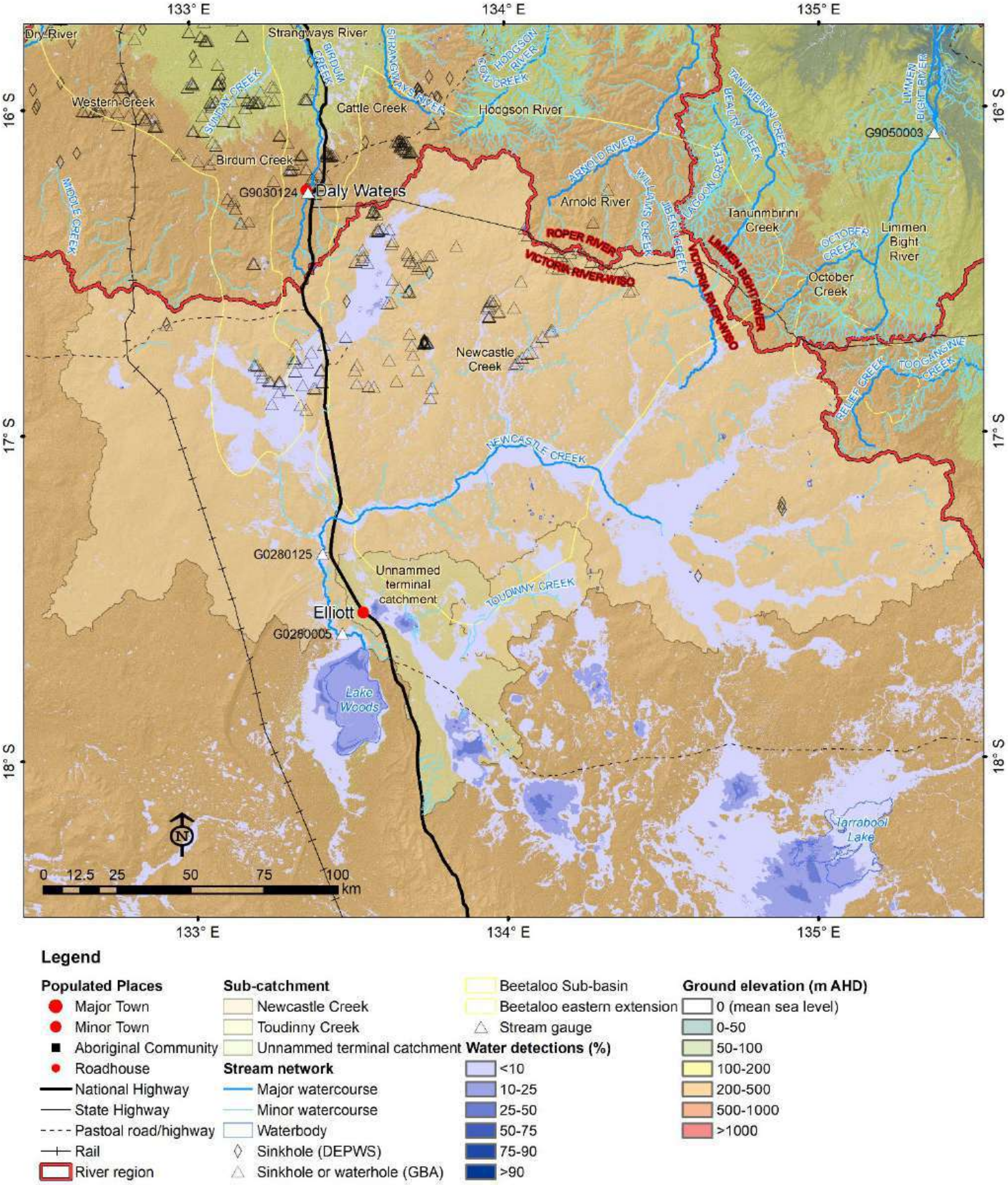

Figure 4-27. Surface water drainage features of the Newcastle Creek catchment and minor endorheic catchment areas of the Victoria River-Wiso basin overlying the Beetaloo Sub-basin.

Recharge from Lake Woods has been inferred based on stable water isotope compositions of CLA groundwater in the area. These compositions display a strongly evaporated signature that is different to many other areas of the CLA. However, they may also be as a result of seepage from the riverbed and floodout areas of Newcastle Creek, which can retain significant amounts of surface water during and after flow events. Groundwater geochemistry in the area around Lake Woods has also been used as an indication that there is active recharge occurring (de Caritat *et al.* 2019).

Stream gauging data was collected for Newcastle Creek at Newcastle Waters (G0280125) between 1993 and 2010, with the highest recorded flow of 750 m^3/s occurring in 2001. During the 2001 wet season, 2,091,000 ML flowed through Newcastle Waters and into Lake Woods. In most years, peak flows failed to exceed 50 m^3/s, with a median annual total discharge of 46,700 ML/year. Three years recorded no flows at all. All flows were recorded during the wet season. The episodic nature of flows demonstrates the irregularity with which groundwater recharge events are likely to occur.

While no perennially flowing waterways occur within the Newcastle Creek catchment, Newcastle Waters and Longreach Waterhole are reaches of near-permanent waterholes stretching for 50 km from south of the Stuart Highway to Lake Woods. Small flows in Newcastle Waters are frequently recorded through to June/July and occasionally even to August, possibly due to the storage effect of the wetland vegetation. These discharges are unlikely to be sourced from the underlying regional groundwater resources because the water table is tens of metres below the ground level. However, these systems may be maintained by localised shallow (perched) groundwater systems as a result of surface water recharging riverbanks during the wet season and releasing stored groundwater over the dry season (bank storage).

4.4.1.3. Roper River catchment

Much of the western and northern areas of the Beetaloo Sub-basin underlie the southern sub-catchments of the Roper River, which itself ultimately discharges to the western Gulf of Carpentaria. These sub-catchments include Elsey Creek (including its headwaters of Western Creek and Birdum Creek), Strangways River (including its tributary Cattle Creek), Hodgson River, Arnold River, as well as the southernmost headwaters of the Roper River itself (Figure 4-28). Although much of the Roper River is perennial (fed by the significant springs and groundwater discharge areas at Mataranka), the headwaters and sub-catchments that overlie the Beetaloo Sub-basin are all ephemeral and are not maintained by any groundwater baseflow.

Western Creek and Birdum Creek flow northwards across much of the western Beetaloo Sub-basin, joining to form Elsey Creek before continuing to flow into the main Roper River channel to the north at Mataranka. Historical data from Birdum Creek and downstream in Elsey Creek indicate initial flows are generally observed in December or January, and rarely continue past May.

Stream gauge site G9030001 on Elsey Creek at Warloch Ponds sits downstream of the Beetaloo Sub-basin and captures all flows from the Western Creek and Birdum Creek catchments, as well as the upstream reaches of Elsey Creek. The maximum recorded flow since 1967 at Warloch Ponds is 800 m^3/s; however, flows do not exceed 20 m^3/s in many years, and in two years no flows were recorded. Median annual total discharge at Warloch Ponds is 48,200 ML/year.

Numerous waterholes have been documented along Western Creek and Birdum Creek and their tributaries, with some of the tributaries considered permanent (Randal 1973), potentially maintained by shallow, perched aquifers. Further north of the Beetaloo Sub-basin, groundwater discharges into the lower reaches of Elsey Creek and the upper Roper River allow for perennial flow along these waterways. However, due to the depth of the water table (> 20 m bGL across most areas), no significant groundwater discharges are known to occur in the catchment areas that overlie the Beetaloo Sub-basin.

Numerous sinkholes also occur within the southern Roper River sub-catchments, particularly in the upper Birdum Creek, Strangways River and Cattle Creek catchments. Of particular note is the area approximately 70 km due west of Larrimah, where Western Creek appears to terminate in an area of flat topography and a high density of mapped sinkholes. In this area, the Cretaceous sediments are relatively thin and sandstone-dominated, which means that groundwater recharge is more likely to occur during wet season rain events, especially when surface runoff is directed into sinkholes and depression (e.g. Yin Foo and Matthews 2001).

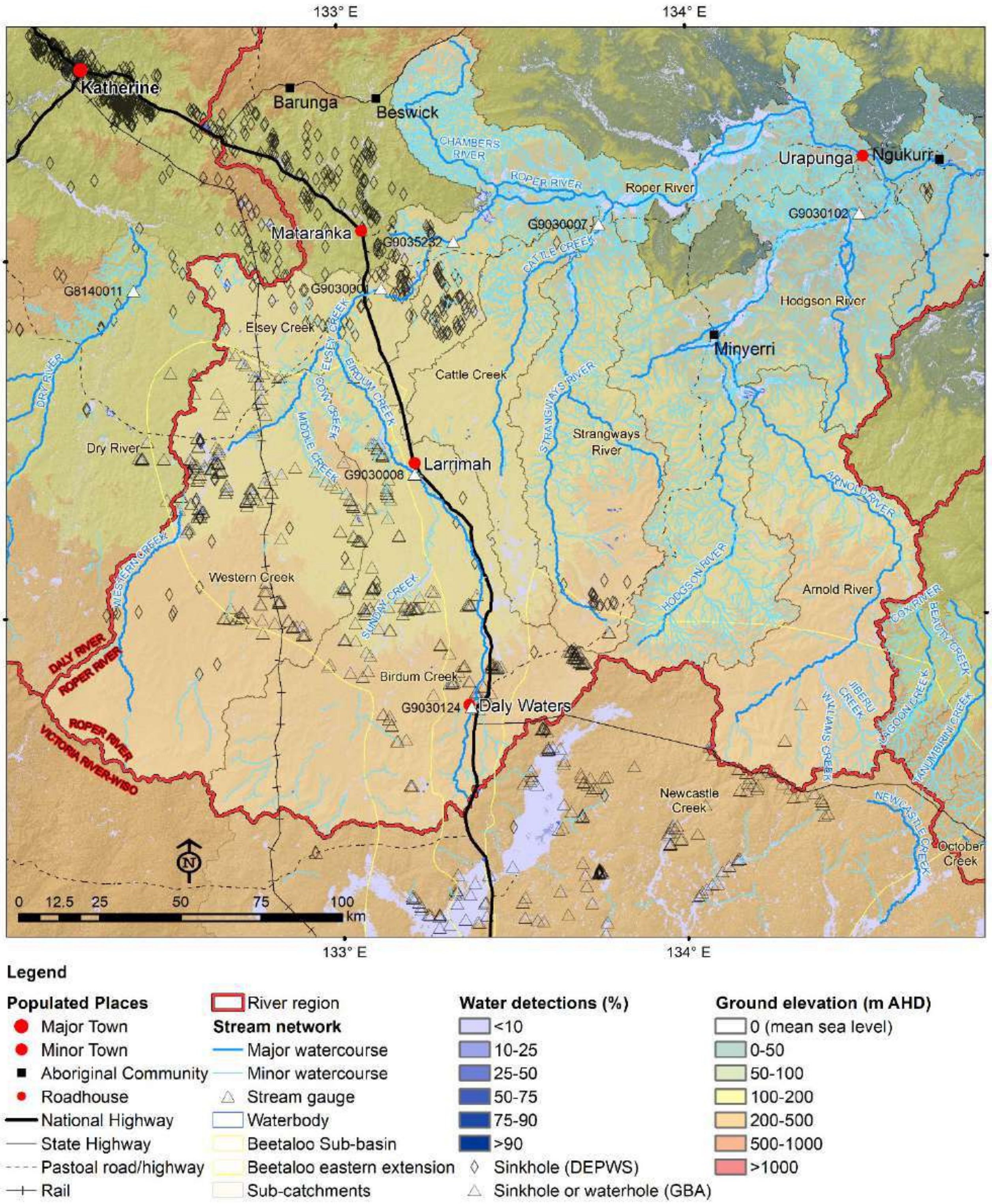

Figure 4-28. Surface water drainage features of the southern Roper River sub-catchments that overlie the Beetaloo Sub-basin.

4.4.1.4. Limmen Bight River and McArthur River catchments

The north-eastern areas of the Beetaloo Sub-basin (including the eastern extension) underlie the upper sub-catchments of the Limmen Bight River and McArthur River, which both ultimately discharge to the south-western Gulf of Carpentaria. This includes the sub-catchments of Lagoon Creek, Tanumbirini Creek and October Creek in the headwaters of the Limmen Bight River, and the Relief Creek/Tooganginie Creek sub-catchment in the headwaters of the McArthur River.

The Lagoon Creek sub-catchment of the Limmen Bight River contains the spring vents that feed Lagoon Creek and Beauty Creek at Hot Springs Valley. These are the only springs known to occur in the sub-catchment areas that overlie this portion of the Beetaloo Sub-basin. As discussed above, Hot Springs Valley is likely sourced from Mesoproterozoic formations that have been uplifted due to faulting along the Lagoon Creek Fault Zone and Mallapunyah Fault Zone, and this includes some of the same formations targeted for petroleum exploration in the Beetaloo Sub-basin. During the September 2022 field visit to Hot Springs Valley, stream flow was observed to not reach the Cox River (downstream of Lagoon Creek and Beauty Creek). This indicates that downstream of the spring vents, most of the water is lost by ET or through infiltration into the riverbed of the downstream watercourse.

Limited data exist for the Limmen Bight River and McArthur River catchments immediately downstream of the Beetaloo Sub-basin area. No current or historic stream gauging has been collected for the Cox River upstream of Lagoon Creek and Tanumbirini Creek, and the only gauging site along the Limmen Bight River upstream of October Creek is G9050003, which is now inactive and located approximately 50 km downstream of the confluence of October Creek and Limmen Bight River. Stream gauging (level only) was recorded at this site between 1973 and 1987, and the data indicate that streamflow is dominated by events driven by wet season rainfall, with increases in water level observed mostly between the months of November and March.

The only active stream gauge for the catchments overlying this area of the Beetaloo Sub-basin is site G9070142 along the McArthur River, where the river flows under the Tablelands Highway south of Cape Crawford (at the Heartbreak Hotel Roadhouse). Data recorded at this gauge site for the period 1965-2022 indicate that maximum flows are typically recorded in February and March, when it can exceed the rating of this site (approximately >960 m^3/s; upper limit of the rating curve) but average wet season flow is more commonly 30-50 m^3/s.

4.4.2. Surface water quality

Due the ephemeral nature of most surface water bodies overlying the Beetaloo Sub-basin, collection of data on surface water quality has been opportunistic and has only occurred during short-duration assessments. The historic surface water quality data for the region have been compiled recently as part of the development of the Beetaloo Sub-basin WAPs. This compilation has also included recent sampling undertaken during the SREBA aquatic ecology surveys. Surface water quality of the Beetaloo Sub-basin SREBA area has also been described in a preliminary baseline assessment of aquatic ecology for the SREBA (Davis *et al.* 2021). The following section summarises the findings of the WAP surface water quality assessments (DEPWS 2022b; 2022c; 2022d) and SREBA aquatic ecology sampling.

Data on surface water quality for the sub-catchments overlying the northern Beetaloo Sub-basin area (Roper and Daly) are available for a total of 38 sites, spanning from 1960 to 2021. Data are mostly sourced from NTG sampling undertaken for the Flora and Mataranka Tindal water planning areas and recent data made available by the Northern Land Council and the SREBA aquatic ecology study. Data on surface water quality for the sub-catchments overlying the southern Beetaloo Sub-basin area are available for ten sites. Data available at these sites include historic NTG assessments in the area, as well as sampling undertaken during the SREBA by the aquatic ecology study.

The ionic composition of surface waters in the Flora Tindall Limestone Aquifer WAP area is closely related to the groundwater source from which the flow originates. Most surface water in the region is dominated by calcium-magnesium-bicarbonate (Ca-Mg-HCO_3), with some sites dominated by sodium-bicarbonate (Na-HCO_3) and sodium-chloride (Na-Cl) (Figure 4-29). Most dry season surface waters in the lower Flora River and the Roper River near Mataranka have salinities of 500-1000 mg/L with slightly alkaline pH (7.1 to 8.4), due to their limestone/dolostone groundwater source. In contrast, sites overlying the local-scale sandstone aquifers in the upper Flora River, or the sites in areas with no groundwater discharge (Western Creek and Dry River), have lower salinity (<100 mg/L) and are slightly acidic (pH 6.2-6.9).

Surface waters of the northern Beetaloo Sub-basin area (Flora River and Roper River) are typically very clear during the dry season, with moderate dry season turbidity across most sites. Similarly, total suspended solids (TSS) concentrations are very low during the dry season but more variable during the wet, depending on the seasonal onset and timing of wet season runoff events. During the dry season, the majority of suspended solids consist of organic material, reflecting the lack of sediment runoff during this time.

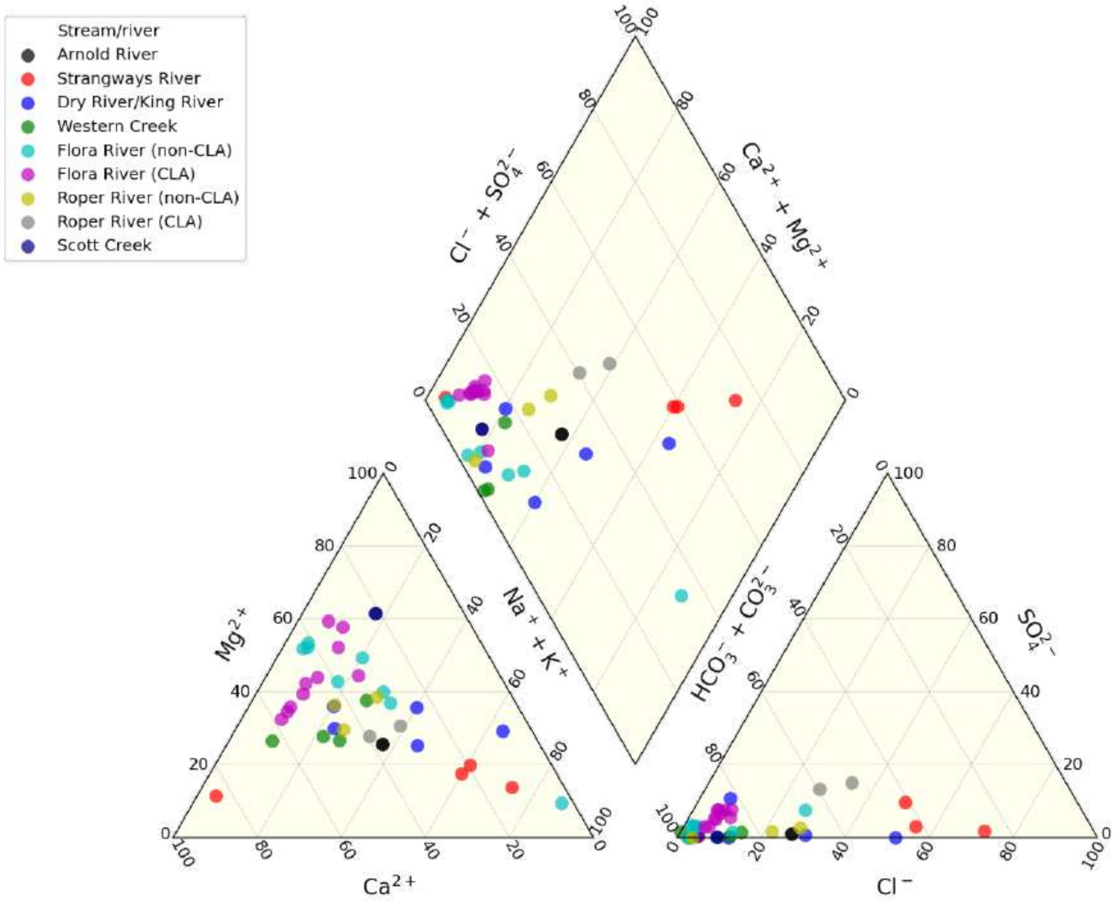

Figure 4-29. Piper diagram showing major ion compositions of surface water overlying the northern Beetaloo Sub-basin area.

Dry season nutrient concentrations are generally low and comparable to those in other streams in the region (e.g. DEPWS 2019). Nitrate concentrations are elevated at some CLA (Tindall) springs compared to other surface waters in the region but remain well below the drinking water guideline value of 11 mg/L. Regional environmental guideline values are not available for the area; however, there is no evidence that elevated nitrate is having a detrimental effect on the aquatic ecosystem. Elevated nitrate concentrations also occur elsewhere in the region where the CLA discharges to the surface; for instance, in the Katherine and Douglas River regions. The cause of these elevated concentrations is unknown but is thought to be at least in part related to human activities (Schult and Metcalfe 2006, Schult 2016).

The collected surface waters are dominated by calcium/magnesium bicarbonate in the Newcastle Creek catchment and at Killarney Spring, while Lagoon Creek Gorge Spring and Beauty Creek Hot Spring are sodium-chloride dominated, all with salinity of <500 mg/L (as TDS).

TSS concentrations were intermediate to high at Lake Woods during intensive sampling in March 1993, ranging from 33 to 380 mg/L, with volatile suspended solids (VSS) concentrations between 6 and 73 mg/L. A single sample was available for Newcastle Creek and had a relatively high TSS concentration of 490 mg/L. It is unclear whether these samples were taken during or between flow events since no additional environmental data were available. TSS/VSS was not measured at SREBA sites in 2021; however, dry season turbidity was very high in Newcastle Creek sites (160–410 NTU) and intermediate at the northern sites (5–39 NTU).

In temporary waters, nutrients can typically be high during initial filling periods, when nitrogen and phosphorus are released from sediments. They subsequently reduce as they are taken up by primary producers and then increase again during the drying period due to evapo-concentration. However, variability is high because other variables can also influence nutrient concentrations.

The historical general parameter samples for Lake Woods and Newcastle Creek include nitrate; however, in 1993 detection limits for this analyte (1 mg NO_3/L) were much higher than today, precluding a meaningful comparison of samples over time. Nitrate at Newcastle Creek was undetectable at this level in the available historical samples, ranging from <1 mg/L to a maximum of 22 mg/L. SREBA sites were sampled for total nitrogen (TN) and phosphorus, with TN levels ranging from 0.4 mg/L to 0.8 mg/L (as N) at Newcastle Creek and 0.6 mg/L to 1.5 mg/L at the northern SREBA sites. Total phosphorus ranged from 0.02 mg/L to 0.06 mg/L in Newcastle Creek with slightly higher levels at the northern region sites (0.04–0.07 mg/L). According to nutrient and chlorophyll concentrations measured at SREBA sites, these areas are classified as mesotrophic to eutrophic.

4.4.3. Development of rainfall-runoff models

Surface water models have been developed for each of the main catchments that overlie the Beetaloo Sub-basin to inform understanding of landscape water balances, to understand potential flood-prone areas, and to provide understanding of constraints on possible recharge mechanisms and fluxes. The catchments of the Daly River and Roper River have been developed into MIKE11 models that form part of the regional coupled surface water-groundwater model (DR2) that was discussed earlier. The other major inland catchments (i.e. Newcastle Creek and the catchments draining into the Barkly lakes) have been developed into hydrological (i.e. rainfall-runoff) models using HEC-RAS.

The hydrological model of the Barkly Basin catchments (Barkly model) is focused on simulating the hydrological process (rainfall-runoff) of the endorheic catchments of the Victoria River-Wiso Basin that feed the Barkly lakes system (i.e. Tarrabool Lake, Eva Downs Swamp, Lake Sylvester, Lake Du Burgh and Corella Lake).

A total of 23 rain gauges were used to develop the meteorological model for a 138-year period (January 1884 to December 2021). The Barkly model was calibrated and validated using observed daily rainfall and flow data covering the period from January 1961 to December 1986 (27 years) and January 1987 to December 2014 (27 years), respectively.

The hydrological model of the Lake Woods Basin (i.e. Newcastle Creek catchment; Gautam 2022a) is largely focused on simulating the hydrological processes of the Newcastle Creek catchment, but also includes some small tributaries to Lake Woods flowing west from the Ashburton Range. Eleven rain gauges were used to develop the meteorological model for a 138-year period (January 1884 to

December 2021). The Lake Woods Basin model was calibrated and validated using observed daily rainfall and flow data covering the period from January 1962 to December 1986 (26 years) and January 1988 to December 2013 (25 years), respectively.

For each of the hydrological models above, results during calibration and validation show a reasonably good agreement between simulated (modelled) and observed daily flows for both periods. The final model configurations can be used to simulate rainfall-runoff processes within the basins for the period of 138 years (1884 to 2021). Synthetic rainfall datasets can also be used to extend the model simulation periods and will allow development of predictive scenarios to account for predicted changes to rainfall patterns and catchment responses as a result of climate change.

4.4.4. Lake Woods inundation mapping

Regional inundation mapping has not been undertaken for the entire SREBA water studies area because the only available topographic data are the coarse topographic data of the Shuttle Radar Topography Mission (SRTM), which only has 90% of its data to an accuracy of better than 6 m relative to reference heights. Given the relatively flat topography of the majority of the landscape overlying the Beetaloo Sub-basin, the inaccuracy and coarse precision of the SRTM data means that flood mapping is more error-prone than in other areas. Thus, petroleum industry developers in the area will need to develop their own site-specific flood models to inform decisions about infrastructure design and environmental risk assessments. This modelling should be built upon more precise elevation data than the SRTM dataset (e.g. LiDAR), and validated using field gauging and the Digital Earth Australia water observations data (or similar dataset).

An example of the type of outputs that can be achieved using the satellite water observations is briefly provided here for Lake Woods as an indicator of the likely frequency of flooding events.

In addition to publicly available products derived from Landsat (5,7,8) and Sentinel (2a,2b), Geoscience Australia have made ‘analysis ready’ versions of the raw satellite imagery publicly available. To better understand the flood dynamics of Lake Woods, the Digital Earth Australia repository was queried using the DEA Sandbox online environment. All Landsat and Sentinel imagery were obtained for the period of July 1987 to October 2022, and to estimate the open water extent of Lake Woods, various wetness indices were calculated using the reflectance band data. The calculations of open water extent were based on the method described in Short *et al.* (2020), who investigated variations in extent of a similar lake (large, flat and ephemeral) in New South Wales.

The satellite imagery for Lake Woods over the 1987-2022 period included 472 Landsat and 246 Sentinel images that had at least 90% cloud-free pixels. Over that period, the lake has undergone several inundation events (Figure 4-30), reaching its maximum extent of almost 900 km^2 in mid-2011 after significant wet season rainfall made its way through the catchment. The most recent maximum occurred in early-2016, when the lake reached almost 800 km^2, but it has not had significant water in it since early 2019 (Figure 4-31). There were other extended dry periods in the late 1980s/early 1990s, and the late 1990s.

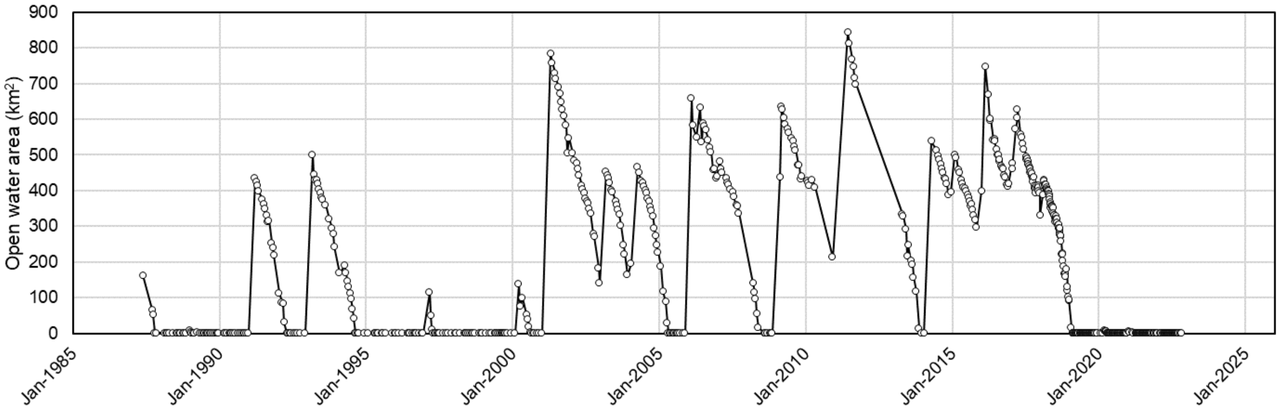

Figure 4-30. Open water area of Lake Woods estimated by Landsat and Sentinel satellite imagery.

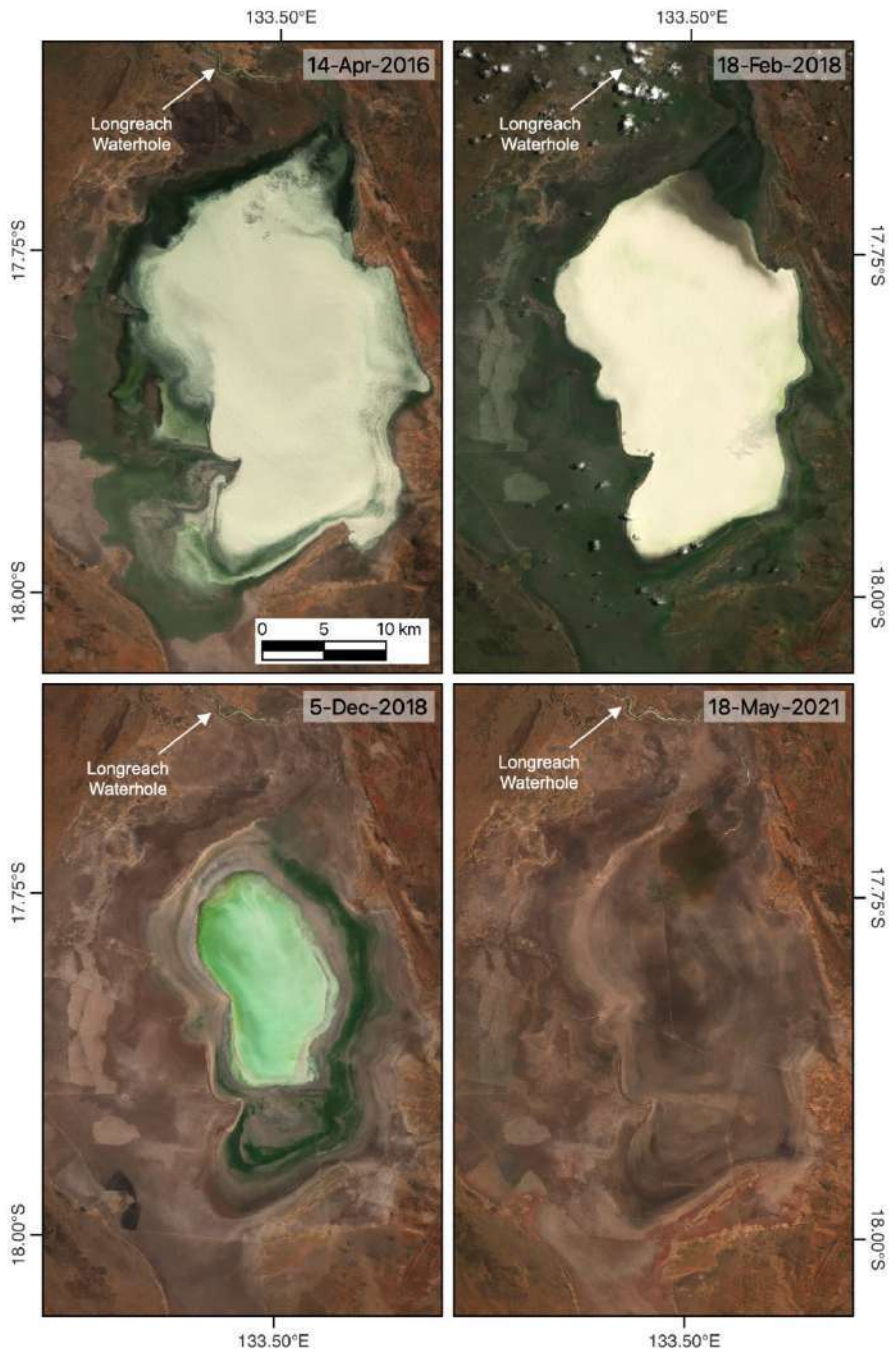

Figure 4-31. Sentinel 2 imagery of Lake Woods over the most recent period of drying.

4.5. Conclusion

Research into the water resources overlying the Beetaloo Sub-basin has spanned decades, with a dramatic increase in funding and resources dedicated to the subject in the last decade. The depth of information relating to the pre-development baseline conditions of the water resources in the area is highlighted by the extensive reference list associated with the Water Studies Baseline Report. The cited assessments, in addition to the work undertaken for the SREBA, collectively form the basis of the pre-development baseline understanding and characterisation and, in turn, support a world-class regional numerical water model.

This region will soon have a series of WAPs declared to set water allocation rules and management objectives for the water resources in the area, informed by the baseline information compiled as part of the GBA and SREBA.

4.5.1. Recommendations for further work

Although the characterisation of water resources overlying the Beetaloo Sub-basin is built upon strong foundations, the scope of the SREBA water studies was deliberately focused on addressing priority knowledge gaps related to the main water supply resources with high environmental and socio-economic values (notably the CLA). There remain knowledge gaps that have not been covered exhaustively at this stage of defining the pre-development baseline. These matters should form part of supporting studies for project-specific environmental risk assessments and management/monitoring plans associated with the progressive development of an onshore gas industry, if this occurs.

It is important that data and reporting from further studies in the region continue to be collated into publicly accessible databases, to build further on the very large data and information described in this report.

Further work in the following areas should be considered.

Continued assessment of the nature and degree of connectivity between the CLA and deeper HSUs

Investigations of interconnectivity of the deep HSUs should be targeted and not solely based on opportunistic data collected during petroleum exploration activities, like most of the data to date. It is recognised that there are high costs associated with effectively drilling and constructing monitoring bores in the deeper formations (i.e. due to the need to seal aquifers and use non-corrosive materials). However, this approach is considered necessary to provide support for the assumptions used in assessing potential risks of onshore gas activities and to provide a basis for ongoing monitoring. The petroleum industry should work with GISERA to implement a deep aquifer investigation/monitoring network that is aimed at following up on the environmental tracer work (Deslandes *et al.* 2019) and the recent mapping of priority areas (Frery *et al.* 2022).

Water supply potential of non-CLA groundwater resources

The petroleum industry proponents should actively investigate other groundwater resources to help reduce their reliance on high-value water resources such as the CLA. The higher salinity of some of the deeper aquifers (e.g. Bukalara Sandstone) is likely to be acceptable for a large portion of petroleum industry water requirements (e.g. hydraulic fracturing fluids) and pumping costs are unlikely to be significantly increased due to similar groundwater levels to those found in the CLA. Exploration of the deeper aquifers will also contribute to more thorough conceptualisation of how they interact with the CLA.

Broadening of project-specific groundwater quality baselines

In the lead-up to applying for production licences, the petroleum industry should collect and report on bore water quality at more than just their well-pad monitoring bore arrays. Companies could make arrangements with surrounding landholders (nominally within a 5 km radius of a well-pad) to collect periodic samples from third-party bores. Given the common detection of methane gas of microbial origin in pastoral bores, pre-development data regarding pastoral bore water quality will enable identification of dissolved gas sources and assist in any potential future assessment regarding any actual or perceived changes in water quality. Sampling of third-party bores should also involve an initial downhole inspection (i.e. confirmation of bore depth and construction) and gamma log acquisition to confirm the targeted HSU.

Assessment of groundwater sources and potential impacts to Hot Springs Valley

The petroleum industry (either as a collective or through the GISERA program) should prioritise investigations of the Hot Springs Valley area, especially those companies undertaking work within 50 km of the springs. This will likely necessitate significant initial work to more accurately define the groundwater source(s) for this feature. These investigations will be crucial to understanding the risk of potential impacts and appropriate management and ongoing monitoring (if required). The area is also likely to be important for monitoring natural surface emissions of greenhouse gases from Beetaloo Sub-basin formations.

Assessment of flood risk and inundation mapping

Project-specific flood inundation modelling needs to be supported by topographic data with an adequate accuracy and precision to model surface runoff and map flood inundation areas. Where higher-quality topographic data have been acquired, they should be shared with the Government and public (e.g. via a platform such as Geoscience Australia's Elevation Information System portal to support ongoing flood assessments.

Sinkhole and waterhole mapping

Project-specific surface water modelling and flood mapping should include a thorough assessment of the location of sinkholes/waterholes that may be affected (i.e. increase or decrease in runoff) by project activities or infrastructure. The mapping should be undertaken using a combination of satellite imagery and LiDAR topography (i.e. identification of potential sinkhole locations), followed by field validation.

Project-specific surface water quality baselines

Baseline surface water quality monitoring programs should be established prior to project approvals and be informed by site-specific surface water modelling. Given the ephemeral nature of most catchments in the region, surface water quality baselines will likely need to be based primarily on using sediment quality as a proxy, and on the reference site methodology of the *Australian & New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000). However, opportunistic surface water sampling should also occur when possible.

Update industry water monitoring standards

The *Preliminary Guideline: Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-basin* (DENR 2018) was developed to provide guidance to the petroleum industry in the interim period between the lifting of the exploration moratorium and up until the completion of the SREBA. Now that the SREBA waters studies have been finalised and a more complete understanding for the groundwater system exists, this guideline should be reviewed and updated where appropriate.

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5. Aquatic ecosystems baseline studies

The Aquatic Ecosystems baseline studies for the Beetaloo Sub-basin SREBA were undertaken in line with the approach set out in the SREBA Framework and the Scopes of Work. The Aquatic Ecosystems studies aimed to address the following attributes:

- aquatic habitats and ecological units
- aquatic vascular plants and macroalgae
- fish and turtle species
- aquatic macroinvertebrate species
- stygofauna
- threatened species and their habitat and other matters protected by legislation
- other significant species and their habitat, including those with high cultural value.

The outputs derived from the collection, analysis and synthesis of these baseline data were:

- mapping and classification of aquatic ecosystems within the SREBA study area
- description of assemblages of aquatic biota and evaluation of environmental determinants
- identification of High Ecological Value Aquatic Ecosystems (HEVAEs)
- identification of dry season refuges
- spatial distribution models for significant species and assemblages
- evaluation of the sensitivity of significant species/ecosystems to development
- description of indicators and methods for regional monitoring.

The Aquatic Ecosystems studies were separated into two projects due to their very different natures — surface aquatic ecosystems and stygofauna — and these are reported separately below.

The surface aquatic ecosystem studies were led by scientific staff from the Flora and Fauna Division of DEPWS, and fieldwork was also undertaken by the Flora and Fauna Division. External expert support was provided in a number of subject matter areas, as detailed in the Aquatic Ecosystems Baseline Report. The stygofauna investigation was undertaken by Biota Environmental Services, which has a background of more than 20 years in working on subterranean fauna in northern Australia, supported by Helix Molecular Solutions for genetic assays and analyses.

5.1. Surface aquatic ecosystems

5.1.1. Study area

The study area for the aquatic ecosystems studies was the SREBA biophysical study area described in Section 3.1 and shown in Figure 3-1. The landscape and surface water context are also described in Section 3.2. Notably, the southern part of the study area is within the southerly (internally draining) Newcastle Creek/Lake Woods drainage, while the northern part incorporates parts of the upper catchments of the Daly, Roper, Limmen-Bight and MacArthur drainages. Most of the surface water in the central part of the study area (and in the Beetaloo Sub-basin) is ephemeral.

Permanent or near-permanent aquatic habitat in the study area mostly occurs around the margins of the study area and includes the permanent spring-fed reaches of the upper Roper system, including Elsey Creek and Salt Creek; Longreach Waterhole and adjacent waterholes on Newcastle Creek; channel pools on King River; a spring-fed section of Cox River; and the upper Limmen Bight River.

Climate in the study area is described in Section 3.2.2. The region lies in the transition between the humid sub-tropical zone and the semi-arid zone, and the climate is strongly influenced by the north-west monsoon. There can be high variability among years in the timing of the brief transition periods between the wet and the dry seasons, and in total annual rainfall (Figure 5-1). Periodic incursions of post-cyclonic rainfall depressions can also result in flooding and filling of temporary wetlands over large areas. Wet season rainfall differed markedly over the SREBA study period. In 2020/21, the seasonal annual rainfall total at Larrimah (Bureau of Meteorology station 14612, calculated from July to June) was 1,217 mm; in 2021/22, the seasonal annual rainfall total was 455 mm.

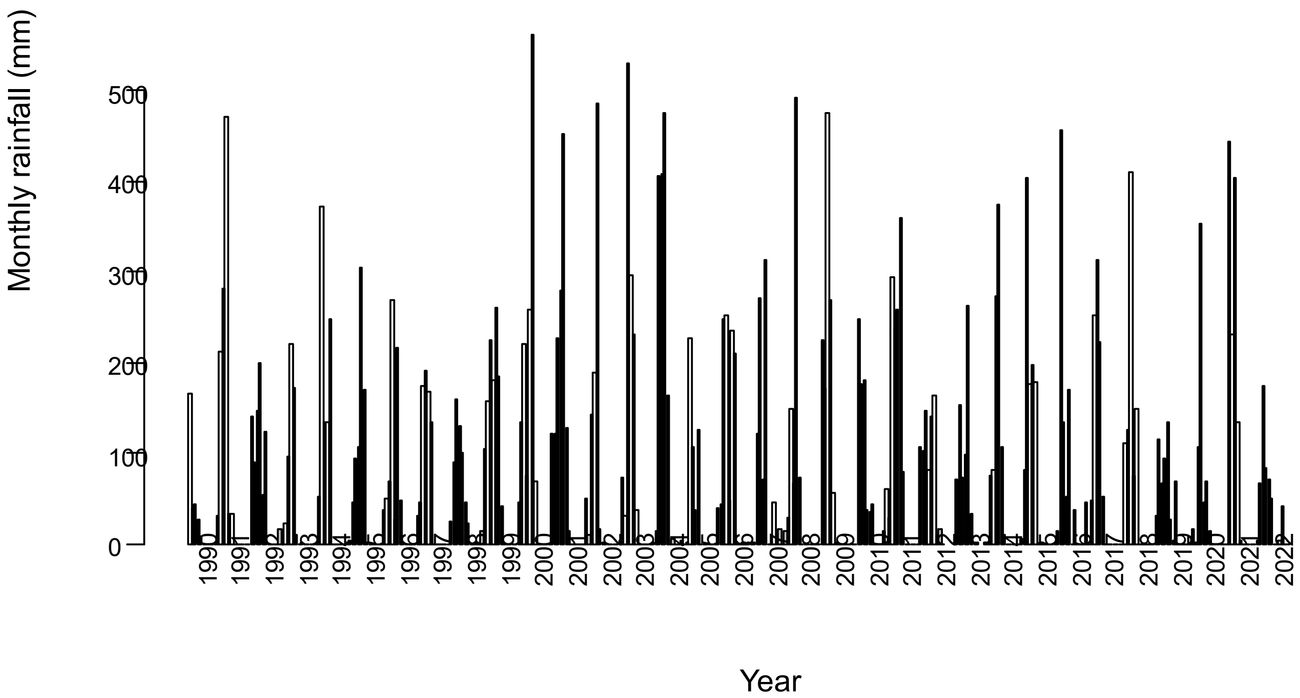

Figure 5-1. Monthly rainfall recorded at Larrimah's Bureau of Meteorology station no. 14612 from January 1990 to September 2022.

5.1.2. Previous studies and data

The only previous systematic survey of aquatic biodiversity in the study area was that for the Beetaloo GBA (Davis *et al.* 2021). That study surveyed 21 waterbodies in 2020 and 2021 and recorded five turtle species, 30 fish species and at least 195 taxa of aquatic invertebrates. Of the 195 aquatic invertebrate taxa, 68 (35%) were identified to species level. DNA analysis of turtle tissue samples collected during the GBA study found that populations of *Elseya dentata* in the Roper and Gulf Rivers are genetically distinct from *E. dentata* in the Daly and other western catchments, and may warrant description as a separate species (Georges *et al.* 2021). Other notable findings included records of the Gulf Snapping Turtle *Elseya lavarackorum*, Giant Glassfish *Parambassis gulliveri* and Elongate Glassfish *Ambassis elongata*.

There have been a number of other studies of aquatic fauna (including Hemiptera, molluscs, caddisflies and fish) in adjacent regions that are relevant because they are likely to include species also occurring in the study region, as well as localised studies on fish in Elsey National Park and Newcastle Creek.

Existing data on the occurrence of freshwater aquatic species in the study area from local-scale studies and opportunistic observations or collections were obtained from the online database of the *Atlas of Living Australia* (ALA). There were 1,656 records of a total of 203 species of fish, frogs and macroinvertebrates (insects, decapods and molluscs) within the study area, with the majority of records (52.4%) being of frogs. For some groups (e.g. frogs and molluscs), the species totals from *Atlas of Living Australia* records represent a high proportion of the species likely to be present, but for other groups (e.g. fish, Coleoptera and chironomids), the species tally is likely to be a significant underestimate.

5.1.3. Ecosystem mapping

Aquatic ecosystems in the study area were mapped and categorised using the Australian National Aquatic Ecosystem framework to identify lacustrine, palustrine, riverine and floodplain systems. The distribution and extent of surface water systems were mapped using three datasets derived from time-series of satellite observations of surface water, covering the periods 1986–2021 (GeoScience Australia Landsat Water Observation Statistics) and 1987–2018 (maximum extent of surface water derived from Landsat imagery).

The Australian Hydrological Geospatial Fabric was also used to identify riverine systems, and the Queensland Department of Environment and Science woody foliage projective cover model was used to differentiate between palustrine and lacustrine waterbodies. The 'Springs of the Northern Territory' database (Northern Territory Government 2019) was used to identify the location of springs. The mapping process is summarised in Figure 5-2.

The extent and distribution of aquatic ecosystems across the study area is shown in Figure 5-3. The mapping identified 1,061,555 ha of surface water ecosystems, covering approximately 12% of the study area. The majority (90%) were classified as floodplain systems (952,323 ha), followed by palustrine systems (99,782 ha; 9%), riverine systems (9,360 ha; 1%) and lacustrine systems (995 ha; 0.01%). Mapped streams, considered to be riverine systems, have a total length of 13,787 km within the study area, of which almost 15% (2,011 km) are classified as major streams. Twenty-two spring locations have been identified within the study area. Interpretation of the mapping product is discussed in Section 3.2.3 of the Aquatic Ecosystems Baseline Report.

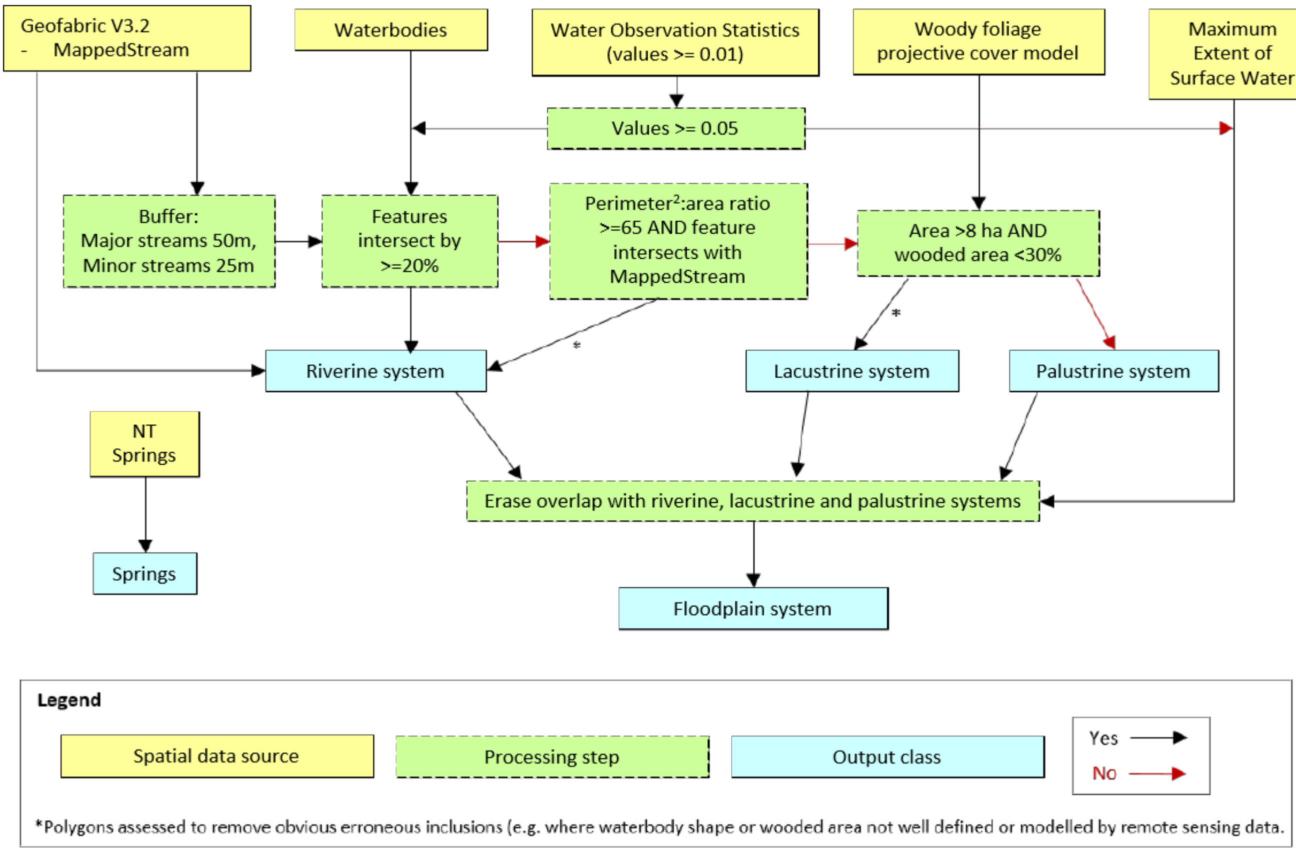

Figure 5-2. Decision rules and processing steps used to map the extent and distribution of aquatic ecosystems across the study area.

Potential aquatic refugia were identified through interpretation of water observation statistics derived from Landsat images from April to October over the years 1986–2021. This showed areas where water is perennial or likely to persist well into the dry season in most years, providing refugia. Additional locations were added to the refugia dataset based on knowledge derived from the waterbird surveys undertaken during the Terrestrial Ecosystems components of the SREBA, and the aquatic fauna surveys undertaken for the aquatic ecosystems study.

Refugia were identified at 89 point locations across the study area (Figure 5-4). Dry season water frequency values greater than 0.8 were recorded at 16 locations, identifying a variety of important waterholes (e.g. Ambullya Waterhole), swamps (e.g. Stuart Swamp) and mapped streams (e.g. Roper River) that are known to have permanent or near-permanent surface water. Frequency values between 0.6 and 0.8 identified potential refugia at 52 locations. Based on aquatic fauna surveys, an additional 21 locations were recorded as refugia, having permanent or near permanent water. It is likely that some additional unidentified refugia exist across the study area, and these locations should be added to the dataset as they are identified.

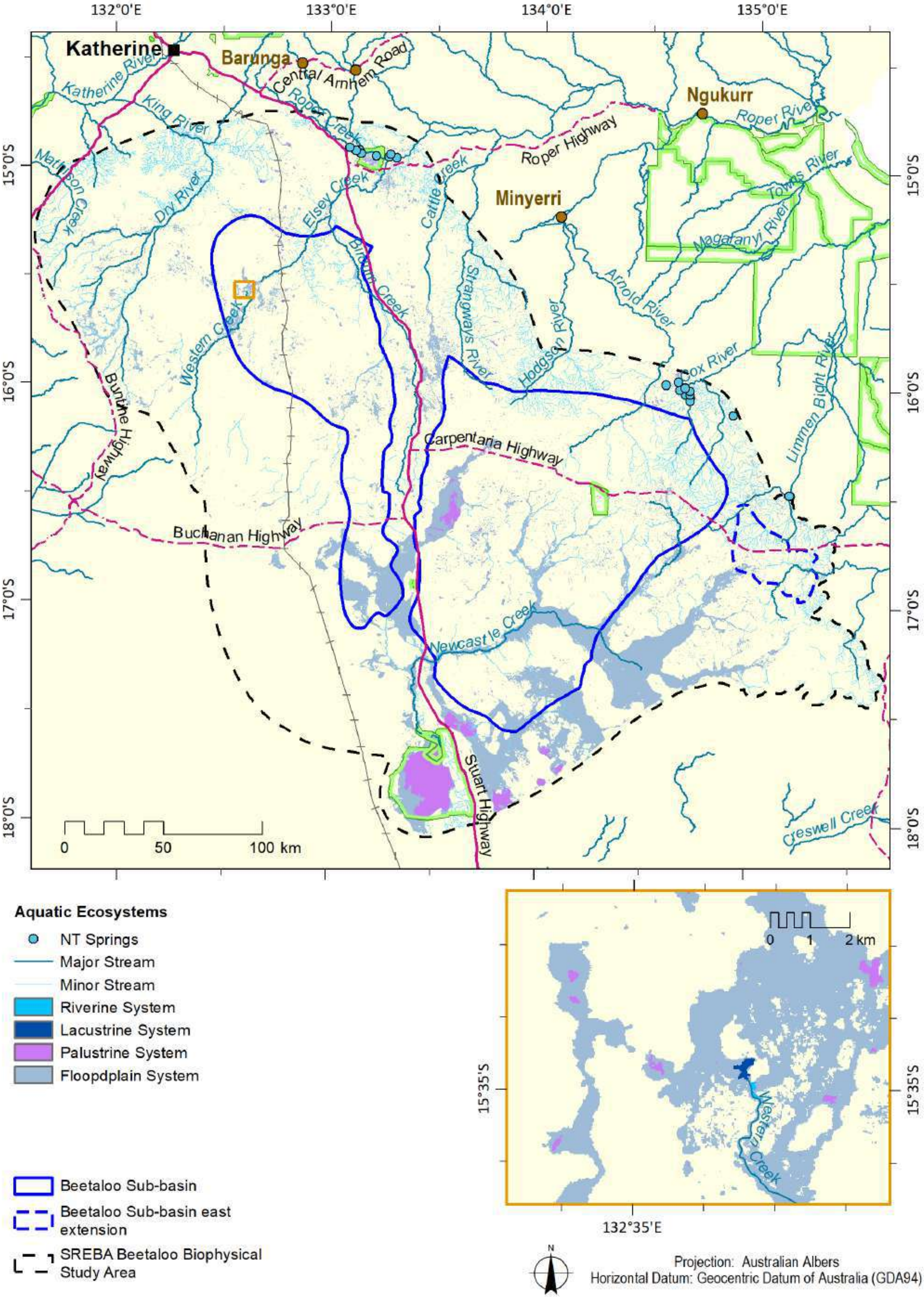

Figure 5-2. The extent and distribution of surface aquatic ecosystems mapped across the study area.

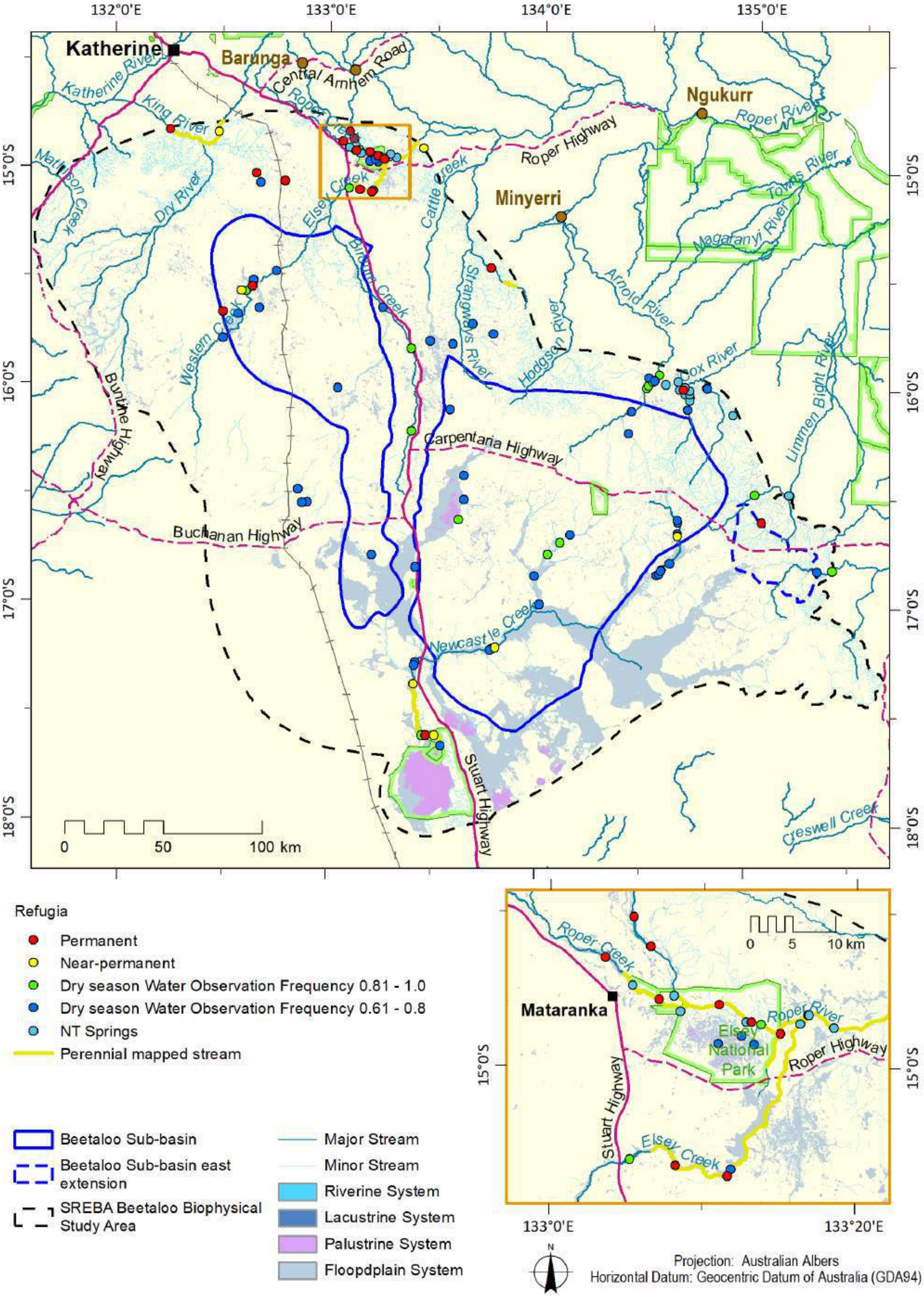

Figure 5-3. Aquatic refugia identified across the study area.

5.1.4. Systematic biodiversity surveys

Systematic surveys of aquatic biodiversity were conducted at 44 sites across the study area, including eight sites in the Daly catchment, 26 sites in the Roper catchment, two sites in the Limmen catchment and eight sites in the Victoria-Wiso catchment. Sites were broadly categorised as: (1) riverine habitat (*n*=24); (2) off-stream channel habitat (*n*=7); and (3) shallow wetland habitat (*n*=13). The location of samples sites is shown in Figure 5-4 and the characteristics of each site are described in Appendix 1 of the Aquatic Ecosystems Baseline Report.

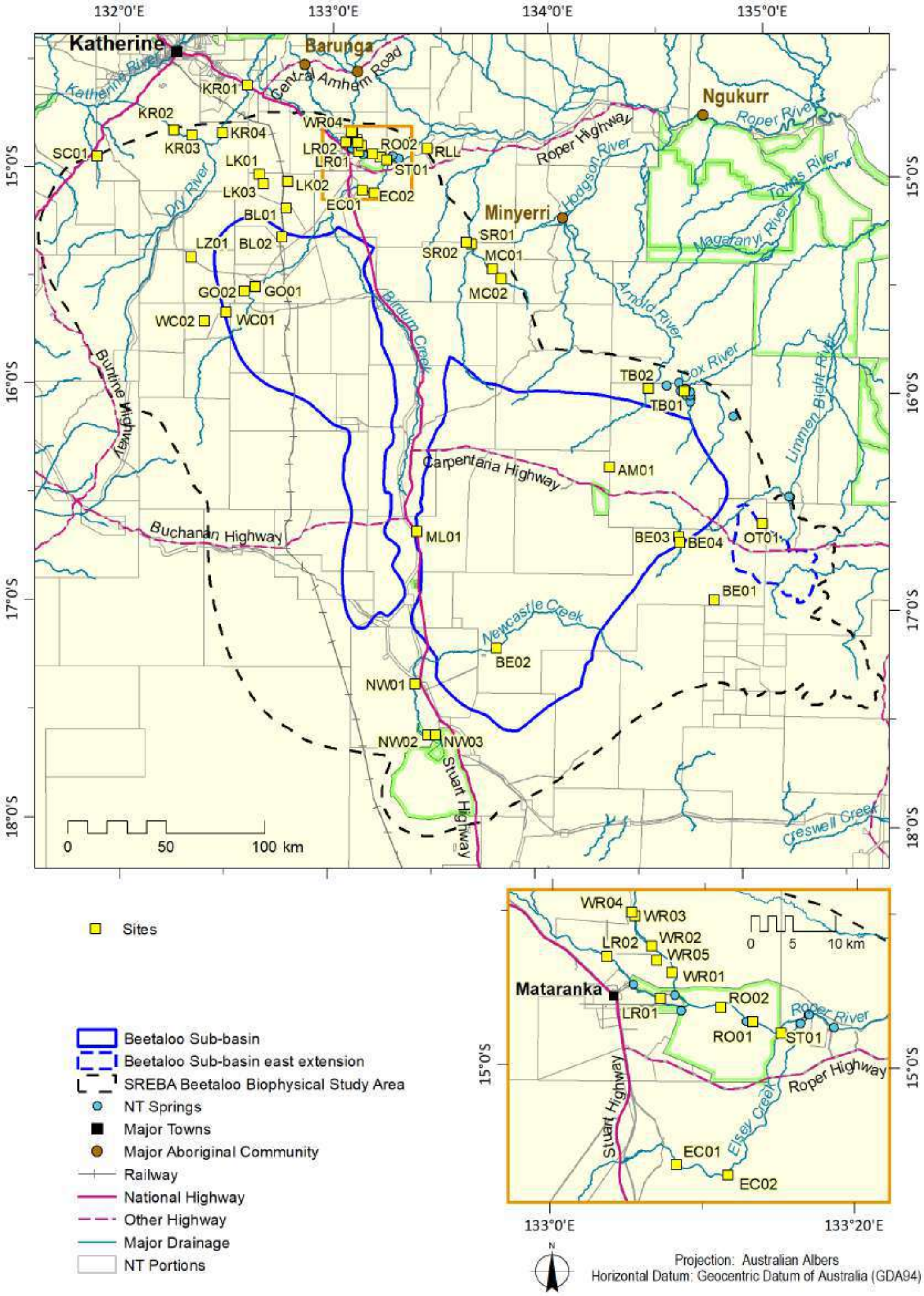

Figure 5-4. Location of the Beetaloo Sub-basin boundaries, SREBA Beetaloo Aquatic Ecosystems study area and survey sites, and tenure boundaries.

It is not feasible to sample all components of aquatic biodiversity, and taxa targeted in this study included fish, turtles and other aquatic reptiles, and selected aquatic macroinvertebrate taxa including molluscs, decapods, chironomid Diptera, Ephemeroptera, aquatic beetles, and aquatic and semi-aquatic Hemiptera. The rationale for the selection of these taxa included the availability of taxonomic expertise and the capacity to identify aquatic life stages to species level, as well as the utility of the taxa in demonstrating biogeographic patterns and potential sensitivity to disturbance.

All aquatic survey sites were sampled in the dry season after the cessation of wet season rainfall. Sampling in 2021 commenced on 25 May and finished on 22 September; in 2022, sampling commenced on 5 April and concluded on 21 June. The commencement of sampling each year was determined by the timing of approval to access unsealed roads on pastoral properties. Most of the 44 survey sites were visited for a period of at least 20 hours; one site was visited during daylight hours by helicopter. In general, the survey team arrived at a site prior to 4 pm, camped overnight at the site and departed at about midday the following day. This routine allowed for standardised deployment of sampling equipment and measurement of water quality; the opportunity to deploy sampling equipment during the crepuscular period from late afternoon to early evening; and the opportunity to conduct active searches of aquatic animals using spotlighting.

To sample invertebrates, three benthic samples at each site were collected using a fine-mesh pond net by sweeping a 10 m transect in the littoral zone. Benthic samples were filtered in the field using nested sieves and preserved in 80% ethanol for later processing. In addition, incidental captures (of mostly larger individuals) were preserved separately as 'extras' from each site. In the laboratory, sub-samples of each benthic sample were examined under a binocular microscope and processed by selecting a minimum of 100 individuals of all recognised invertebrate types. Some taxa, including chironomids and caenid mayflies, were slide-mounted in Hoyer's medium for identification using a Leica DM4B compound microscope. Chironomids, mayflies and non-atyid decapods were identified by Dr Peter Dostine using published taxonomic keys. Remaining taxa were identified by taxonomic specialists as described in the Aquatic Ecosystems Baseline Report.

Multiple methods were used to sample aquatic vertebrates, including: (1) ten small bait traps baited with dry cat pellets deployed overnight from late afternoon; (2) four fyke nets set in shallow water over a 4 h period spanning sunset; (3) a 3 inch gill net set over a 2 h period spanning sunset; (4) ten cast net throws; (5) 500 seconds of backpack electro-fishing; (6) five modified cathedral-style turtle traps baited with meat and deployed in the late afternoon and early evening; and (7) spotlight surveys conducted from the bank or boat in the early evening (including using a dip net to capture fish and turtles). Not all methods could be deployed at all sites. Most specimens were released at the point of capture, though some fish and decapods were retained as voucher specimens and lodged at the Museum and Art Gallery of the Northern Territory in Darwin. Tissue samples were collected for DNA analysis either from voucher specimens, or non-injurious sampling from captured turtles.

5.1.4.1. Species diversity

Systematic surveys identified 291 species of aquatic fauna, including 36 fish species; 11 species of aquatic and semi-aquatic reptile species including seven turtle species; 28 mollusc species; seven decapod species; 49 species of aquatic and semi-aquatic water bugs; 15 mayfly species; 69 species of non-biting midges (Chironomidae); and 76 species of aquatic beetles. Detailed species lists are presented in the Baseline Report.

When data from all sources are combined (including plants and frogs described below), a total of 400 species associated with surface water habitats were identified in the study area. This is not a complete account of the total aquatic biodiversity, as some prominent components of freshwater biodiversity were excluded from the study, and the achievable sampling period means some ephemeral components were missed. Aquatic (surface) biodiversity in the region probably therefore exceeds 500 species of plants and animals.

Aquatic invertebrates comprised 61.5% (249) of the total number of recorded species, with Coleoptera contributing a fifth (19.0%, 76) of all species, while vertebrates comprised 17.8% (72) of the total. Species richness tallies from the study area generally accord with regional inventories from the Daly River for molluscs (Willan and Kessner 2021), the Gulf region for aquatic and semi-aquatic bugs (Weir 2017), and Darwin region for chironomids (Dostine and Wells 2022).

5.1.4.2. Biogeographic patterns

The number of species of fish and of all aquatic species was mapped to display the distribution of site species richness across the study area. For fish, species richness per site ranged from 0 to 21 (Figure 5-5). Fish were absent from five sites, all of which were internal-draining wetland systems with absent or infrequent connection to the drainage network. Most sites with high fish species richness occurred along the northern margin of the study area, and fish diversity in the study area centred on the perennial reaches of the upper Roper River. Parts of Western Creek hold a diverse fish fauna but are probably dependent on upstream migration from the Roper through Western Creek. Sites along Newcastle Creek had up to six species, with richness declining with distance upstream from refugial waters in the permanent channel of Longreach Waterhole. This pattern of low species richness, and diminishing richness with reduced connectivity, occurs throughout the majority of the study area. The most persistent colonist is invariably the Spangled Perch *Leiopotherapon unicolor*.

Waterbodies throughout most of the study area feature a sub-set of common, widespread fish species. Spangled Perch and the Rainbowfish *Melanotaenia splendida* are virtually ubiquitous. However, there are some distinctive elements; for example, *Melanotaenia australis* is only present in Daly catchment sites, *Porochilus argenteus* occurs in the Newcastle Creek system (but is not confined to the Newcastle Creek system), *Parambassis gulliveri* only occurred at one site on the Cox River, and *Ambassis elongata* is known from previous surveys from the upper section of Elsey Creek.

The spatial pattern for all aquatic species mirrors the pattern for fish, with highest diversity along the northern margin of the study area, and low total richness throughout the majority of the region (Figure 5-6).

Multivariate analyses were conducted to analyse the similarity in sites according to aquatic species composition, to identify groups of similar sites, and to examine what environmental factors influence species composition. This analysis identified 12 discrete types of sites (Figure 5-7) and five higher-level clusters of site type (Figure 5-9):

Group 1 is an outlier group in the classification and consisted of a single site on an ephemeral wetland without fish or decapods.

Group 2 consisted of two sites on cattle-impacted waterholes without fish or decapods. Both sites lacked connection to the drainage network. Characteristic species included several species of dytiscid beetles and notonectids.

Group 3 consisted of eight sites mostly on shallow wetlands. Several sites feature an excavated sump or dam to hold water for cattle throughout the dry season. Characteristic species are all invertebrates; a depauperate fish fauna is present at some sites.

Group 4 consisted of seven sites, four of which are remnant channel pools on Newcastle Creek. Characteristic species included *Leiopotherapon unicolor*, *Tasmanoceonis arcuata*, *Ambassis* sp. NW and

Melanotaenia splendida. The Newcastle Creek system fish fauna comprises six species: *L. unicolor*, *M. splendida*, *Porochilus argenteus*, *Neosilurus hyrtlii* and *Nematalosa erebi*. The number of species present at a site declines with distance from refugial habitat. Only two fish species (*L. unicolor* and *M. splendida*) were recorded at the most upstream site on Newcastle Creek. There are high median values for total nutrients, chlorophyll and turbidity.

Group 5 consisted of five sites and forms a high-level cluster with Group 4. The fish fauna at sites on Newcastle Creek was depauperate; characteristic species included *L. unicolor* and *M. splendida*.

Groups 6, 7 and 8 form sub-groups within a high-level cluster of sites, mostly on the upper Roper River and tributaries. Sites in Groups 6 and 7 are mostly spring-fed riverine sites with high conductivity and low total nutrients, chlorophyll and turbidity. Group 6 consisted of two sites: one featured a diverse mollusc fauna with nine species and the other a diverse fish fauna of 21 species. Group 7 consisted of five sites, all on the upper Roper River and tributaries. Characteristic species of Group 7 included five fish species and the atyid *Caridina* sp. D complex. Group 8 consisted of three sites, all off-stream billabongs in the Roper system. One of these sites featured a diverse fish fauna (21 species) and high total species richness (76 species).

Groups 9, 10, 11 and 12 form part of a high-level cluster of sites, mostly within the Daly and Roper system. Group 9 consisted of a single site on a spring-fed escarpment sandstone steam. This site is the sole example of this habitat type. Group 10 consisted of a single site in the upper King River. Group 11 consisted of four sites, mostly on large riverine channels. Characteristic species included three fish species. Group 12 consisted of five sites on riverine channels with low total nutrients, chlorophyll and turbidity. All sites are located on streams near the northern margin of the study area. Characteristic species included seven fish species, including *Scortum ogilbyi*.

The characteristic species for each group and their environmental features are described in more detail in the Aquatic Ecosystems Baseline Report.

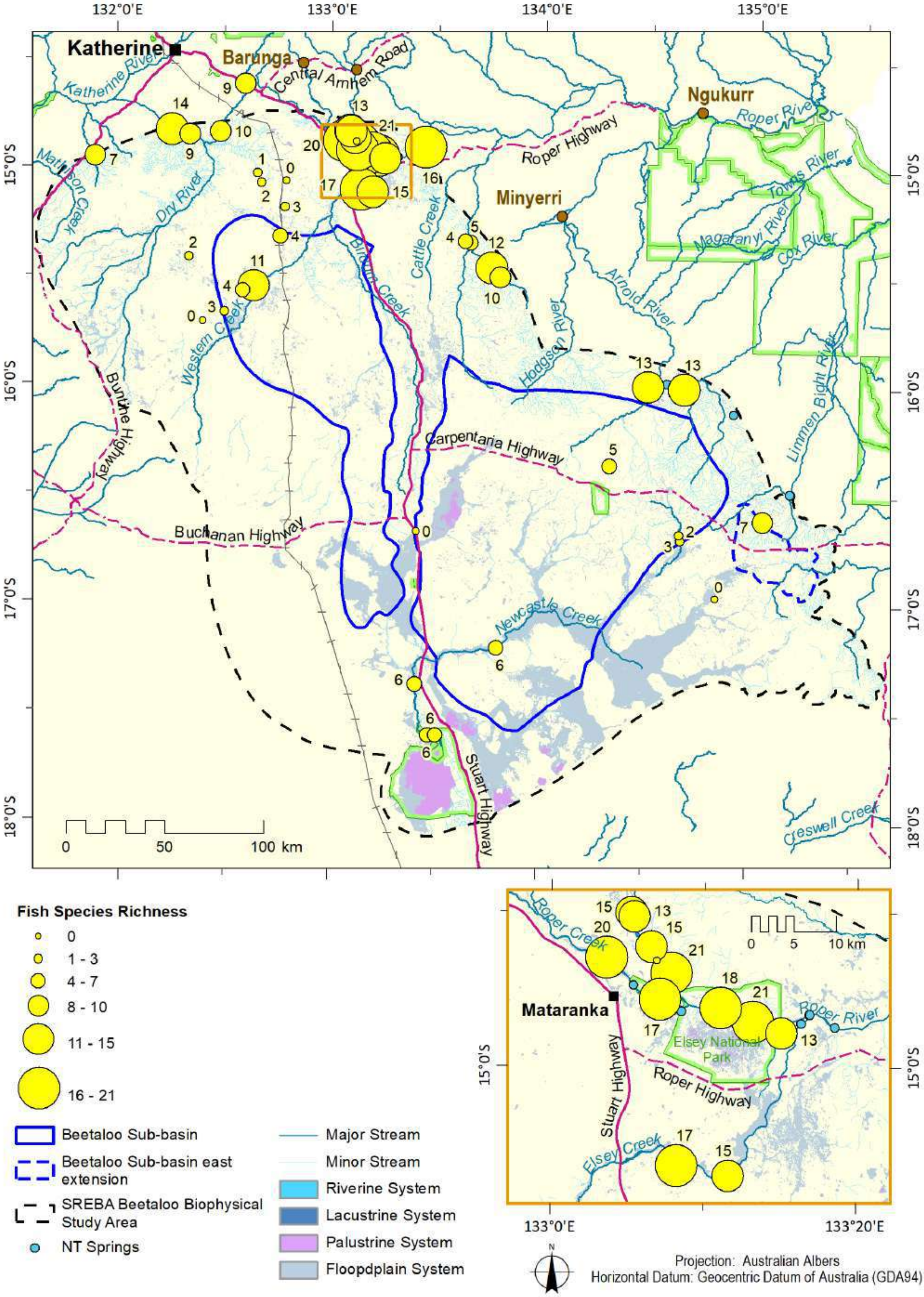

Figure 5-5. Fish species richness at 44 survey sites in the study area.

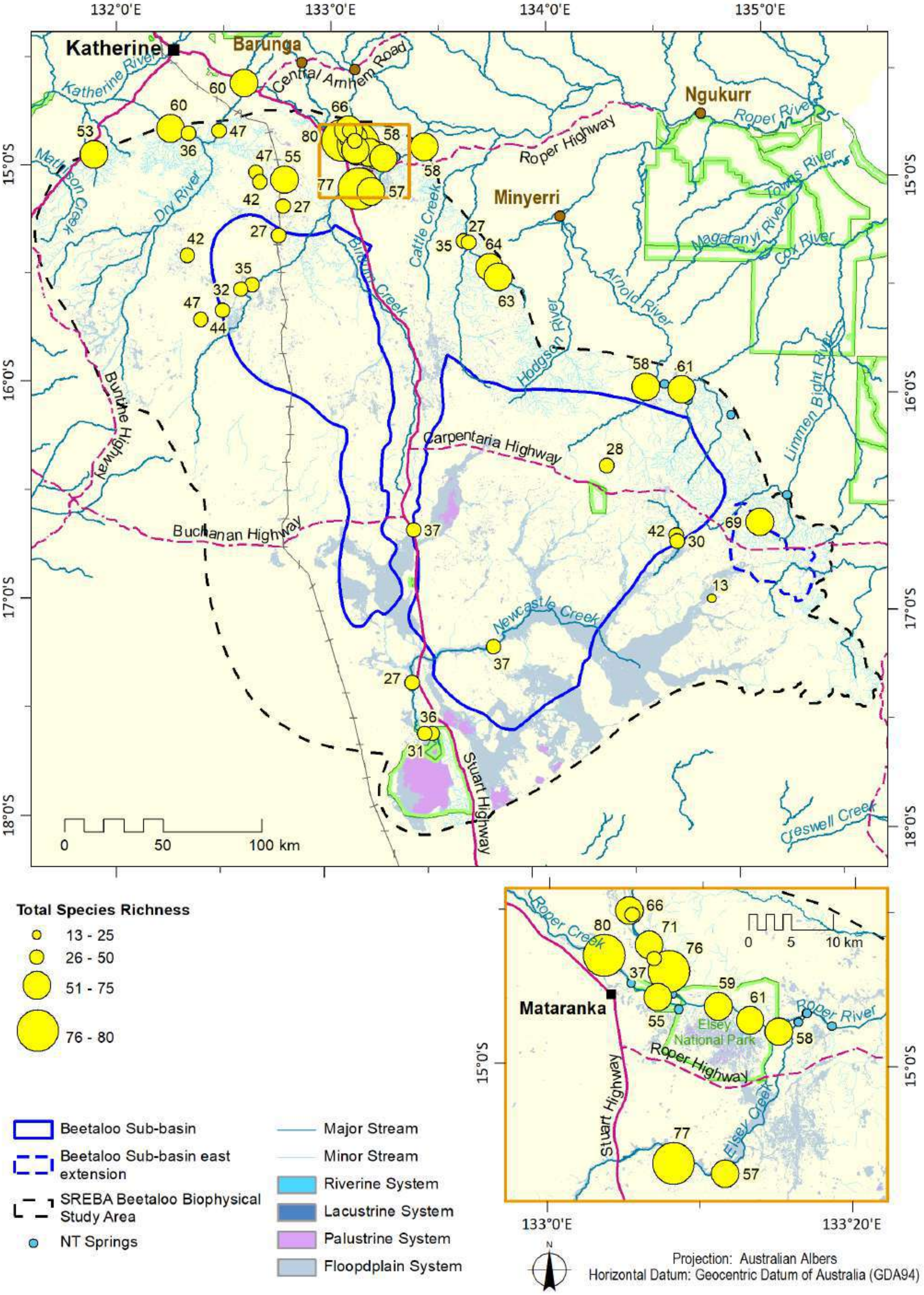

Figure 5-6. Total aquatic species richness at 44 sites in the study area.

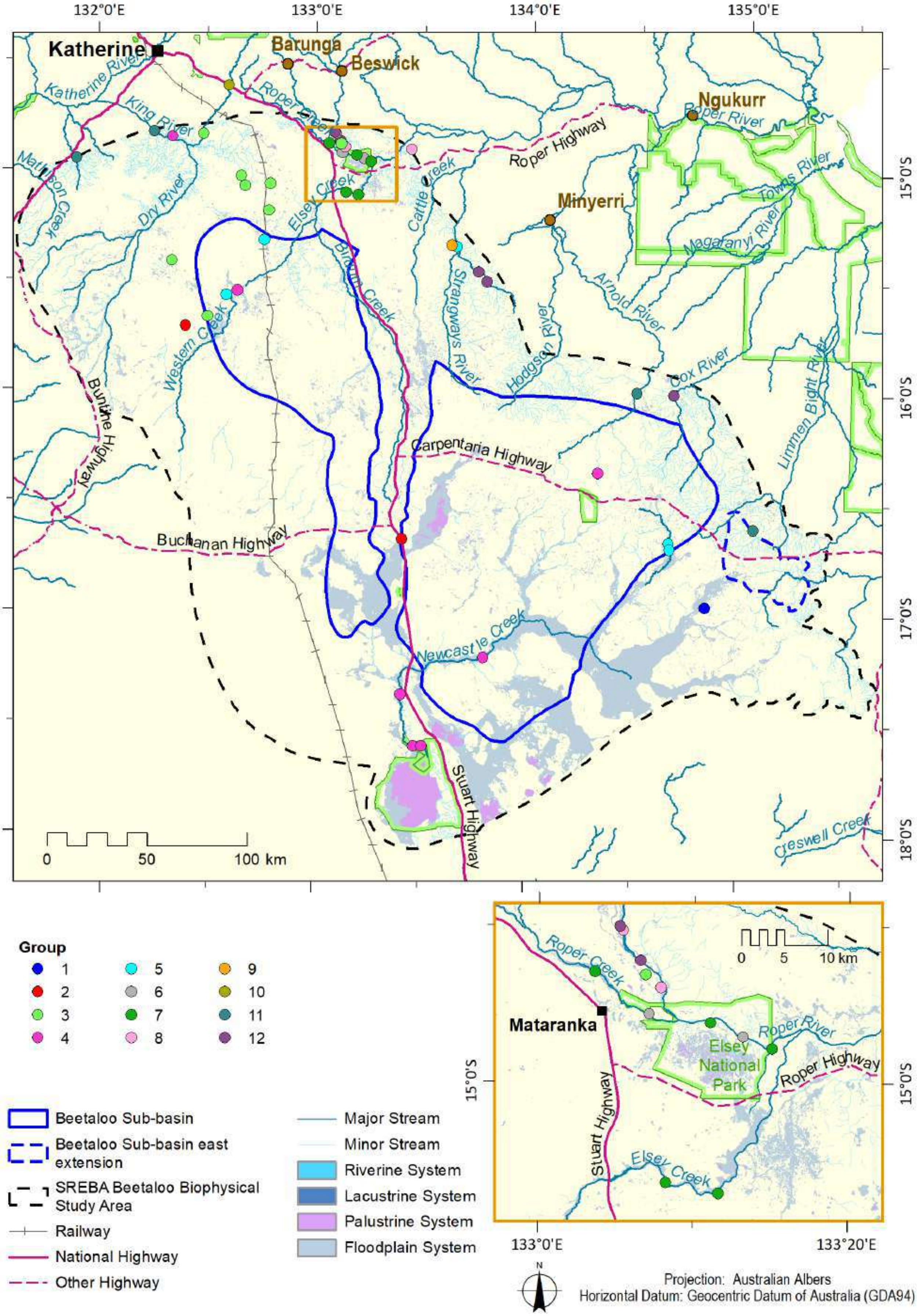

Figure 5-7. Distribution of 12 site groups derived from CLUSTER classification of aquatic species data.

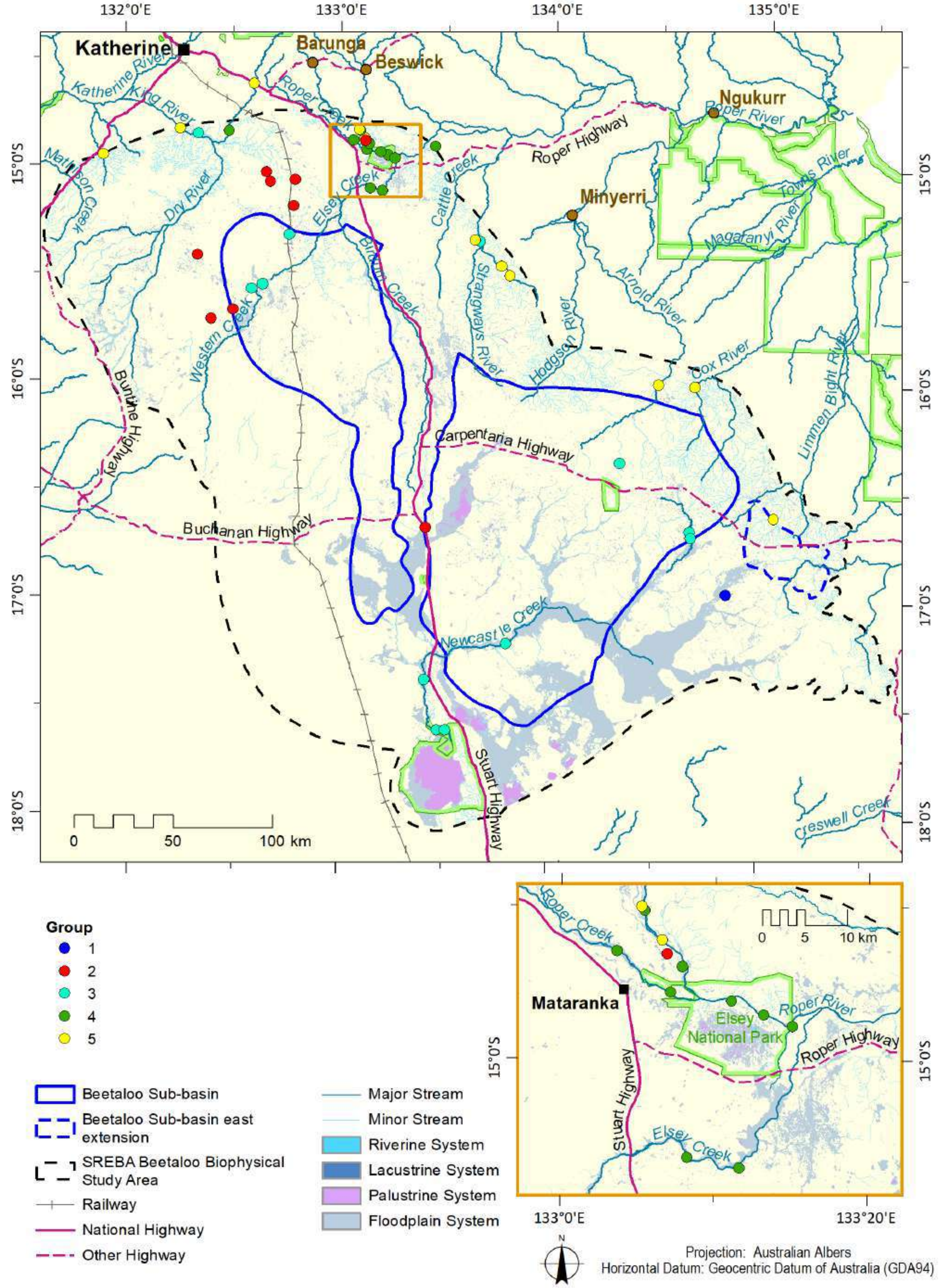

Figure 5-9. Distribution of five high-level clusters derived from CLUSTER classification of aquatic species data.

5.1.4.3. Temporal patterns

There was high turnover in species composition between years, with 113 species (38.1%) only recorded in one year of sampling. Overall, the number of species recorded in 2021 (228) and 2022 (247) was similar. The median number of all species combined per site in 2021 was 37, whereas the median number in 2022 was 57. This particularly reflects a much greater richness of beetles (order Coleoptera) in 2022 compared to 2021. Results of multivariate analyses indicate inter-annual differences in species composition for Coleoptera, Mollusca, chironomid Diptera, and all species combined, but no support for inter-annual differences in species composition for fish and Hemiptera. As sites could each only be sampled on one occasion, spatial and temporal effects on species composition cannot be easily disentangled. Nevertheless, the site groups based on species composition identified above clearly reflect differences in the environmental characteristics as well as geographic location of sites.

5.1.5. Aquatic plants

Aquatic and semi-aquatic plants were recorded and collected at the 44 aquatic survey sites in the study area. Most observations were opportunistic during other sampling activities at a site, rather than being systematic plot-based sampling of aquatic plants. The timing of sampling mitigated against comprehensive inventory of aquatic plants at most sites, as the ephemeral component of the aquatic flora were generally senescent or absent. Plant specimens were collected and preserved in a field press, or as wet specimens in 80 % ethanol, for later identification at the Darwin Herbarium.

Eighty-four species of plants were identified from collections at the aquatic survey sites (see the Baseline Report for the full species list). Of these, 33 were aquatic and 33 were semi-aquatic according to an *a priori* categorisation of the Northern Territory flora. Eighteen species that had not previously been categorised as either aquatic or semi-aquatic were collected, mostly on the dry floodplain fringe of waterbodies. Two of the record species have a recognised conservation significance: *Dentella minutissima* is listed as Near Threatened and *Ioatasperma sessilifolium* is listed as Data Deficient under the *Territory Parks and Wildlife Conservation Act 1976*.

5.1.6. Frogs

Frogs were surveyed in the study area using recognition of vocalisations in digital recordings from 31 sites. The frog fauna of the study area is relatively well documented, and a key objective of this survey was to test the use of audio sampling as a method of site-based assessment for frogs and its potential utility for monitoring.

Sound recorders were deployed in February 2022 in suitable frog habitat within the study area, including beside creek lines, roadside drains and borrow pits along main roads (including the Stuart Highway, Roper Highway, Carpentaria Highway and Gorrie Road). All recorders were scheduled to record for one minute at ten-minute intervals from 8 pm to 12 midnight, and were deployed for approximately 20 days.

The study collected a total of 12,378 digital recordings of 1 minute duration. Manual assessment of individual sound files is time-consuming; therefore, a systematic strategy to sub-sample the data was implemented. Seven hundred and two recordings (5.7% or nearly 12 h) were examined to identify frog calls using the sound analysis software program ‘Audacity’ and using call recognition and examination of the spectrogram of each file. A small number of recordings were sent to experts in the Flora and Fauna Division and at the Australian Museum to confirm species identifications.

For data analysis, data were scanned by processing a single file (at 21:00 hours) from each day and site to detect the species present. Results were tabulated to show frequency of occurrence of frog species across all sampled sites per survey day, and these data were used to analyse temporal variation in detection. These results were used to target addition assessment of recordings from 20:00, 22:00 and 23:00 h during peaks of calling activity.

Analysis of sound recordings at 31 survey sites identified 17 species. Four species (*Rhinella marina*, *Litoria rubella*, *L. rothi* and *Cyclorana australis*) are common and widespread throughout the region and were found to occur at most sites. Twenty-nine species are known to occur in the region and eight species not detected by the sound recordings were observed during the SREBA surveys. Some species (*Litoria coplandi* and *Litoria meiriana)* that were not recorded occur only in rocky upland streams, which were not sampled. The timing of the audio survey reduced the probability of detection of many *Cyclorana* species, which tend to emerge and commence breeding early in the wet season.

Sound recorders may provide a useful method for monitoring frog activity and assemblage composition, as they can be deployed over extended periods in multiple locations. This study demonstrated that the very large amount of data collected can be sub-sampled to substantially reduce processing time. The location and timing of sampling requires careful consideration in relation to the objectives of monitoring, especially if one objective is to maximise the number of frog species that are recorded.

5.1.7. Water quality

Environmental data, including data on water quality parameters, were collected at each survey site in order to provide information on baseline condition, as well as to provide explanatory variables for the analysis of biological data. At each site, *in situ* data were collected on physico-chemical variables, including water temperature, dissolved oxygen, pH, conductivity and turbidity. Water samples were also collected for laboratory analysis of total nutrients, ionic composition, alkalinity, hardness, total dissolved solids, isotopic composition and chlorophyll concentration.

There was high variability in water quality parameters among sites across the region, and this variability was mostly aligned with latitude (Figure 5-10). The most marked contrast was between sites from Newcastle Creek, and those from the upper Roper River and spring-fed tributaries (including Elsey Creek, Salt Creek and the Little Roper River). Newcastle Creek sites are characterised by low conductivity and high nitrogen, phosphorus and turbidity; Roper River sites are characterised by high conductivity and low nitrogen, phosphorus and turbidity.

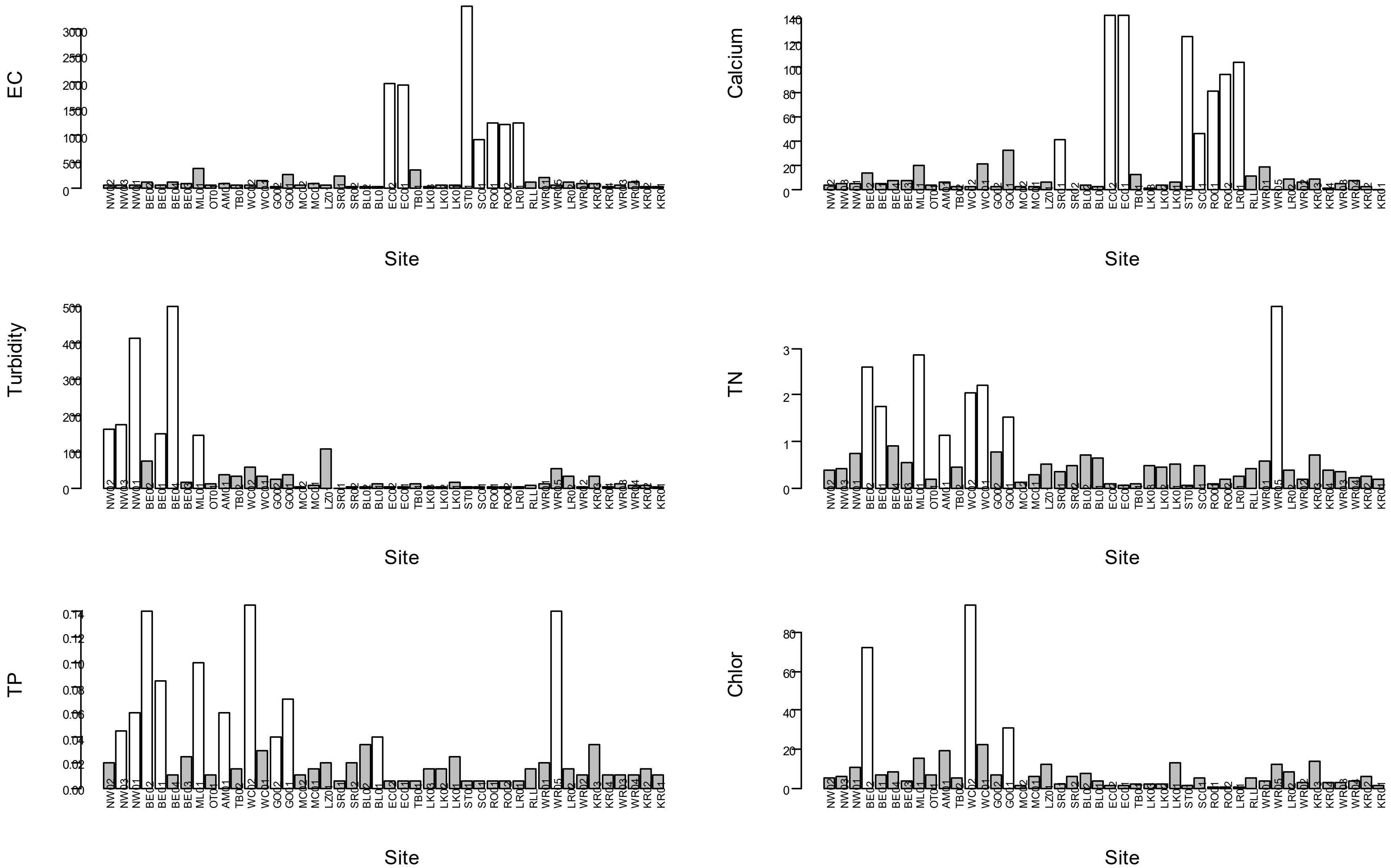

Figure 5-10. Bar plots of values of six water quality variables at 44 SREBA study sites, ordered by latitude from south to north. EC = electrical conductivity, TP = total phosphorus, TN = total nitrogen, Chlor = chlorophyll *a*.

5.1.8. eDNA surveys for significant species

Existing data and sampling undertaken during the GBA and SREBA aquatic ecology surveys highlighted two species of conservation significance — Largetooth Sawfish *Pristis pristis* and Gulf Snapping Turtle *Elseya lavarackorum* — which are poorly documented and are difficult to detect using conventional survey methods. Thus, use of environmental DNA (eDNA) to detect these species was trialled during the aquatic surveys.

In August 2022, water samples for eDNA analysis were collected and preserved on site at 15 locations in the Roper River system. Environmental DNA extractions were carried out in the eDNA laboratory at TropWATER, James Cook University, Townsville and DNA detection was performed using species-specific qPCR assays developed by Cooper *et al.* (2021).

There were no positive detections of the DNA of Largetooth Sawfish in samples from the Roper River, even at a site where the species is known to occur. Most of the sampling locations (14 of 15) were located on the main river channel or in flowing tributaries. Previous studies reported failure to detect Largetooth Sawfish in the main river channel of the Daly River, where they are known to occur, possibly because of high water flow and high turnover rates.

DNA of the Gulf Snapping Turtle was detected at six of 15 survey sites (Figure 5-11). There were detections at two of the three sites (12 Mile Yard and Four Mile) at which the Gulf Snapping Turtle is known to be present from physical searches, and an eDNA detection from a site at which the species was not found during physical searches. These results should be considered to be preliminary as further testing is required to validate the ability of the eDNA method to differentiate *Elseya lavarackorum* and *Elseya dentata* (Roper).

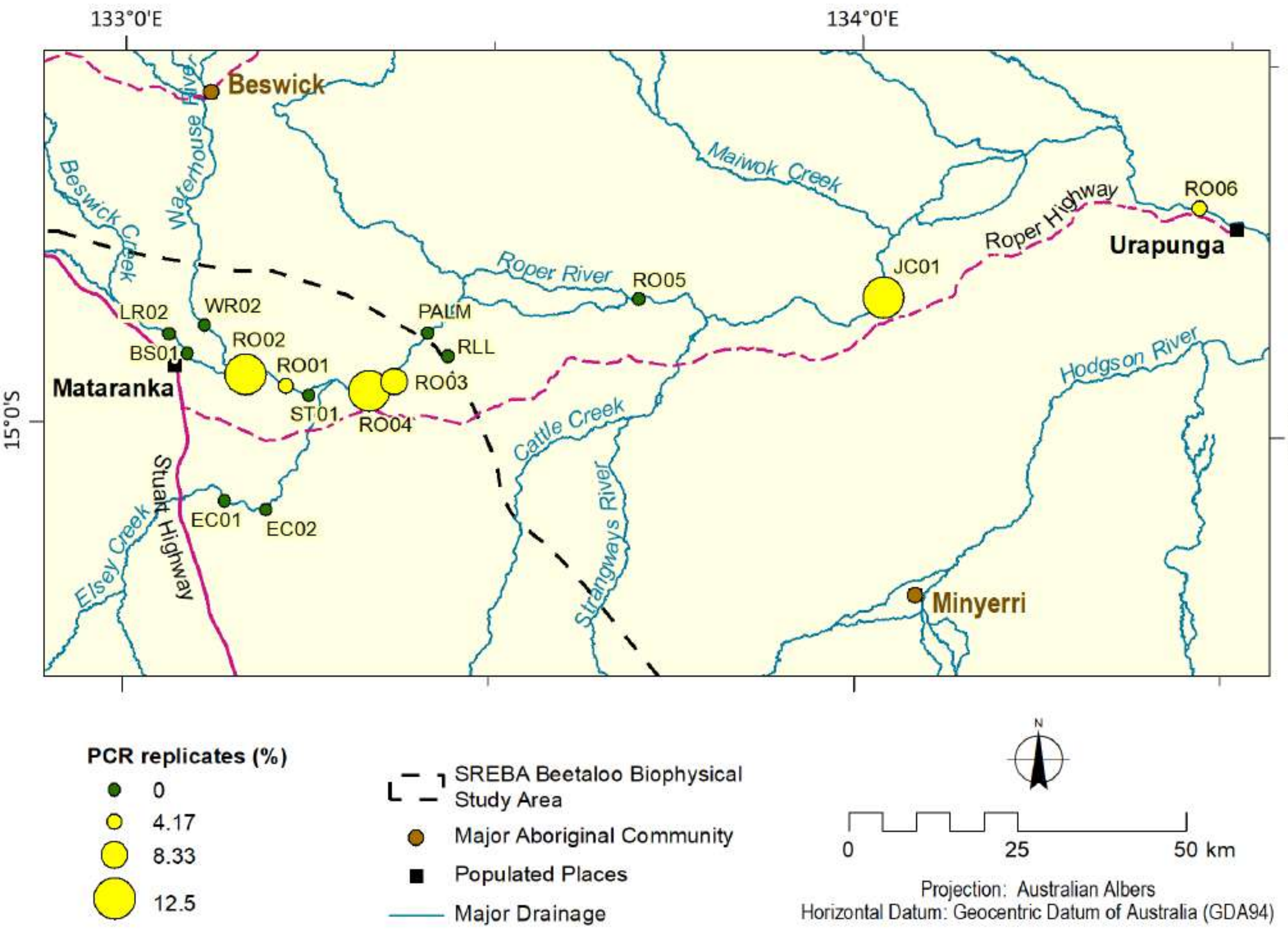

Figure 5-11. Sampling and detection sites for environmental DNA from the Gulf Snapping Turtle.

5.1.9. Resolving taxonomic uncertainties

Intensive biodiversity surveys, such as the ones undertaken for the SREBA, often collect samples that cannot readily be attributed to a known species, or belong to taxonomic groups where species-level identities and distributions are poorly understood. Taxonomic uncertainty can limit the interpretation of results from biodiversity surveys in terms of both understanding biogeographic patterns and identifying significant species and sites. The Museum and Art Gallery of the Northern Territory was engaged to assist with fish identification and to help document the ecological assets of the study area. This involved contribution to fieldwork planning and standard operating procedures and for quality assurance through expert identification of voucher material. Additionally, molecular analyses conducted by the Museum and Art Gallery of the Northern Territory were used to clarify or resolve taxonomic problems in several species-groups of fish and decapods, and to correct anomalies in field identifications. In many cases, these analyses contribute to larger-scale studies of problematic taxa, and so place records from the SREBA region in the context of broader-known distributions patterns.

Analyses and results are described in detail in Section 5 of the Aquatic Ecosystems Baseline Report but are summarised below.

- Fork-tail Catfishes (family Ariidae): Both *Neoarius graeffei* and *Neoarius berneyi* appear to occur in the Roper River, but initial genetic data were complex and there is significant variation in some morphological identification features in specimens attributed to *Neoarius berneyi.*
- Eel-tailed Catfishes (family Plotosidae): A new record of Silver Catfish *Porochilus argenteus* was made during the SREBA study from the Roper River system; this species was otherwise only known from inland Australia and the eastern Gulf of Carpentaria. Two lineages were observed in Hyrtl's Catfish *Neosilurus hyrtlii* in the Roper system, but a much bigger dataset is required to resolve species' boundaries in this group.
- Rainbowfishes (family Melanotaenidae): Two species are known from the study region: Western Rainbowfish *Melanotaenia australis* occurs in north-western flowing rivers including the Daly; while Eastern Rainbowfish *Melanotaenia splendida* occurs in eastern Arnhem Land and across the Gulf, as well as in inland drainages such as the Barkly Tablelands. Preliminary genetic data show that both the *M. s. inornata* and *M. s. tatei* genetic groups occur in the study region. A third species of Rainbowfish — the Exquisite Rainbowfish *Melanotaenia exquisita* — was recorded as a single individual from Dooley Swamp, Roper River system. This is a narrow-range species that occurs in escarpment habitats and the fish encountered appears to have washed down from known populations further upstream in the Waterhouse River catchment.
- Swamp Eels (family Synbranchidae): The Australian Swamp Eel *Ophisternon gutterale*, which occurs from the Daly River across northern Australia and down the east coast to Brisbane, is thought to represent multiple taxa. Genetic analyses to date suggest that there is a distinct lineage (likely a species) present in the Roper River and Gulf region of the Northern Territory, including in the study area.
- Glassfishes (family Ambassidae): Two freshwater species of *Ambassis* were well represented in SREBA sampling: *Ambassis macleayi* and *Ambassis* sp. NW. Recent research has identified a third freshwater *Ambassis* from the Roper, *Ambassis elongate*, that occurs in the study area, including in Warloch Ponds and Elsey Creek. A verified sample of *Parambassis gulliveri* from within the study area at Clint's Gorge, Cox River is a significant range extension into the western Gulf region.
- Purple-spotted Gudgeons (family Eleotridae): three distinct genetic groups of Purple-spotted Gudgeons that likely represent species occur in the study area, each in discrete geographic areas.

- Genetic analysis confirmed that a specimen provisionally identified as Toothed River Herring *Clupeoides papuensis*, which was thought to be a new record for the study area and region, was actually a juvenile Bony Bream *Nematalosa erebi*.
- Redclaw Crayfish *Cherax quadricarinatus* (family Parastacidae): genetic assessment of samples from the SREBA area and surrounds showed an unexpected third lineage unique to the Roper system (Little Roper), in addition to the previously known northern and eastern lineages.
- Freshwater Crabs (family Gecarcinucidae, genus *Austrothelphusa*): Considerable variation was noted in gross morphology (e.g. claw shape) and colour between animals from different sites in the SREBA study area and this warrants further genetic analysis within a broader investigation of this group.

5.1.10. High-value sites and significant species

5.1.10.1. Threatened species

There are four listed threatened fauna species in the study area (Table 5-1).

Table 5-1. Threatened aquatic fauna that occur within the study area, with status under the *Territory Parks and Wildlife Conservation Act 1976* (TPWC Act) and the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Common name	Species name	TPWC Act	EPBC Act
Mertens' Water Monitor	*Varanus mertensi*	Vulnerable	Not listed
Mitchell's Water Monitor	*Varanus mitchelli*	Vulnerable	Not listed
Gulf Snapping Turtle	*Elseya lavarackorum*	Least Concern	Endangered
Largetooth Sawfish	*Pristis pristis*	Vulnerable	Vulnerable

Mertens' Water Monitor (*Varanus mertensi*) and Mitchell's Water Monitor (*Varanus mitchelli*) are semi-aquatic and occupy coastal and inland rivers, margins of watercourses and swamps and lagoons. In the Northern Territory, both species have declined following the spread of the Cane Toad. *Varanus mertensi* was detected at four sites and *Varanus mitchelli* at one site.

The Gulf Snapping Turtle (*Elseya lavarackorum*) is known to occur in the Nicholson-Gregory drainage, the Calvert drainage and the Roper drainage (Georges *et al.* 2021). The presence of *Elseya lavarackorum* in the upper Roper system was confirmed by analysis of genetic samples collected during the Beetaloo GBA surveys. These analyses also found that *Elseya dentata* from the Roper and Limmen Bight drainages are distinctly different from *E. dentata* from the Daly River, and probably represent a new and distinct taxon (Georges *et al.* 2021). In the upper Roper, *E. lavarackorum* co-occurs with *Elseya dentata* (Roper form) and *Emydura subglobosa worrelli*. *Elseya lavarackorum* was detected at three adjacent sites plus at additional eDNA sample sites.

In contrast to all other turtle species in the area, *E. lavarackorum* could not be caught by trapping and all individuals were captured at night with a dip-net and spotlight. The biology and ecology of the species are largely unknown but it appears likely that the species is herbivorous. It was most abundant at site RO01 (12 Mile Yard), which featured high conductivity, low total nitrogen and chlorophyll, high water clarity, and dense meadows of submerged macrophytes including *Anopogeton vanbruggenii* and *Ottelia alismoides*. Potential threats to the species in the Roper River include reduction of dry season flows and increases in nitrate concentration of groundwater from agricultural development (Abascal *et al.* 2022).

Largetooth Sawfish (*Pristis pristis)* is listed under the *Environment Protection and Biodiversity Conservation Act 1999* as a threatened species and as a migratory species. Largetooth Sawfish probably occur throughout the Roper system but there have been no systematic surveys to map their distribution within the river. Largetooth Sawfish give birth to young in their natal river system, resulting in genetically distinct populations within each river drainage across the species' range (Feutry *et al.* 2015). The freshwater reaches of the Roper River and tributaries act as a nursery area for Largetooth Sawfish, but adult-sized individuals do occur in upstream waters and this study captured a Largetooth Sawfish measuring 3.4 m in length at 12 Mile Yards. Barriers to migratory pathways due to excessive water extraction leading to low water levels are a potential threat to the persistence of populations of Largetooth Sawfish in the Roper River system.

5.1.10.2. High-value sites

Four metrics derived from the systematic aquatic biodiversity surveys were used to assess high-value sites, based on previous frameworks to identify High Conservation Value Aquatic Ecosystems (HCVAE) (e.g. Kennard 2010). For each metric, data were mapped and the top-ranked sites for each metric were listed.

a) Total taxa richness is the sum of the number of species in each of the eight taxa groups: fish, aquatic reptiles, Coleoptera, Hemiptera, Decapoda, Ephemeroptera, chironomid Diptera and Mollusca.

Total taxa richness ranged from 13 to 80 species, with a median value of 47 species. High values of total taxa richness occur on riverine sites in northern-draining catchments (Figure 5-12). Eight of the top ten sites occur in the Roper catchment, with the maximum value of 80 at site LR02, which was on a seasonally flowing channel of the Little Roper River.

b) Mean standardised richness is the average of species richness for each taxa and site divided by the maximum number of species for each taxa. The score may be biased by taxa with smaller numbers of species. It provides an unweighted measure of the diversity of all groups.

Mean standardised richness varied from 7.9 to 62.2, with a median value of 32.4. All of the top ten ranked sites occur within the Roper catchment, mostly within the area of the Mataranka Thermal Pools Site of Conservation Significance.

c) Number of unique species is the sum of species at each site that only occur at a particular site. The score may be biased for sites in rarely sampled habitats or that occur in another biogeographic province.

A total of 60 species occurred only at a single site. Five of the top ten ranked sites occur in the Roper catchment, with the maximum value of six at site WR02 on the Waterhouse River (Figure 5-13).

d) Number of threatened species is the number of species that are listed under relevant Northern Territory or Australian legislation.

Threatened taxa were found at six sites, with one site having three of these species.

Multiple lines of evidence indicate that the highest conservation values for aquatic biodiversity occur in the northern margin of the study area, and largely align with the Mataranka Thermal Pools Site of Conservation Significance. These lines of evidence include data on the distribution of fish and total aquatic species richness, the presence of listed species including a significant population of Gulf Snapping Turtle, the high proportion of the known stygofauna of the region, and data on genetic diversity.

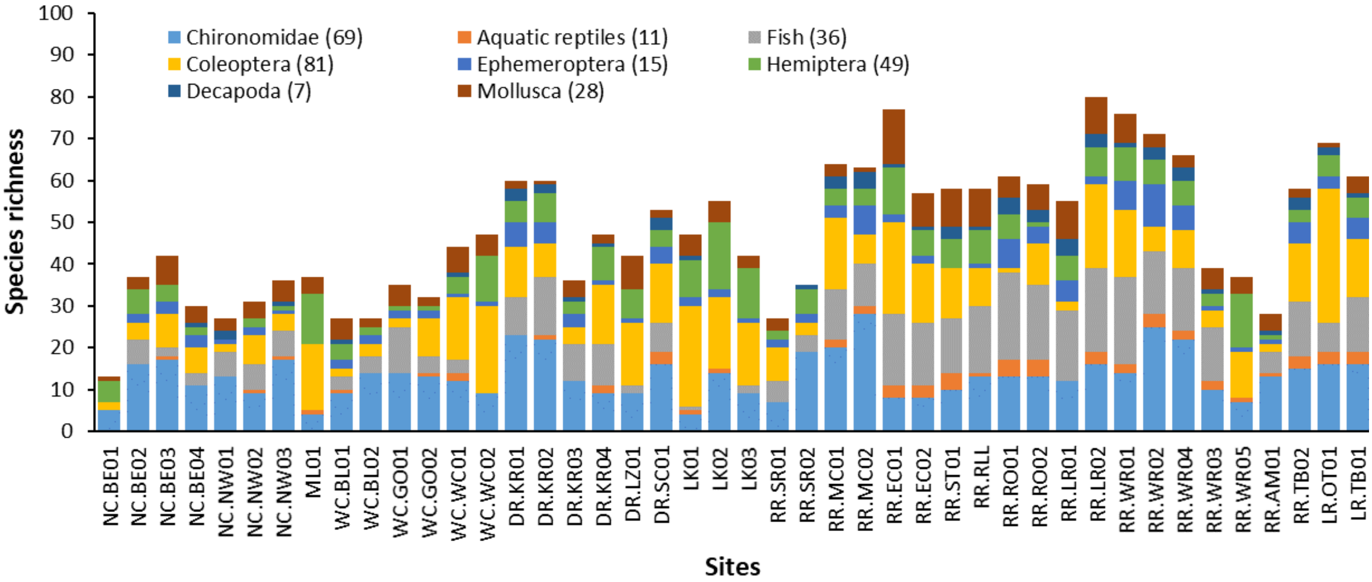

Figure 5-12. Bar plot of species by taxa group at 44 survey sites, ordered by river system, where NC = Newcastle Creek, WC = Western Creek, DR = Daly River, RR = Roper River (not including Western Creek), LR = Limmen River.

There are two main clusters of groundwater springs in the region that sustain distinctive aquatic ecosystems: in the upper Roper, Elsey Creek and Salt Creek; and in the vicinity of Clint's Gorge on the upper Cox River. There are several other sites with some groundwater influence, including Paddy's Spring, Maryfield Creek, King River and OT Lagoon.

By contrast, waterbodies within the Beetaloo Sub-basin would predominantly be Group 4 and Group 5 site types and feature low fish species diversity and a widespread, disturbance-tolerant invertebrate community.

Nevertheless, refugia throughout the region are important for the maintenance of aquatic biodiversity. Upstream migration to locate and exploit new resources is a fundamental feature of fish ecology in northern Australia. For example, wet season flooding opens corridors for fish movement through intermittent systems such as Western Creek. Field data and information from landowners on Western Creek indicate regular wet season connection with downstream refugia. This places high priority on the protection of refugia, and the need to maintain connectivity with refugia.

Notable taxa in the Victoria-Wiso catchment include the large gastropod *Notopala waterhousii*, Silver Catfish *Porochilus argenteus* and Cann's Turtle *Chelodina canni*. *Notopala waterhousii* is the largest freshwater gastropod in Australia; the Silver Catfish occurs across the catchment boundary into the upstream reaches of northern flowing streams; and Cann's Turtle occurs in ephemeral waterbodies and aestivates in mud during the dry season. The details of the ecology of this remarkably tolerant species are not well known.

Waterbodies on intermittent systems in the region also have high conservation value as waterbird habitat, as described in the SREBA Terrestrial Ecosystems report. For example, some nutrient-enriched, shallow waterbodies on Newcastle Creek are highly productive, with high phytoplankton density underpinning enormous populations of fish and large numbers of piscivorous waterbirds, including cormorants and pelicans.

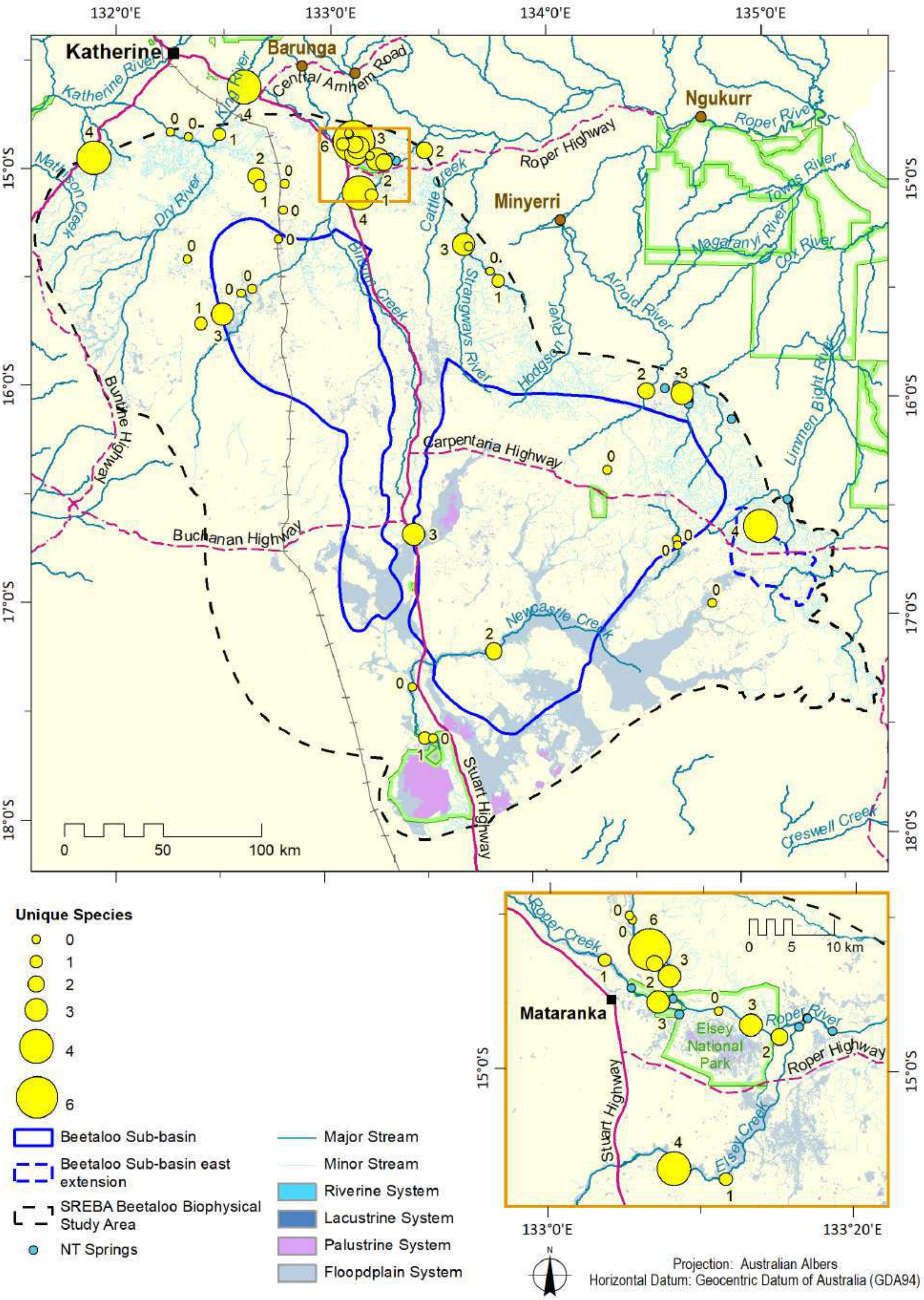

Figure 5-13. Number of unique species at 44 study sites in the study area.

5.1.11. Monitoring

Much of the aquatic fauna of the region is comprised of vagile species, many of which are widely distributed across northern Australia. In general terms, monitoring should focus on fully aquatic species rather than air-breathing species (which are at lower risk of water-borne contaminants), on perennial rather than ephemeral waterbodies, and pay special attention to the water quality and water volume needed to sustain sites of high conservation value.

Monitoring should target fully aquatic species such as fish, molluscs and decapods, rather than air-breathing aquatic species at low risk from water-borne contaminants. These taxa have the additional advantages of well-established taxonomy, relative ease of identification, public recognition of their value as monitoring indicators, and some species are utilised for human consumption. Other taxa with claims for selection as indicators for monitoring include odonates, aquatic beetles, and turtles. Odonates (dragonflies and damselflies) have fully aquatic immature stages, enjoy a high public profile, and are easily identified as adults. As for many invertebrate groups, sampling for odonates may need to be restricted to the window of peak activity at the transition of the wet and dry season. Aquatic beetles have the advantages of well-established taxonomy and relative ease of identification. In this study, beetles comprised a fifth of the total number of all aquatic species. Turtles are relatively easily surveyed and are important food items for Aboriginal people.

The design of future monitoring studies needs to consider contaminant transport pathways, the nature and scale of potential development-related impacts, the choice of target indicators for monitoring, the appropriate timing of sampling for monitoring, and have the capacity to distinguish other confounding effects such as cattle grazing and climate change (Capon *et al.* 2021). Establishing the power to separate development-related impacts from natural variability requires a carefully stratified design and ongoing sampling to improve the temporal baseline.

Sampling methods will be determined by the choice of target indicators. Sampling the entire fish assemblage at a site may require the use of multiple sampling methods. However, sampling could be refined to target particular species, or a group of species, rather than the entire assemblage present at a site. Standard methods such as electro-fishing may be ineffective in sites with high turbidity that restrict the visibility, capture and identification of immobilised fish.

Candidate sites for monitoring should be selected from the set of sites identified as potential aquatic refugia by the Aquatic Ecosystems study, and more detailed recommendations are provided in the Baseline Report. Special attention needs to be directed to sites of high conservation value that are potentially vulnerable to impacts associated with water extraction and contamination of groundwater, such as the spring-fed upper reaches of the Roper River and Clint's Gorge on the Cox River.

Sampling based on the analysis and detection of environmental DNA may circumvent some of the practical difficulties of sampling in remote, frequently turbid waterbodies, but requires a reference DNA database for local species, and validation studies to compare the probability of detection of eDNA versus conventional methods of sampling.

5.2. Stygofauna

5.2.1. Background

The stygofauna assessment described here forms part of the Aquatic Ecosystems baseline studies for the Beetaloo SREBA program.

Stygofauna comprise aquatic taxa occurring in groundwater aquifers and subterranean water bodies. Stygobites are obligatory subterranean habitat dwellers that, while they may occur close to surface environments, are strongly adapted to subterranean environments and cannot persist in surface habitats. Stygal communities in northern Australia are predominantly crustacean in composition, with typical groups including Amphipoda, Isopoda, Decapoda, Syncarida, Ostracoda and Copepoda. However, worm taxa and other faunal groups are also commonly collected, and there are a small number of stygal vertebrate species. Subterranean fauna habitats are characterised by shared physical parameters that include an absence of light, stable temperatures, limited nutrient infiltration from surface environments and a constant humidity or saturation. These habitat characteristics have resulted in evolutionary convergence in body morphology amongst many subterranean fauna, such as reduction or absence of pigmentation, reduced or lack of eyes, elongate body morphology, and appendages adapted for sensory movement

The Northern Territory has, in general, had very limited sampling for stygofauna relative to other parts of Australia. The lack of historical contextual data presented a limitation to placing the findings of the current work into wider context. Recent surveys in the north of Australia have collected subterranean fauna from a range of geological units such as limestone, calcretes, unconsolidated alluvium, channel iron deposits and hard rock aquifers. It is inferred from this that the suitability of a formation as habitat for subterranean fauna is mostly a function of the availability of habitable space, rather than being inherent to any specific geological unit.

Troglofauna are a suite of fauna that survive only in air-filled cavities and interstices occurring between the ground surface and the water table. Troglofauna were not considered in the current study.

5.2.1.1. Study area

The study area was the biophysical study area described in Section 3.1 and shown in Figure 3-1. However, because the Tindall Limestone formation was clearly important for stygofauna, sites were also sampled in this formation to the north of the study area (in the vicinity of Katherine), to provide additional context to the results.

The Beetaloo SREBA region includes part of the sedimentary Daly Basin, extending to the north, and the Wiso and Georgina basins, which extend beyond the area of the Beetaloo Sub-Basin to the south-west and south-east, respectively. The most important aquifer in the study area is the Cambrian Limestone Aquifer, which is an extensive regional groundwater system covering approximately 474,000 km^2 of the central NT (Lamontagne *et al.* 2021). The Cambrian Limestone Aquifer is separated into several formations, five of which occur within the study area: Jinduckin (which overlies the Tindall formation in the northeast), Tindall, Montejinii, Gum Ridge and Anthony Lagoon (which overlies the Gum Ridge formation in the southeast) (Figure 5-14). The three most important formations for the purposes of this study are the Tindall, Gum Ridge and Montejinni formations.

Based on its structural characteristics, the Tindall limestone is the most likely formation to represent stygofauna habitat, considering its structure provides suitable widely-connected and highly transmissive habitat space for fauna below the water table, and significant recharge occurs from the surface through sinkholes and other surface karst features. Karstic limestone is widely recognised as an important habitat for subterranean fauna in Australia and globally.

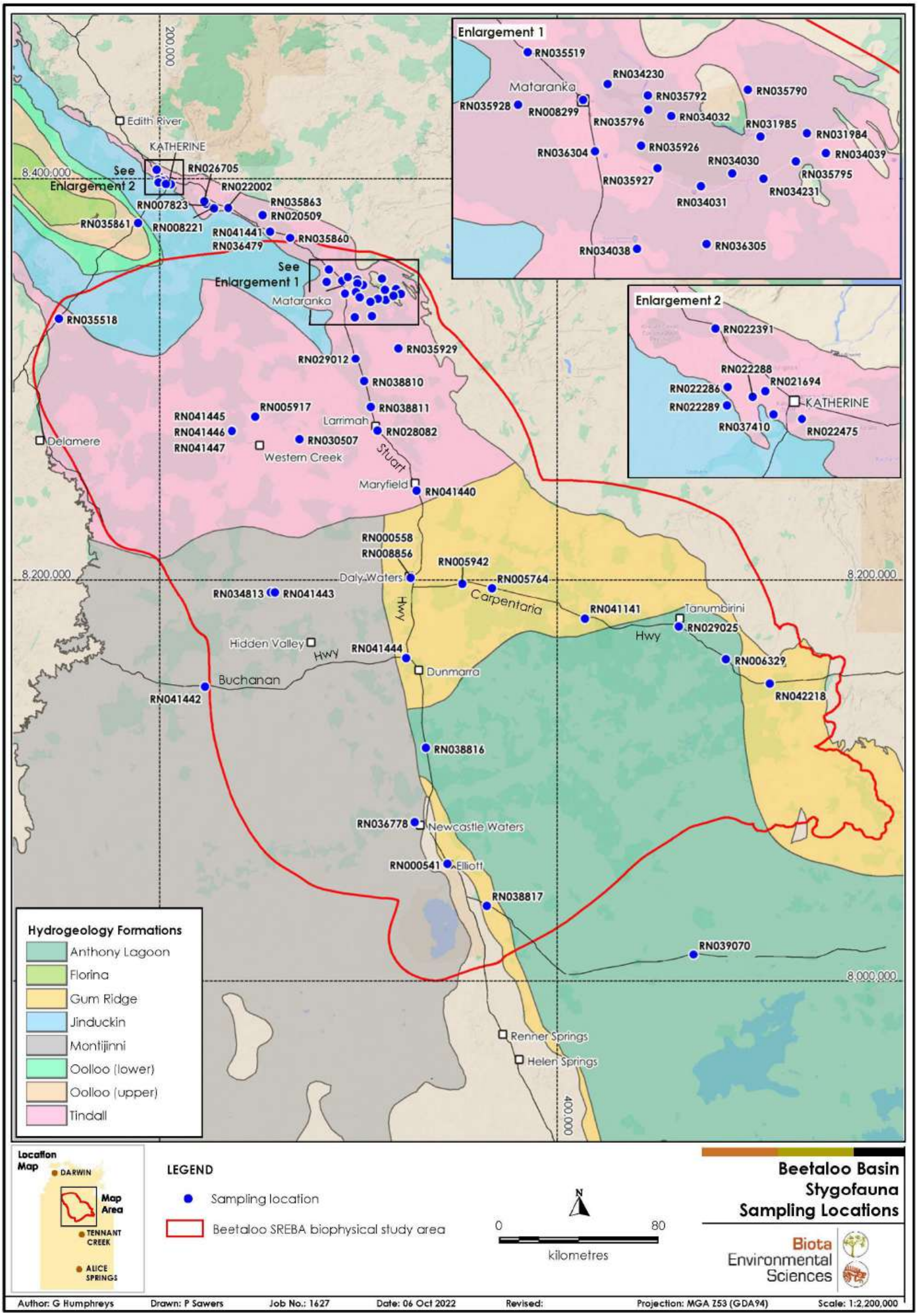

Figure 5.14 Sites sampled for stygofauna in context with the study area boundary and hydrogeological formations.

5.2.2. Methods

5.2.2.1. Existing information

A desktop review of existing information was undertaken to collate any available context to the baseline assessment of stygofauna in the study area. This considered previous relevant work in the vicinity of the study area, information on hydrogeology and searches of relevant databases, notably the *Atlas of Living Australia*, which also incorporates all specimen records from museum collections.

Only one systematic study of relevance was identified: stygofauna sampling undertaken by CSIRO in collaboration with Charles Darwin University and Latrobe University during 2019 (Rees *et al.* 2020). That study involved sampling of 26 bores and two surface springs within the study area and documented 17 stygal taxa from a range of taxonomic groups, with the widespread decapod crustacean *Parisia unguis* identified as a potential apex predator. Other work in the study area appears to be limited to informal or opportunistic collecting exercises by individual researchers and speleologists.

Records from the relevant publicly available sources located during the desktop review were consolidated into a standardised taxonomic hierarchy and format, which is summarised in the Baseline Report. The majority of the *Atlas of Living Australia* records are quite dated, spatially inaccurate and with varying taxonomic resolution.

5.2.2.2. Field surveys

The field survey was undertaken over two phases of sampling in October 2021 and May 2022. Stygofauna can only be readily sampled via groundwater bores that intersect, and are screened within, aquifers where stygofauna may occur. Bores for sampling were selected in order to obtain adequate spatial coverage across the study area; to stratify sampling across the main hydrogeological formations and basins present in the study area; and to obtain an overall number of sampling sites that would adequately characterise the stygal assemblage of the study area, as informed by past studies of a similar scale.

Sampling sites for Phase 1 were selected within the constraint of the existing distribution of boreholes that were accessible for sampling. Site selection for Phase 2 additionally took account of:

- re-sampling sites that reliably yielded specimens during Phase 1
- eliminating sites from Phase 1 where depth to water table was excessive (less likely to yield fauna and time consuming to sample)
- adding sites that were opportunistically located in the field during Phase 1
- including sites near Cutta Cutta Caves to the immediate north-east of the study area to add important contextual data for the *Parisia* specimens sequenced after Phase 1
- focusing effort on the Tindall Limestone aquifer (structurally suitable habitat for stygofauna, shallower water table and downstream of any future potential impacts in the Beetaloo Sub-basin, in addition to Phase 1 data indicating much of the fauna was recorded from this unit).

Of the 91 potential sites selected, 66 were successfully sampled for stygofauna across the two phases (Figure 5-15). Twenty-one of the sites were sampled during both phases, so a total of 87 bore samples were taken. Overall, sites were spatially biased toward the Tindall Limestone formation, and the Daly Basin. This was due to the distribution of groundwater bores within the study area but this formation also has the highest potential to support stygofauna diversity within the study area.

5.2.2.3. Stygofauna sampling

Stygofauna were sampled at each site using custom-built plankton haul nets, constructed from 70 µm plankton mesh, with 50 mm and 100 mm apertures attached to a stainless-steel catch cylinder to weigh the sampling net (EPA 2021). To consolidate a sample for that site, nets were lowered to the bottom of the bores before being hauled through the groundwater to the surface a minimum of five times on each sampling visit.

Samples were sorted under dissecting microscopes by zoologists to recover all stygofauna and to complete initial morphological identifications. Specimens were preserved in 100% ethanol once separated into morphotypes to maximise their utility in molecular (DNA) analysis.

All stygofauna specimens from both phases of sampling were sequenced for variation at the mitochondrial cytochrome oxidase subunit I gene (COI), with some taxonomic groups also sequenced for variation at the more conserved 16S rRNA (16S) gene to enable further clarification of phylogenetic placement. Sequences from the specimens were analysed along with all available reference sequences. The objective of this was to determine the best-fit model of evolution and group haplotypes into lineages and to delineate the number of species-level taxa present. Some specimens could not be successfully sequenced and therefore could not be assigned to known or unknown species.

Groundwater physicochemistry was also logged at each sampling site using a multi-parameter groundwater probe; the aim of this was to characterise groundwater conditions where stygofauna were recorded. Parameters measured were depth (by pressure), dissolved oxygen, electrical conductivity, temperature and pH, with data logged at 5 m below the water table at each site.

5.2.2.4. eDNA sampling

Groundwater samples were also collected and processed from each site for environmental DNA (eDNA) analysis. This relies on the assaying of environmental samples that contain residual DNA that has been shed into the environment from target species. The approach has also been shown to work in groundwater systems and the utility of the eDNA protocols in mapping target stygal species' distributions has been well demonstrated for the Blind Cave Eel *Ophisternon candidum*.

The decapod crustacean *Parisia* sp. (nominally, the described *Parisia unguis*) is a likely apex predator within the study area and indirectly mapping its distribution by means of eDNA has the potential to provide insights into connectivity between aquifer systems. A species-specific eDNA assay for *Parisia* sp. was therefore developed in this study as an adjunct to conventional sampling methods. The assay was tested to demonstrate that it did not amplify other species that had been recorded from the study area and that it was able to detect all known mitochondrial haplotypes of *Parisia* sp. identified from the mitochondrial DNA analysis.

Environmental DNA sampling took place on completion of stygofauna haul net sampling. Three replicate water samples were collected from each sampling site using a 1 L bailer lowered into the bore until the bailer was approximately 1 m from the bottom of the hole. Water samples were filtered at on-site temporary lab facilities through sterile filter membranes (0.45 µm), and the membrane frozen after processing and kept cold during transport to the analysis laboratory. A total of 250 eDNA samples were collected from the 66 sites across the two phases.

A trial degradation study was also performed to assess how long *Parisia* sp. DNA persisted at detectable levels in a sealed aquatic environment. This used live *Parisia* sp. specimens collected in the field and transported to the analysis laboratory, one of which remained alive for over a month.

5.2.3. Results

5.2.3.1. Species diversity

A total of 280 stygofauna specimens were recorded over the two phases of sampling, with records coming from 23 (35%) of the 66 sites sampled. The recorded assemblage comprised at least 28 species-level taxa, excluding indeterminate specimens that could not be resolved to species level. The fauna was strongly dominated by the Crustacea, which was represented by seven orders. Maxillopoda (copepods) and Decapoda (decapods) accounted for over half the specimens collected (42% and 15% of total specimens, respectively).

The genetic sequencing and analysis of all specimens is described in detail in the Baseline Report. For most taxa recorded, the results of the phylogenetic analyses were very clear: the lineages detected were strongly divergent from all available reference data, leaving little doubt that they represent newly recorded species. This is an unsurprising result given the general lack of past stygofauna survey work in the Northern Territory and that novel species are frequently recorded when prospective subterranean habitats are subject to sampling effort.

While the outcomes of the molecular analysis of most groups were relatively clear, the distribution of lineages within some taxa, particularly the decapod *Parisia unguis*, suggests that additional cryptic species could be present. The phylogenetic analysis of the Decapoda also uncovered potential taxonomic confusion within the family Atyidae, indicating that some genera require further taxonomic revision.

The *Parisia* specimens analysed showed considerable genetic structure, with five lineages delineated within *Parisia unguis*. Some lineages appear to be widespread while others are apparently restricted to a formation or basin. Additional sampling and analysis is required to determine both phylogeographic patterns and possible definition of additional species within *Parisia*.

Species accumulation curves and non-parametric predictors of species richness indicate that the stygal assemblage is not fully documented and it is very likely that more taxa remain to be detected in the study area. Estimates of total stygal species richness varied between a predicted 50 and 59 taxa for the study area.

5.2.3.2. eDNA analysis

Of the 66 sites that were sampled for eDNA over the two phases, 32 amplified for the presence of *Parisia* sp. DNA (Figure 5-15). This represented an additional 25 sites beyond those where physical specimens were collected, significantly expanding the mapped distribution of *Parisia unguis* compared to conventionally collected specimen records alone. These additional data demonstrate that the taxon occurs in all hydrogeological formations within the study area, highlighting the value of eDNA sampling as an adjunct survey method.

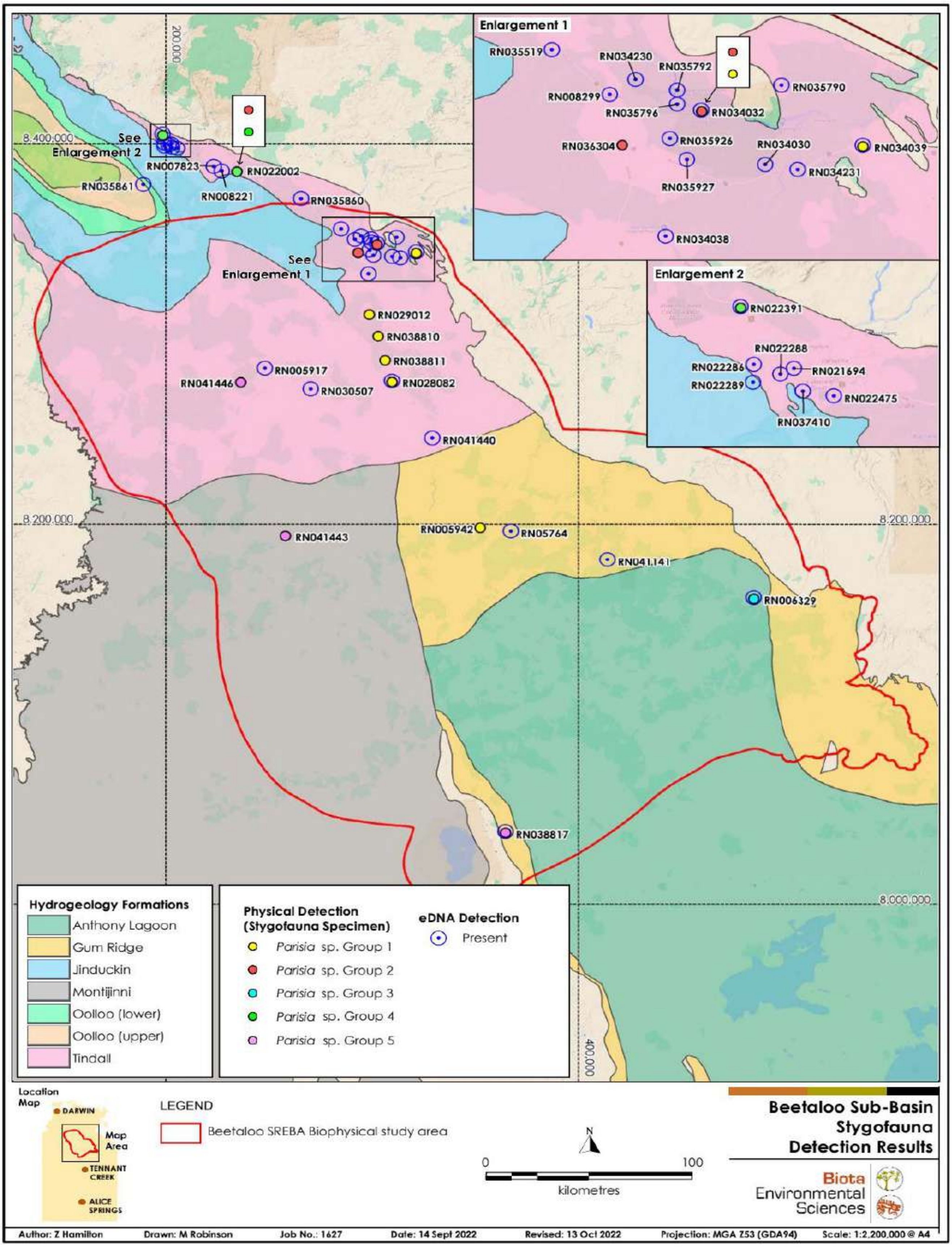

Figure 5-15. Sites with positive *Parisia* sp. environmental DNA detections relative to specimen records of *Parisia unguis* lineages and hydrogeological formations.

5.2.3.3. Spatial and environmental patterns

The highest diversity of stygofauna came from the Tindall Limestone in the north-east of the study area, where 26 of the 28 taxa detected during the survey were recorded. This formation also had the highest proportion of sample sites with stygofauna (73%), and all of the eight sites with more than a single species detected. Only a single stygofauna species (*Parisia unguis*) was recorded from the four sites in the Wiso basin, while five species were recorded from the Georgina Basin, with four of these recorded only within that Basin.

A small proportion of the sites were particularly species-rich and also yielded significant numbers of specimens, a pattern that is common in subterranean fauna sampling. Three bores within the Tindall formation had six, eight and ten taxa and accounted for 61% of the total number of animals collected. All three sites had relatively short distances to groundwater (<16 m) and were dominated by limestone in the superficial portion of the saturated stratigraphy. Overall, mean depths to groundwater in sampled bores in the Tindall formation (25.9 m) were significantly less than in the Gum Ridge (69.0 m), Anthony Lagoon (64.1 m) and Montejinni (84.0 m) formations.

Physicochemical data from the sample sites indicated the groundwater of the study area was, on average, warm (mean: 31.55°C ± 0.15 (standard error)), slightly brackish (mean conductivity of 1,345.46 ± 116.94), neutral (mean pH of 6.98 ± 0.07) and relatively low in dissolved oxygen (1.69 mg/L ± 0.11). There was substantial variability in the measured parameters within each formation and no significant differences between formations. There were significant changes in aquifer conditions between Phase 1 and 2, presumably in response to recharge from surface sources following major rainfall events in the months preceding Phase 2. In particular, mean conductivity in Phase 2 dropped to less than half that in Phase 1, from brackish to within freshwater range.

5.2.4. Conclusions

This study represents the most detailed study of subterranean biodiversity in the Northern Territory to date, and has signficantly increased knowledge of the stygofauna assemblage of the Beetaloo region. When the data from this study are combined with that of Rees *et al.* (2020), and species identifications rationalised as far as is possible, the known stygofauna of the study area now conservatively stands at 38 species-level taxa, 34 of which occur in the Tindall Limestone formation.

Estimates of total stygal species richness varied between a predicted 50 and 59 taxa for the study area. This may still be an underestimate, and experience from regional surveys elsewhere in northern Australia suggest up to ten phases of sampling may be required to come close to comprehensively documenting the fauna.

This study has highlighted the value of the Cambrian Limestone Aquifer as habitat for stygofauna in the study area, and the Tindall Limestone aquifer in particular. This is consistent with the structural and hydrological nature of the Tindall Limestone, as it has a relatively shallow water table, well-developed superficial karst features, and a transmissive and interconnected saturated habitat space through deeper parts of the underlying profile.

The maintenance of this aquifer habitat, and the biophysical processes that sustain it, is important in ensuring the persistence of the diverse stygal community inhabiting the Tindall Limestone. Annual recharge events during the wet season lower groundwater salinity to within fresh range and are likely to bring a reliable influx of nutrients and organic matter from surface sources. Both of these episodic processes are likely to be critical to stygal ecosystems for maintaining suitable groundwater quality and providing primary trophic level inputs to subterranean food webs. Any future development within the Beetaloo Sub-basin should ensure that surface hydrology regimes that are important to the recharge of the Tindall Limestone are not reduced or degraded in any way, particularly in the north-eastern extent of the study area where sinkholes and other features provide more direct connections to the water table.

Similarly, any proposed groundwater abstraction and any consequent lowering of the water table should be adequately assessed in this north-eastern area. Any abstraction of groundwater within the Beetaloo Sub-basin should be designed and monitored to remain within sustainable yields and to avoid desaturating stygofauna habitat strata. The cumulative impact of any future development in this regard should also be taken into account, recognising that existing groundwater abstraction occurs from the Tindall Limestone for a variety of purposes. This is likely to require modelling of both predicted magnitude and spatial extent of aquifer drawdown, as well as additional targeted sampling for stygofauna, specific to any area of potential development. The data from the current study can be used to set broader context to such assessments and the additional sampling for specific developments can contribute incremental knowledge gains to stygofauna data in the region, along with additional data from any future monitoring work.

Any potential contamination of groundwater arising from future development should also be carefully evaluated. The majority of the Beetaloo Sub-basin is upstream of the Tindall Limestone from a groundwater flow perspective. This means that any perturbations to up-gradient aquifers further south-east may ultimately affect the more important stygal habitats further north-east within the Tindall formation. The sensitivity of stygofauna to most contaminants is poorly studied and ecological risk assessments are likely to lack an established ecotoxicology framework for this fauna.

To expand on the existing knowledge base, a longitudinal sampling program should be undertaken over at least two further years to better document the stygofauna of the study area. This will allow for successive sampling after major recharge events and —by dint of additional effort — the accrual of further records of known species, and currently unrecorded taxa that are likely to be present.

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6. Terrestrial ecosystems baseline studies

6.1. Background

The Inquiry considered that there was generally poor spatial coverage of data on terrestrial biodiversity in the regions of the Northern Territory most likely to be affected by any onshore shale gas industry, including the Beetaloo Sub-basin. The limited information on biodiversity assets and their location in prospective regions represented a significant knowledge gap, impeding the ability to properly assess the risks of any shale gas development (particularly cumulative risks over large areas). It also reduced the ability to plan the location of infrastructure in order to avoid, or minimise, the risk of unacceptable impacts.

In relation to terrestrial ecosystems, the Final Report identified the following objectives.

- Identify locations of high conservation value within affected IBRA bioregions through systematic survey of vascular plants, vertebrates and selected invertebrate taxa.
- Establish current distribution and densities of occurrence of weed species throughout the region.
- Determine if any threatened species are likely to be seriously affected by the cumulative effects of habitat loss and fragmentation that could accompany any onshore shale gas development.

The Final Report also noted that:

- regional assessments should be comprehensive, both in terms of space (covering all major vegetation types across the region) and biota (including all groups of vascular plants and terrestrial vertebrates, and representative terrestrial invertebrates). The data should be assessed for patterns of species richness and endemism, and for the occurrence of threatened species.
- across much of the Northern Territory, there is insufficient coverage of survey data to be able to place a strong degree of reliance on existing mapping datasets. Significant on-ground work would therefore be needed to comprehensively map the occurrence and distribution of terrestrial biodiversity assets of regions likely to be affected by the extraction of any onshore shale gas.
- it will be critical to ensure that verifiably consistent methods are used during the baseline assessment.

The SREBA Framework and Scope of Works for the Terrestrial Ecosystems baseline studies reflected the Inquiry's considerations and provided further detail on study requirements. Data collection was to include environmental mapping, systematic regional biodiversity surveys for vascular plants, terrestrial vertebrates and selected invertebrate groups, and targeted surveys for significant species such as threatened species and waterbirds. The required information outputs were:

- regional ecosystem mapping
- description of regional biogeographic patterns
- spatial distribution models for significant species
- identification and mapping of areas of high conservation value
- evaluation of sensitivity of significant species to development
- description of indicators and methods for regional monitoring.

Initial work to address these objectives was undertaken as part of the Beetaloo GBA Program during 2020, including development of a draft regional ecosystem map, a pilot survey of ant biodiversity, and initial surveys for some threatened fauna species. The SREBA Terrestrial Ecosystem studies followed in 2021 and 2022.

6.1.1. Study area

The study area for the Terrestrial Ecosystems studies was the SREBA biophysical study area described in Section 3.1 and shown in Figure 3-1. The landscape and climate context are also described in Section 3.2. Conducting environmental mapping and biodiversity surveys in similar habitats in the area surrounding the Sub-basin was important to provide context to, and aid interpretation of, results from within the Sub-basin, especially given the sparsity of existing biodiversity data from most of the broader region.

6.2. Environmental mapping

Accurate, uniform mapping of environmental values is important for managing natural resources, and must be scale-appropriate for assessing potential development scenarios. Environmental mapping was undertaken across the study area for the purpose of:

- providing an environmental stratification for regionally representative, site-based sampling of biodiversity
- providing a basis to design sampling for, and predict the distribution of, threatened or significant taxa
- allowing ecosystems or habitats described at a local (project) scale to be placed in a regional context
- delineating the location and extent of sensitive and/or significant ecosystems
- providing a regional baseline layer for the analysis of potential cumulative impacts.

Prior to 2020, vegetation and land resource information for the study area was coarse in scale (typically 1:1,000,000) and lacked the spatial resolution and attribute specificity to facilitate accurate identification of ecological values. In 2020, a preliminary base environmental map was produced at a map scale of approximately 1:100,000 as part of the Geological and Bioregional Assessment (GBA) Program for the Beetaloo Sub-basin (Davis *et al.* 2021).

Assessment of the 2020 preliminary environmental base map revealed that polygon attributes were generally accurate for broad floristic formations but not suitable for accurately mapping vegetation communities at 1:100,000 scale. It was determined that a classification scheme equivalent to National Vegetation Information System (NVIS) Level 4 Sub-Formation or NVIS Level 3 Broad Floristic Formation would yield improved results for the spatial accuracy of the map, and that a numerical classification of full floristic inventory plot data should inform the definition of a vegetation typology for the study area.

The objective of the SREBA environmental mapping was to create a vegetation map for the study area accurate to 1:100,000 scale (and 1:25,000 for sensitive and/or significant ecosystems), for the purpose of identifying the spatial distribution of environmental values relevant to assessment of the potential impacts from development scenarios of onshore gas exploration and production.

6.2.1. Methods

6.2.1.1. Image analysis

The distribution of vegetation communities were mapped across the study area using an Object Based Image Analysis (OBIA) approach, implemented through the software eCognition Developer v9.5 (Trimble Germany GmbH 2019). Spatial data used included:

- Sentinel-2 2020 annual composite image
- vegetation indices derived from the Sentinel-2 2020 annual composite image
- seasonal fractional cover derived from Sentinel-2 2020 image data (Joint Remote Sensing Research Program, 2018; Scarth *et al.* 2011)
- canopy height model (Staben *et al.* 2018)
- hydrologically enforced Digital Elevation Model (DEM-h) (Geoscience Australia 2011)
- slope and relief derived from DEM-h
- Geoscience Australia Landsat Water Observation Statistics Collection 3 (Geoscience Australia, 2022)
- Maximum Extent of Surface Water
- Distance to Mapped Stream.

The Sentinel-2 2020 annual composite image was selected as the primary image data as it corresponded temporally to field surveys and showed the smallest extent of burn scars compared to 2018, 2019 and 2021. The spatial and spectral resolution of Sentinel-2 are appropriate for producing a vegetation map of approximately 1:100,000 scale, including the delineation of distinct map features, such as closed forests, at a resolution corresponding to approximately 1:25,000 scale.

Due to the large volume of data and associated processing requirements, the study area was divided into two sections for OBIA, a northern section and a southern section, approximately aligned with the delineation between Birdum and Newcastle IBRA subregions. Both sections were processed using the same methodology before being merged to create a final mapping product.

Extensive tracks, roads and fence lines intersect the study area, and these were buffered by 15 m and removed from the analysis.

To classify the objects derived from the image analysis as vegetation communities, field data points assigned with a vegetation community attribute (see below) were used to train a random forest model that was then applied across the study area. Approximately 75% of the data points were randomly assigned as training data, with the remainder kept for accuracy assessment. A confusion matrix was generated to quantitatively assess the accuracy of the OBIA classification.

6.2.1.2. Vegetation site data

Three different approaches were taken towards collecting floristic information during vegetation surveys: full floristic inventory plots, dominant species plots and rapid vegetation assessment sites, with the latter two primarily collected to inform classification and validation of the vegetation mapping. Dominant species plots allow for the collection of information sufficient to characterise vegetation communities based on dominant species, following the methodology outlined in Brocklehurst *et al.* (2007). Rapid vegetation assessment sites allow classification of point locations to vegetation type based on dominant species floristics, structure and soil/geology.

Field surveys for the environmental mapping and flora survey components of the terrestrial work program occurred between 5 May 2021 and 10 September 2021, and 12 February and 7 April 2022. Surveys in 2021 were timed to predominantly collect information on the perennial component of vegetation communities. Surveys conducted in 2022 occurred at an optimal time of year to detect the annual component of the flora and were therefore primarily concerned with full floristic inventory.

Existing site information of a suitable standard housed in the DEPWS corporate Vegetation Site Database (VSD) were also compiled for use in typology development and for classification and validation of the vegetation map.

6.2.2. Results

Data from 12,768 vegetation sites were compiled for the study area (Figure 6-1, Table 6-1). The 2020-2022 field program collected vegetation data from 706 full floristic inventory plots, 218 dominant species plots, and 10,690 rapid vegetation assessment sites, and legacy data contributed information from 1,154 sites.

Table 6-1. Vegetation site data compiled across the study area. Compiled legacy data were used in a similar manner to rapid vegetation assessment site data.

Data source	Full floristic inventory plot	Dominant species plot	Rapid vegetation assessment site
SREBA 2022	426	11	0
SREBA 2021	233	11	4,342
GBA 2020	47	196	6,348
Compiled legacy data	0	0	1,154
TOTAL	706	218	11,844

Vegetation communities defined according to the results of the numerical analysis of vegetation site data (see Section 6.3) were aggregated into 19 broad vegetation groups (BVGs) for the purposes of mapping. These BVGs are described in detail in the Baseline Report, and their distribution across the study area is shown in Figure 6-2.

The most extensive vegetation group was *Corymbia/Eucalyptus open woodland on sandy loam*, covering approximately 26,400 km (31%) of the study area. Subtle variations in soil texture and topography influence the distribution of vegetation communities within this broad vegetation group, and extensive ecotones occur. This map unit is most prevalent on loamy soils associated with the Birdum and Newcastle IBRA subregions.

Lancewood forests cover approximately 7,730 km^2 (9%) of the study area and are closely associated with *Bullwaddy shrublands and woodlands*, which cover a further 4,000 km^2 (5%) of the study area, predominately within the Newcastle IBRA subregion. These widespread vegetation types are associated with Cainozoic duricrusts (ironstone jump-ups) plains or gently undulating slopes and hilltops with a residual surface derived of duricrust; or on Tertiary-early Quaternary loamy and sandy clay plains overlying duricrust. Confusion in the mapping may occur between the two vegetation groups where they intergrade.

Snappy gum low open woodland (2,050 km^2) is found on rocky, gravelly soils on the margins and slopes of Cainozoic duricrusts, and occasionally on plains with a residual gravelly and rocky surface derived of duricrust. Within the group, a community dominated by *Eucalyptus leucophloia* is widespread throughout the study area, except in the northern regions where it is replaced by a community dominated by *E. umbrawarrensis*.

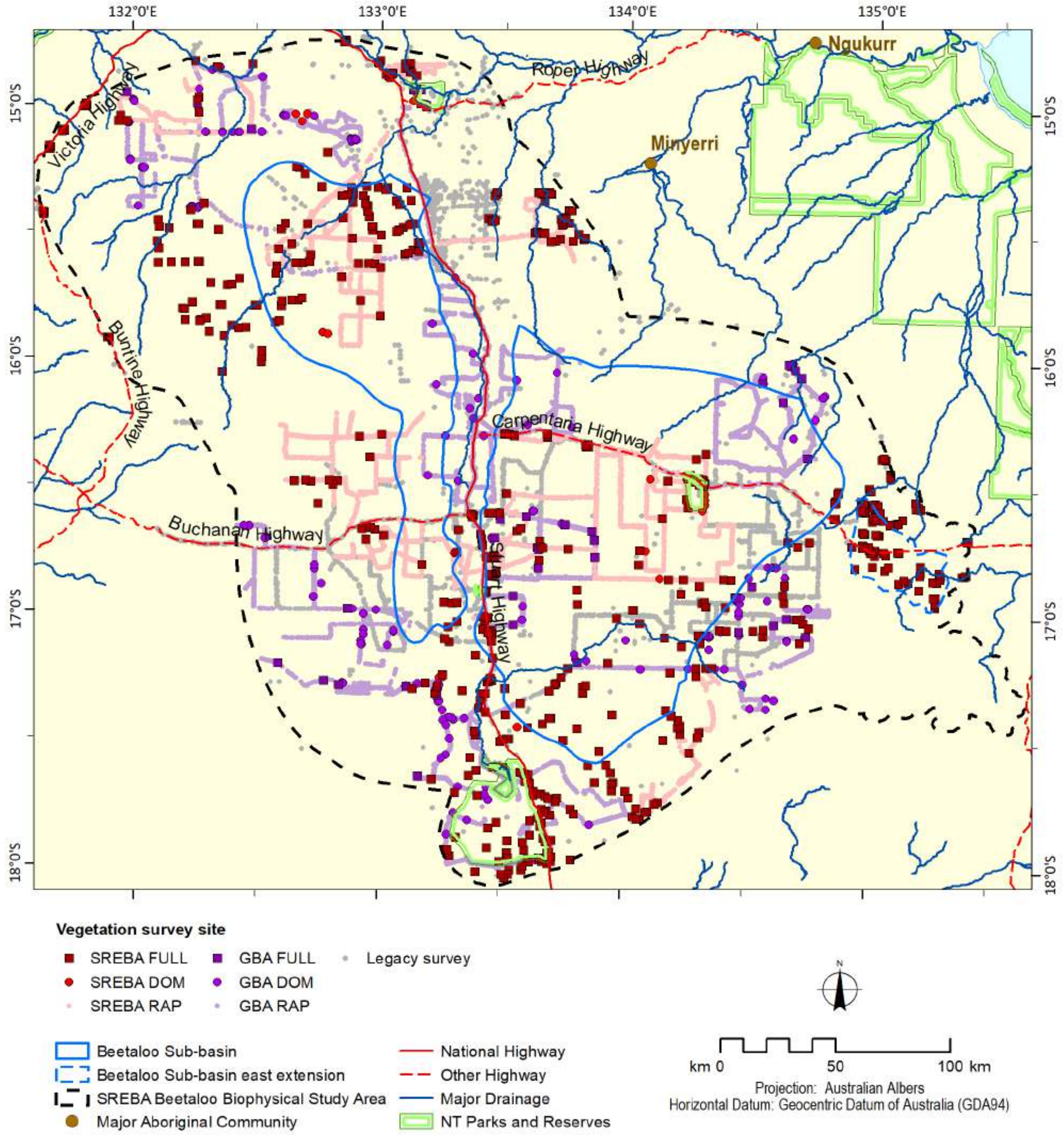

Figure 6-1. Vegetation survey site locations, including those undertaken during SREBA (2021-22), GBA (2020) and compiled from legacy data. FULL = full floristic inventory plot; DOM = dominant species plot; RAP = rapid vegetation assessment site.

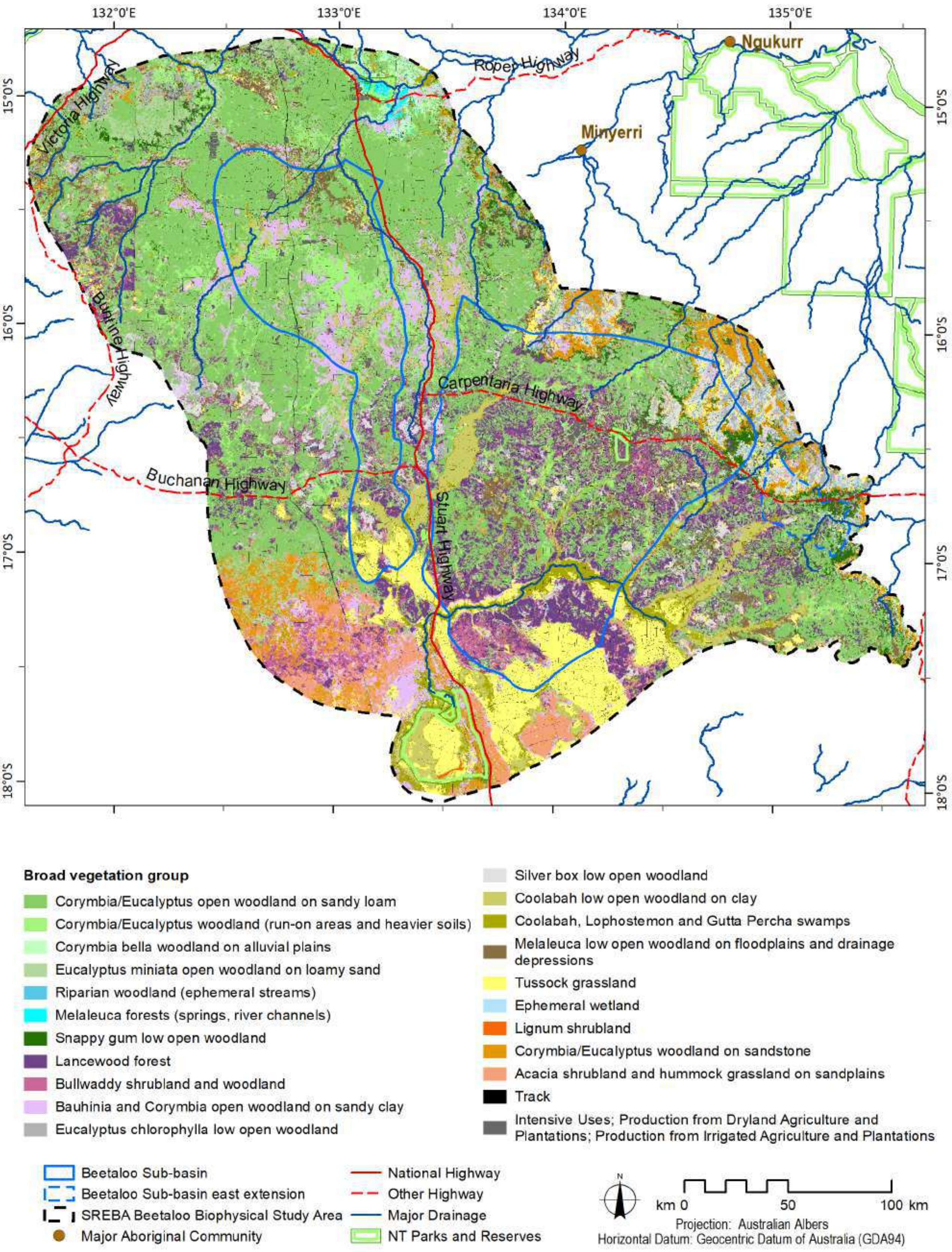

Figure 6-2. Broad vegetation groups mapped across the study area

Eucalyptus miniata open woodland on loamy sand (2,770 km^2) is found on rapidly draining, deep sandy soils on plains, footslopes, hillslopes and rise crests. It has a distinct assemblage of plant species and is easily recognised on ground.

Extensive clay plains with *Coolabah low open woodland on clay* (4,160 km^2); *Coolabah, Lophostemon and Gutta Percha swamps* (2,680 km^2); and *Tussock grassland* (5,620 km^2) dominate the lower elevation portions of the study area, and collectively cover 15% of its area. *Coolabah low open woodland on clay* and *Coolabah, Lophostemon and Gutta Percha swamps* are associated with periodically or ephemerally waterlogged sites. Mapping confusion may occur where *Coolabah low open woodland on clay* transitions into *Coolabah, Lophostemon and Gutta Percha swamps* on the wetter parts of floodplains, fringing ephemeral swamps, or forming woody communities on wetlands that do not typically persist long into the dry season.

Tussock grassland occur mostly on clay plains derived *in situ* from fine-grained sedimentary rocks. *Astrebla* grasslands on cracking clay black soil clay plains are predominantly found in the south of the study area, extending into the Barkly Tableland Bioregion, whereas *Chrysopogon fallax* mixed tussock grasslands are more common towards the north of the study area.

Other woodlands on clay soils include *Bauhinia and Corymbia open woodland on sandy clay* (4,220 km^2), *Silver box low open woodlands* (3,590 km^2) and *Eucalyptus chlorophylla low open woodland* (3,620 km^2), which together cover approximately 13% of the study area. *Silver box low open woodland* occurs on imperfectly drained clay soils. As clay content becomes lighter, and soils increase in sand or loam, this broad vegetation group intergrades with *Eucalyptus chlorophylla low open woodland* and *Bauhinia and Corymbia open woodland on sandy clay*. These three broad vegetation groups also intergrade with *Coolabah low open woodland on clay*, *Bullwaddy shrubland and woodland*, and *Corymbia/Eucalyptus open woodland on sandy loam*, occurring as part of a broad soil texture-drainage sequence. As such, precisely mapping these broad vegetation groups was difficult and a primary source of confusion in the vegetation mapping, because large areas can contain many small patches of each of these groups or can form considerable areas of ecotone.

Corymbia/Eucalyptus woodland on sandstone (3,680 km^2) and *Acacia shrubland and hummock grassland on sandplains* (2,450 km^2) cover approximately 7% of the study area. These broad vegetation groups were predominately mapped in the east of the study area where the study area overlaps the edge of the Gulf Fall & Uplands bioregion, and in the south of the study area on the Ashburton Range and areas of sandier soils characteristic of the adjacent Tanami Bioregion.

Four vegetation groups are spatially restricted, in total covering less than 1% of the study area: *Riparian woodland (ephemeral streams)* (504 km^2), *Melaleuca forests (springs, river channels)* (254 km^2), *Ephemeral wetlands* (27 km^2) and Lignum shrubland (17 km^2).

One broad vegetation group, *Monsoon forest and thicket*, is not represented in the vegetation map due to a lack of field survey data for training (and validation) purposes. Previous mapping of monsoon rainforest, at a scale of 1:250,000 (Russell-Smith 1991), was deemed too coarse to integrate with the current vegetation map, particularly as rainforest patches within the study area are of very small spatial extent. Rainforest patches in the study area identified by Russell-Smith (1991) were classified as *Melaleuca forests (springs, river channels)* and *Riparian woodland (ephemeral streams)* in the current vegetation map.

A qualitative assessment of the vegetation map suggested good mapping accuracy, with patterns of broad vegetation groups occurring across the landscape corresponding to what was observed during field surveys. The quantitative accuracy assessment revealed that misclassifications in the mapping were mostly amongst closely aligned broad vegetation groups, as described above. Future field descriptions of sites should be based on the vegetation community descriptions provided in the Baseline Report in addition to the map product.

6.3. Flora and vegetation communities

6.3.1. Background

The aim of the terrestrial flora component of the Beetaloo SREBA program was to improve knowledge of flora of the study area, following the preliminary documentation undertaken in 2020 as part of the GBA Program (Davis *et al.* 2021). Extensive vegetation surveys were undertaken across the study area to collect data to inform:

- assessment of significant species
- derivation of a vegetation typology to describe vegetation communities in the area
- evaluation of floristic and vegetation attributes and environmental relationships of vegetation groups
- vegetation mapping at a scale of 1:100 000
- identification of biodiversity values and risks related to the development of onshore gas industry.

6.3.2. Methods

6.3.2.1. Vegetation site data

The three different approaches used to collect floristic information are described in Section 6.2.1.2. Full floristic inventory plots were surveyed to provide a comprehensive inventory of the flora of the study area and to produce data for a numerical classification of the vegetation. Dominant species plots and rapid vegetation assessment sites were primarily used to inform vegetation mapping, but also provided supplementary information for definition of floristic assemblages.

Flora surveys occurred between May and September 2021, and February and April 2022. The 2021 surveys were primarily focused on perennial flora, apart from some full floristic inventory plots surveyed during May and at some wetter sites (e.g. riparian sites and springs). Surveys conducted in 2022 occurred at an optimal time of year to detect the annual component of the flora and were therefore primarily concerned with full floristic inventory.

Sampling stratification and site selection was based on the preliminary environmental base map produced as part of the GBA program (Davis *et al.* 2021). The survey design also incorporated the rainfall gradient so that broadly occurring vegetation types were sampled across five 100 mm isohyet bands that span the latitudinal extent of the study area. Site selection aimed to capture vegetation communities in 'best-on-offer' condition, where practicable. To reduce the potential influence of disturbance, sites were situated at least 100 m from roads, tracks and cleared areas, and were at least 2 km from bores, stock yards and stock watering points. For some vegetation communities, including those associated with wetland and riparian systems, there was limited or no opportunity to survey sites that were not heavily disturbed.

A plot size of 400 m^2 was used consistently throughout the survey. Within each plot, an inventory of all plant taxa was undertaken and the percent cover of each taxon was visually estimated and recorded. Plant voucher specimens were collected for identification purposes as required. Nomenclature was consistent with the NT vascular plant checklist (Cowie *et al.* 2017). Vegetation description methods followed Brocklehurst *et al.* (2007), which complies with the National Vegetation Information System standards for the collection of floristic and structural attributes to support vegetation classification and mapping. A set of environmental covariates was scored for each survey site following Lewis *et al.* (2007) and Hill and Napier (2015). A record of disturbance type (if present) and intensity was also made for each plot.

A reduced set of data were collected at dominant species plots and rapid vegetation assessment sites, as described in the Baseline Report.

6.3.2.1. Classification of vegetation communities and broad vegetation groups

Vegetation data from the full floristic inventory plots were analysed using a range of multivariate techniques. Numerical analysis of the data for the classification of the vegetation was undertaken as a two-step process. First, following Lewis *et al.* (2021), analysis was based on a matrix of upper stratum woody plants exclusively, which is an established approach for mapping savanna landscapes. Hierarchical agglomerative clustering using group-average linkage (CLUSTER) was then used to generate a dendrogram that depicts site relationships on the basis of floristic composition of woody canopy species. Statistically meaningful groups were defined using a type-1 similarity profile routine (SIMPROF). The second step in the classification involved repeating a similar analysis within each upper-stratum group using species cover data for the upper, mid and ground strata. This allowed new sets of clusters to be generated to identify relationships among sites with similar canopy species composition. To develop a final typology of vegetation communities for the study area, results from the numerical classification were assessed by botanists with expert knowledge of vegetation in the study area. The defined vegetation communities were then aggregated into broad vegetation groups for environmental mapping at a resolution of approximately 1:100,000, resulting in a two-tiered classification scheme.

6.3.2.2. Attributes of the broad vegetation groups

Differences in estimated cover (%) and height (m) of the upper-storey, mid-storey and ground-storey between broad vegetation groups were analysed using generalised linear models (GLMs) in the program 'R'. The same approach was used to test for differences between broad vegetation groups in richness (number of species) of native species; rainforest-allied species; species that are mainly killed by fire ('seeders'); species that resprout after fire ('resprouters'); introduced species; species aligned with the tropical region of the NT, and species aligned with the arid region of the NT.

6.3.2.3. Environmental relationships of the broad vegetation groups

Biogeographic patterns were examined by testing the relationship between vegetation composition and a set of measured and derived environmental variables, as detailed in the Terrestrial Ecosystems Baseline Report. The analysis was based on survey sites that had full floristic and environmental data.

6.3.2.4. Significant species and areas of high botanical value

Significant species within the study area were identified from vegetation site data collected during this study and from existing records within the Northern Territory Flora Atlas, with significant species defined as those:

- listed as threatened (Vulnerable, Endangered or Critically Endangered) under the *Environment Protection and Biodiversity Conservation* (EPBC) *Act 1999* or the *Territory Parks and Wildlife Conservation Act 1976* (TPWC Act)
- considered to be restricted-range or endemic species
- listed as Data Deficient or Near Threatened under the TPWC Act, but where available ecological information indicates that additional data are likely to confirm that the species is threatened.

To test for aggregations of significant plant species ('hotspots'), a set of 50 km x 50 km grid cells across the extent of the study area was created. For each grid cell, the number of significant species was calculated and values were evaluated using the criteria developed by Ward and Harrison (2009) for identifying sites of conservation significance in the Northern Territory. This provided an assessment at a relatively broad scale, and any identified ‘hotspots’ could be refined using a finer grid cell size.

6.3.3. Results

6.3.3.1. Plant diversity

Flora surveys collected vegetation data from 659 full floristic inventory plots, 22 dominant species plots and 4,342 rapid vegetation assessment sites. In total, data from 12,768 vegetation sites were compiled for the study area, including flora surveys undertaken as part of the SREBA and GBA programs and other legacy data (Table 6-1).

Flora surveys contributed 15,419 new plant records for the study area, representing a 28% increase on the pre-survey total. The number of plant taxa (described at least to species level) known from the study area following SREBA surveys is 1,818, an increase of 9% on the pre-survey total, and which represents almost 30% of the total number of plant taxa known to occur in the Northern Territory. Within the Beetaloo Sub-basin, 6,471 new plant records were collected, representing a 43% increase on the pre-survey total. The number of plant taxa known from within the Beetaloo Sub-basin is 1,093, an increase of 18% on the pre-survey total, and which represents 18% of the total number of plant taxa known to occur in the Northern Territory.

6.3.3.2. Vegetation communities and broad vegetation groups

Numerical analysis of the species composition data identified 109 vegetation units. The process of expert review resulted in a typology of 49 vegetation communities. Two vegetation communities (*Riparian rainforest* and *Monsoon vine thicket associated with sinkholes*) were not represented in survey data but have been identified within the study area. These were added to the final typology of vegetation communities, bringing the total number to 51 (Table 6-2). Vegetation communities were then aggregated into 21 broad vegetation groups appropriate for environmental mapping. Detailed descriptions for each broad vegetation group, and nested finer-scale vegetation communities, are provided in the Terrestrial Ecosystems Baseline Report.

Table 6-2. The 51 vegetation communities and 21 broad vegetation groups (BVG) comprising the final vegetation classification for the study area. Vegetation communities identified as significant vegetation and groundwater-dependent ecosystems (GDE) are attributed accordingly; GDE nature reflects the hydrological regime (seasonal or permanent); GDE type is the designation as Type 2 or Type 3 according to Richardson *et al*. (2011); and GDE confidence reflects the confidence level of the GDE attributions.

BVG #	Broad vegetation group description	Vegetation community description	Significant vegetation	GDE	GDE nature	GDE type	GDE conf.
1	*Corymbia/Eucalyptus* open woodland on sandy loam	*Corymbia dichromophloia* (+/- *C. ferruginea*, *Eucalyptus miniata*, *Eucalyptus tetrodonta*) low open woodland with variable tussock/hummock grassland	-	-	-	-	High
		Corymbia dichromophloia and *Bauhinia cunninghamii* (+/- *Eucalyptus pruinosa*) low open woodland with variable mixed tussock grassland	-	-	-	-	High
		Eucalyptus tectifica low woodland to open woodland (+/- mixed *Corymbia/Eucalyptus* spp.) with a sparse shrub layer of broadleaf species and a variable mixed tussock grassland	-	-	-	-	High
		Eucalyptus tetrodonta and *Corymbia dichromophloia* mixed low open woodland with mixed tussock grassland (+/- *Triodia bitextura*)	-	-	-	-	High
		Eucalyptus tetrodonta variable mixed woodland to open forest	-	-	-	-	High
		Petalostigma pubescens low open woodland to low woodland with mixed tussock grassland	-	-	-	-	High
2	*Corymbia/Eucalyptus* woodland (run-on areas and heavier soils)	*Corymbia polycarpa* mixed low open woodland to woodland on relictual drainage features	Run-on	-	-	-	High
		Eucalyptus patellaris +/- *Corymbia polycarpa* mixed open woodland to woodland on loamy flats and run-on areas	Run-on	-	-	-	High

BVG #	Broad vegetation group description	Vegetation community description	Significant vegetation	GDE	GDE nature	GDE type	GDE conf.
3	*Corymbia bella* woodland on alluvial plains	*Corymbia bella* mixed woodlands to low open woodlands on alluvial plains	Floodplain	GDE	S	3	Mod.
4	*Eucalyptus miniata* open woodland on loamy sand	*Eucalyptus miniata* and *Corymbia ferruginea* low open woodland with hummock grass on sandy surfaced soils on the lateritic plateau	-	-	-	-	High
5	Riparian woodland (ephemeral streams)	*Corymbia ptychocarpa* subsp. *ptychocarpa* low open riparian woodland	Riparian	GDE	S	2 / 3	Mod.
		Eucalyptus camaldulensis +/- *Casuarina cunninghamiana*, *Terminalia platyphylla* mixed riparian low woodland to woodland on sandy stream channels	Riparian	GDE	S	3	Low
6	*Melaleuca* forests (springs, river channels)	*Melaleuca cajuputi* open forests associated with drainage depressions and major river channels	Riparian	GDE	P	2 / 3	High
		Melaleuca dealbata and *Melaleuca acacioides* low open forest	Wetland	GDE	P	2 / 3	High
		Melaleuca leucadendra tall open forest on springs, seeps and major river channels	Riparian	GDE	P	2 / 3	High
7	Monsoon forest and thicket	Monsoon vine thicket associated with sinkholes	Monsoon vine forest or vine thicket	-	-	-	Mod.
		Riparian rainforest	Rainforest	GDE	P	2 / 3	High
8	Snappy gum low open woodland	*Eucalyptus leucophloia* low open woodland to mid woodland with *Triodia* spp. hummock grassland	-	-	-	-	High
		Eucalyptus umbrawarrensis low open woodland to woodland	-	-	-	-	High

BVG #	Broad vegetation group description	Vegetation community description	Significant vegetation	GDE	GDE nature	GDE type	GDE conf.
9	Lancewood forest	*Acacia shirleyi* low open woodland to mid open forest with a sparse variable tussock grass understorey	-	-	-	-	High
		Acacia shirleyi mid open forest with *Macropteranthes kekwickii* and *Terminalia volucris* shrubland	-	-	-	-	High
10	Bullwaddy shrubland and woodland	*Macropteranthes kekwickii* and *Acacia shirleyi* low woodland to mid open woodland	-	-	-	-	High
		Macropteranthes kekwickii closed tall shrubland to low woodland +/- scattered *Corymbia polycarpa*, *Eucalyptus chlorophylla* and/or *E. pruinosa*, and emergent *Acacia shirleyi*	-	-	-	-	High
11	*Bauhinia and Corymbia* open woodland on sandy clay	*Bauhinia cunninghamii* (+/- scattered *Corymbia flavescens, C. polycarpa, C. terminalis* and/or *Eucalyptus pruinosa*) low open woodland with variable tussock grassland	-	-	-	-	High
		Terminalia arostrata and/or *T. volucris* tall sparse shrubland to low open woodland with *Corymbia flavescens* and/or *C. terminalis*	-	-	-	-	High
12	*Eucalyptus chlorophylla* low open woodland	*Eucalyptus chlorophylla* (+/- *Corymbia polycarpa* and/or *C. terminalis*) low open woodland with tussock grassland	-	-	-	-	High
		Eucalyptus distans low open woodland with variable tussock grassland	-	-	-	-	High
13	Silver box low open woodland	*Eucalyptus pruinosa* low open woodland (with sparse *Corymbia flavescens*, *C. polycarpa*) with variable tussock grassland	-	-	-	-	High
14	Coolabah low open woodland on clay	*Eucalyptus microtheca* or *E. cyanoclada* low open woodland +/- scattered *Corymbia flavescens* and/or *C. polycarpa*	Floodplain	-	-	-	High
		Eucalyptus microtheca or *E. cyanoclada* with *Bauhinia cunninghamii* low open woodland	Floodplain	-	-	-	High

BVG #	Broad vegetation group description	Vegetation community description	Significant vegetation	GDE	GDE nature	GDE type	GDE conf.
15	Coolabah, *Lophostemon* and Gutta Percha swamps	*Eucalyptus camaldulensis* open woodland to woodland on sinkhole depressions and swamps associated with clayey soils	Wetland	-	-	-	Mod.
		Eucalyptus microtheca or *E. cyanoclada* and *Excoecaria parvifolia* low open woodland	Floodplain	-	-	-	Mod.
		Eucalyptus microtheca or *E. cyanoclada* and *Lophostemon grandiflora* (+/- *Eucalyptus camaldulensis*) low open woodland to woodland in sinkhole depressions and swamps	Wetland	-	-	-	Mod.
		Excoecaria parvifolia low open woodland to woodland (+/- *Melaleuca citrolens*), and variable mixed tussock grassland	Floodplain	-	-	-	Mod.
		Lophostemon grandiflorus low woodland to woodland with mixed grassland	Wetland	-	-	-	Mod.
16	*Melaleuca* low open woodland on floodplains and drainage depressions	*Melaleuca citrolens* and *Melaleuca minutifolia* shrubland	Floodplain	-	-	-	High
		Melaleuca citrolens low woodland (+/- scattered *Corymbia/Eucalyptus*) with mixed tussock grassland	Floodplain	-	-	-	High
		Melaleuca minutifolia low open woodland to low woodland (+/- emergent *Corymbia/Eucalyptus*) with tussock grassland	Floodplain	-	-	-	High
		Melaleuca nervosa low open woodland (+/- *M. viridiflora*, *Grevillea pteridifolia*) with *Triodia bitextura* mixed tussock grassland on sandy plains	Drainage depression	-	-	-	High
		Melaleuca viridiflora +/- *M. citrolens* tall sparse shrubland with *Triodia bitextura* hummock grassland on sandy plains	Drainage depression	-	-	-	High
		Melaleuca viridiflora low open woodland to low woodland (+/- emergent *Corymbia flavescens* and/or *C. polycarpa* and/or scattered *Eucalyptus chlorophylla*) with variable tussock grassland	Drainage depression	-	-	-	High

BVG #	Broad vegetation group description	Vegetation community description	Significant vegetation	GDE	GDE nature	GDE type	GDE conf.
17	Tussock grassland	*Astrebla* spp. mixed tussock grassland on cracking clay soils	-	-	-	-	High
		Chrysopogon fallax mixed tussock grassland +/- scattered shrubs and isolated *Corymbia/Eucalyptus* spp.	-	-	-	-	High
		Variable mixed tussock grassland on clay soils +/- emergent *Corymbia flavescens* and/or *C. grandifolia* and/or *Eucalyptus pruinosa*	-	-	-	-	High
18	Ephemeral wetland	Ephemeral wetland	Wetland	-	-	-	Mod.
19	Lignum shrubland	Lignum shrubland	Wetland	-	-	-	High
20	*Corymbia/Eucalyptus* woodland on sandstone	*Eucalyptus miniata* and *Corymbia dichromophloia* (+/- *C. setosa*, *E. phoenicea*) low open woodland to woodland with hummock grass on sandstone	-	-	-	-	High
		Hummock grassland and open shrubland on stony substrates and sandstone rises +/- emergent to low open woodland of *Corymbia aspera* and/or *C. dichromophloia*	-	-	-	-	High
21	*Acacia* shrubland and hummock grassland on sandplains	*Acacia lysiphloia* shrubland	-	-	-	-	High
		Corymbia opaca low open woodland on sandy lateritic plains, grading into Barkly Clays and Tanami desert sandplains	-	-	-	-	High
		Triodia pungens hummock grassland and/or *Acacia* spp. shrubland on desert sandplains +/- emergent *Corymbia setosa*	-	-	-	-	High

6.3.3.3. Attributes and environmental relationships of BVGs

Upperstorey height and cover was notably high in *Melaleuca* forests, and upperstorey cover was also high in lancewood forest. Ground storey cover was moderate in most broad vegetation groups, but highly variable in some (*Corymbia bella* woodland on alluvial plains, ephemeral wetland), notably high in *Melaleuca* low open woodland on floodplains and drainage depressions and in tussock grassland, and notably low in *Melaleuca* forest.

Midstorey cover was quite low in most vegetation groups but notably high (and variable) in *Corymbia bella* woodland and low in Coolabah low open woodland on clay, Silver box low open woodland, and *Corymbia/Eucalyptus* woodland on sandstone. *Corymbia bella* woodland, *Melaleuca* forest, and riparian woodland (ephemeral streams) had relatively high litter cover. Litter cover was particularly low in Silver box low open woodland, *Corymbia/Eucalyptus* woodland on sandstone, Snappy gum low open woodland and tussock grassland. The Normalised Difference Vegetation Index, an index of vegetation productivity derived from satellite imagery, was high for *Melaleuca* forest; riparian woodland; and *Corymbia bella* woodland; and low for *Acacia* shrubland and hummock grassland on sandplains; *Corymbia/Eucalyptus* woodland on sandstone; and tussock grassland.

Native plant plot species richness was highest in riparian woodland and high in *Bauhinia* and *Corymbia* open woodland on sandy clay; *Eucalyptus chlorophylla* low open woodland; *Eucalyptus miniata* open woodland on loamy sand; *Corymbia/Eucalyptus* open woodland on sandy loam; and *Corymbia/Eucalyptus* woodland (run-on areas and heavier soils). Richness of rainforest-allied species was highest in Bullwaddy shrubland and woodland, while richness of tropical-allied species was highest in riparian woodland. Richness of arid-allied species was highest in *Bauhinia* and *Corymbia* open woodland on sandy clay.

Plot richness of introduced plant species was markedly high (and variable) in *Corymbia bella* woodland on alluvial plains and was also high in *Corymbia/Eucalyptus* woodland (run-on areas and heavier soils).

Disturbance was prevalent across all broad vegetation groups, despite site selection being biased towards ‘best on offer’ condition. Cattle grazing was the predominant disturbance recorded, and was most extensive and intense within ephemeral wetland, and equally intense (but less extensive) in riparian woodland (ephemeral streams). The majority of ephemeral wetland sites were impacted by cattle and, on average, 82% of their area was affected with 60% of this area being highly degraded (i.e. no vegetation cover due to grazing, trampling and pugging). *Melaleuca* forests (springs, river channels) often displayed substantial impacts of disturbance from pig foraging and wallows and, where unfenced, also from cattle.

Environmental relationships with plant species composition in the study area are complex. The multivariate model that was constructed to explore the combined effects of rainfall and the set of focal environmental gradients performed poorly in explaining the total variation in the flora. This is interpreted as being a result of the effect of the multitude of physical and disturbance variables and their interactions with each other and the rainfall gradient.

Overall, the latitudinal-rainfall gradient was found to be significantly related to variation in vegetation structure, floristic composition and with a range of species groups and habitat attributes. However, other environmental drivers can override the otherwise simple relationships with rainfall. The most prominent example of this is soil type, with a distinctive species composition on clay plains and, to a lesser extent sandy soils. This relationship is largely independent of rainfall, in contrast to the composition of the flora on more loamy soils.

Categorical multivariate analyses also showed that there were interactive effects of rainfall, soil type and disturbance factors (fire and grazing regimes). At high fire frequencies, there was a collapsing of floristic differences between adjacent rainfall bands. Heavy grazing intensity also disrupts the floristic-rainfall gradient, and this was most pronounced in the drier portion of the landscape.

6.3.3.4. Significant species

Two threatened species were recorded in the study area during SREBA surveys: *Eleocharis retroflexa* (Vulnerable; EPBC Act) and *Carex fascicularis* (Vulnerable; TPWC Act). These records are the first observations of any threatened flora within the study area (Figure 6-3).

Three restricted-range species were recorded in the study area for the first time: *Eleocharis retroflexa*, *Spermacoce reticulata* and *Oldenlandia intonsa*. A fourth restricted-range species, *Cladium mariscus*, is also known from the study area but was not observed during SREBA surveys (Figure 6-3). Based on current knowledge, no plant species are endemic to the study area or the Sub-basin. The NT endemic species *Macropteranthes kekwickii* (Bullwaddy) occurs extensively across the study area and has approximately 85% of its distribution within the study area and within the Sturt Plateau bioregion. The NT endemic *Eucalyptus cyanoclada* is similarly largely restricted to the study area.

A total of 22 plant species listed as Near Threatened and 83 listed as Data Deficient (TPWC Act) are known from the study area. Most of the species listed as Near Threatened have the majority of their populations outside of the Northern Territory, predominantly in northern Queensland and northern Western Australia. More information on these species is provided in the Baseline Report. No species were identified where available ecological information indicated that the species was likely to be threatened.

No 50 km x 50 km grid cell met the criteria of Ward and Harrison (2009) for identifying areas of high conservation value, on the basis of flora records.

6.3.3.5. Declared weeds and introduced plant species

There are 111 species of plants recorded within the study area that are introduced to the Northern Territory. This includes 32 species listed under the *Weeds Management Act 2001*; 12 are Class A weeds (to be eradicated) and 20 are Class B weeds (growth and spread to be controlled).

Introduced species were mostly associated with areas of higher productivity, such as run-on areas with heavier soils, drainage depressions, riparian areas, springs, floodplains, and wetlands. The highest average frequency of introduced species was detected in survey plots associated with *Corymbia bella woodland on alluvial plains*, *Corymbia/Eucalyptus woodland (run-on areas and heavier soils)* and *Riparian woodland (ephemeral streams)*.

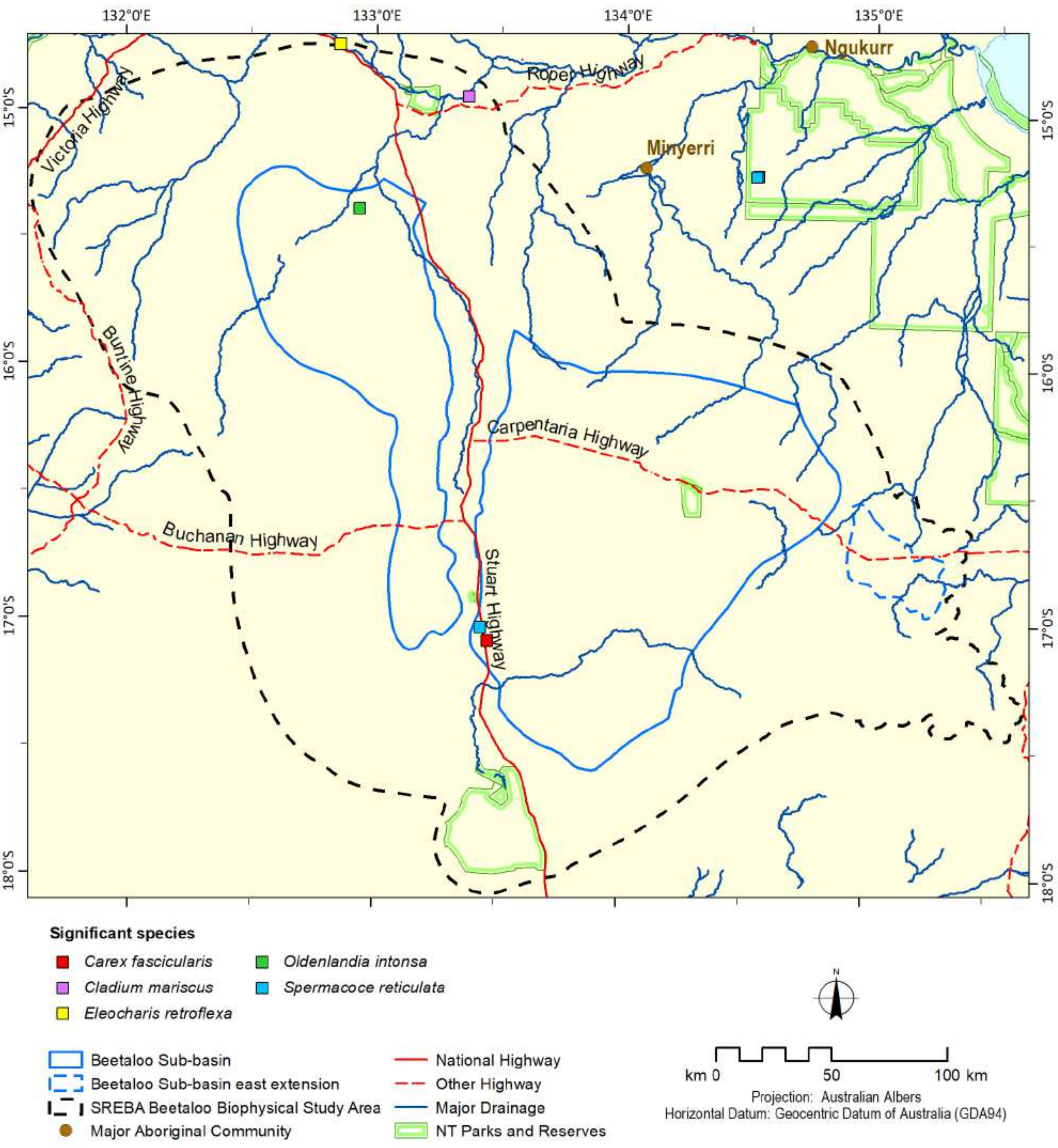

Figure 6-3. Significant plant species known from the study area.

6.3.4. Significant vegetation

Significant vegetation was defined for this study as vegetation communities or broad vegetation groups that have at least one of the following characteristics:

a) classified as sensitive or significant vegetation types according to the *NT Land Clearing Guidelines* (Northern Territory Government 2021) (e.g. rainforest, riparian vegetation)
b) associated with features subject to protective measures in the *NT Land Clearing Guidelines* (e.g. as a wetland, floodplain or drainage depression)
c) groundwater-dependent ecosystems
d) ecosystems other than (a), (b) or (c) that have relatively high values for some components of biodiversity, as identified in SREBA studies (e.g. run-on areas)
e) extensive ecosystems that are endemic to the Northern Territory.

Significant vegetation types were attributed as being of high or moderate ecological value, based on their importance for supporting elements of the biodiversity of the regions, spatial extent and sensitivity to disturbance.

Of the 51 vegetation communities described for the study area, 25 were identified as significant vegetation. These vegetation communities were classified as rainforest, riparian, wetland, floodplain, drainage depression and ‘run-on’ areas; denoting characteristics of the vegetation community or of the landscapes in which they occur. Seven of the vegetation communities were identified as potential groundwater-dependent ecosystems (Table 6-2).

Five broad vegetation groups are considered to have high ecological value (occupying 80,157 ha or 0.9% of the study area) and four are considered to have moderate ecological value (occupying 1,773,616 ha or 20% of the study area) (Figure 6-4, Figure 6-5). Bullwaddy is additionally included as a moderate ecological value community due to its status as a Northern Territory endemic ecosystem with a distribution that is largely confined to the study area.

Three broad vegetation groups were identified as likely to be groundwater-dependent: *Melaleuca forests (springs, river channels)*; *Corymbia bella woodland on alluvial plains* and *Riparian woodland (ephemeral streams)* (Table 6-2, Figure 6-6). In areas mapped as potential groundwater-dependent ecosystems where depth to regional aquifers is relatively deep, vegetation may be accessing a shallower perched groundwater system or be in an area of increased soil moisture due to inflow of surface water from adjacent areas, and with soils of higher water-holding capacity.

6.3.5. Risks to floral biodiversity

Seven major current and potential risks to terrestrial vegetation were identified for the study area:

- habitat degradation, fragmentation and loss
- inappropriate fire regimes
- reduction in surface water and/or groundwater availability
- surface water and/or groundwater contamination
- soil contamination, erosion and sedimentation
- overgrazing and disturbance from introduced herbivores
- introduced plants.

These risks are discussed further in Section 6.7.4.

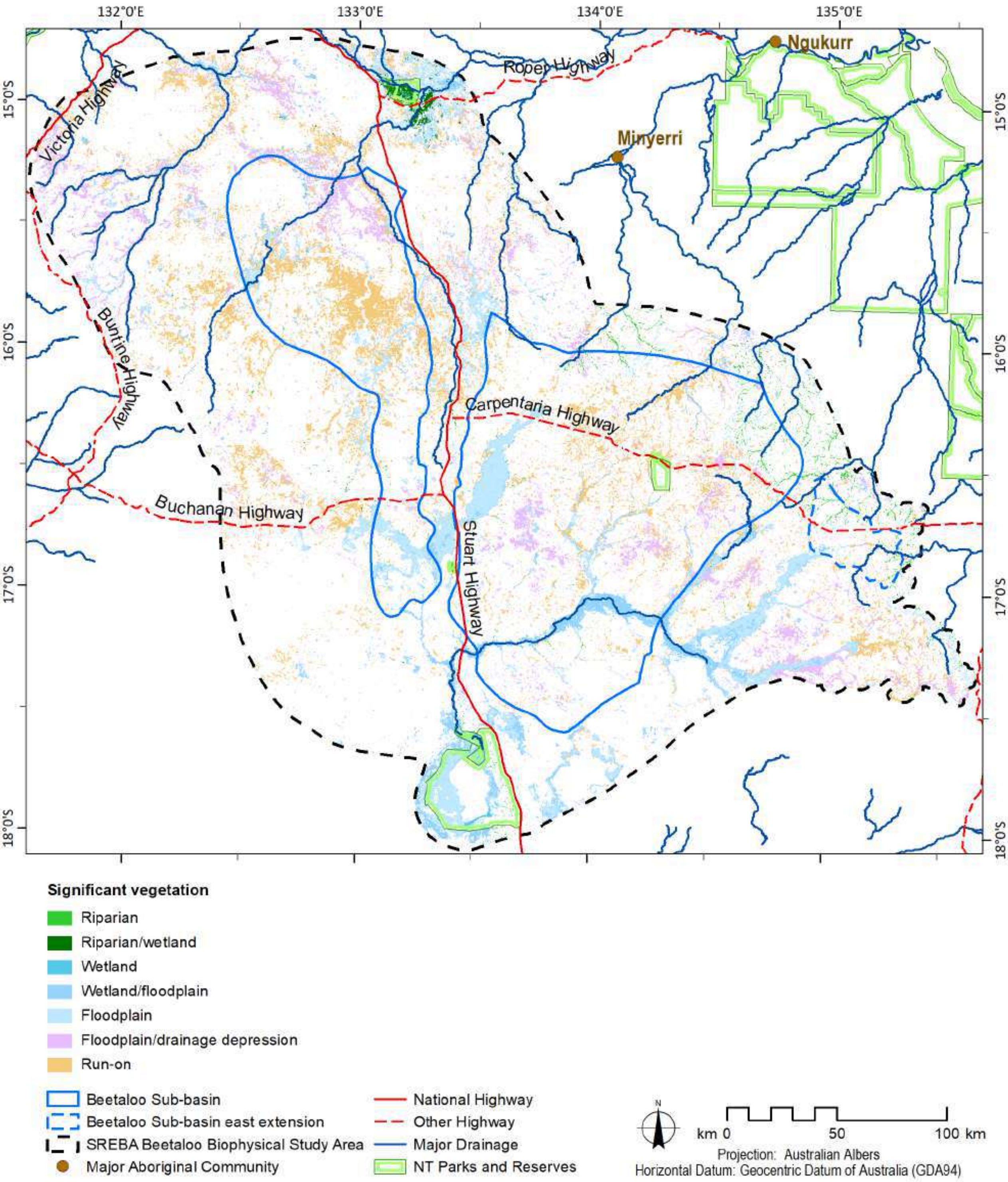

Figure 6-4. Areas of significant vegetation mapped across the study area.

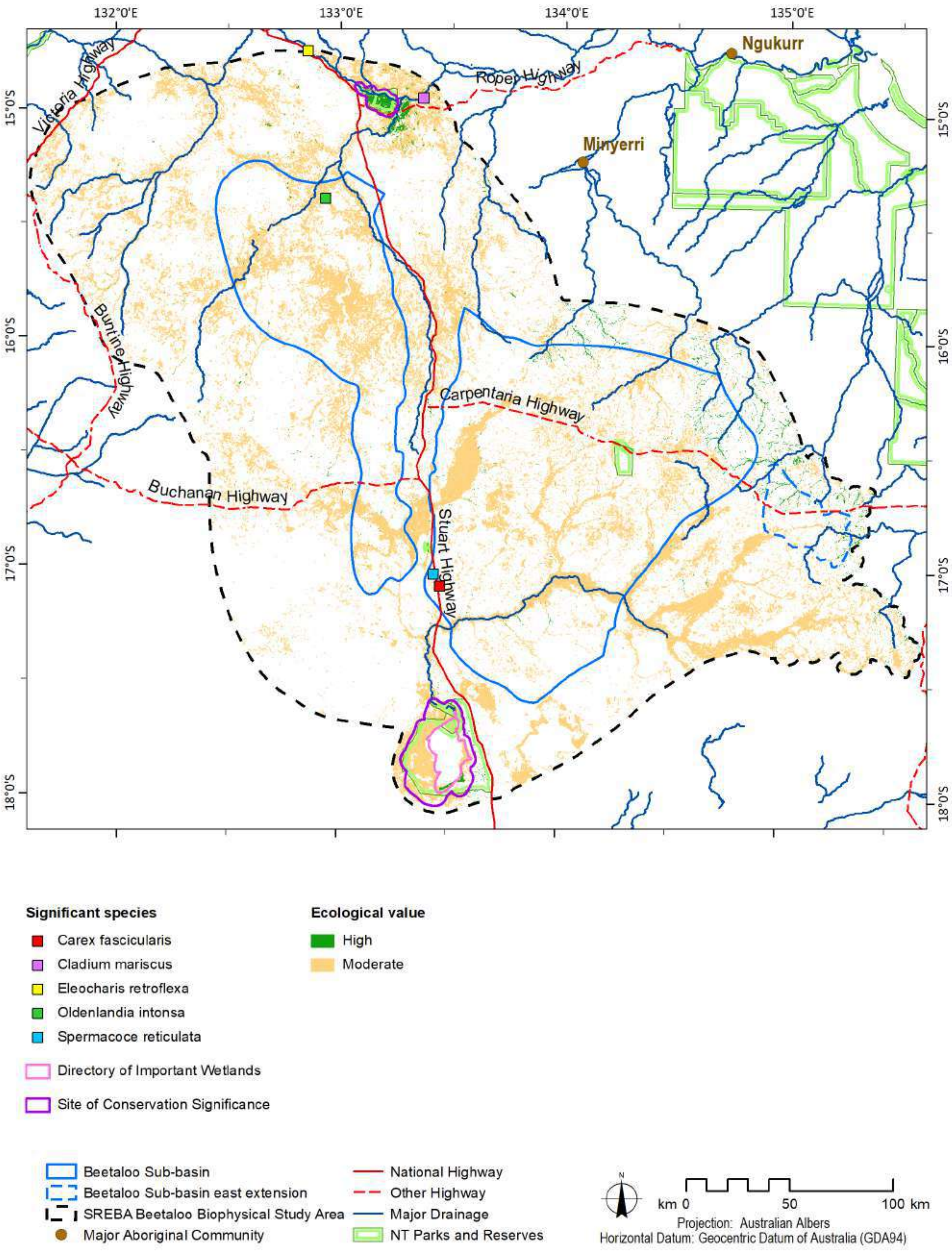

Figure 6-5. Significant biodiversity values related to flora and vegetation across the study area, showing areas rated as being of high and moderate ecological value.

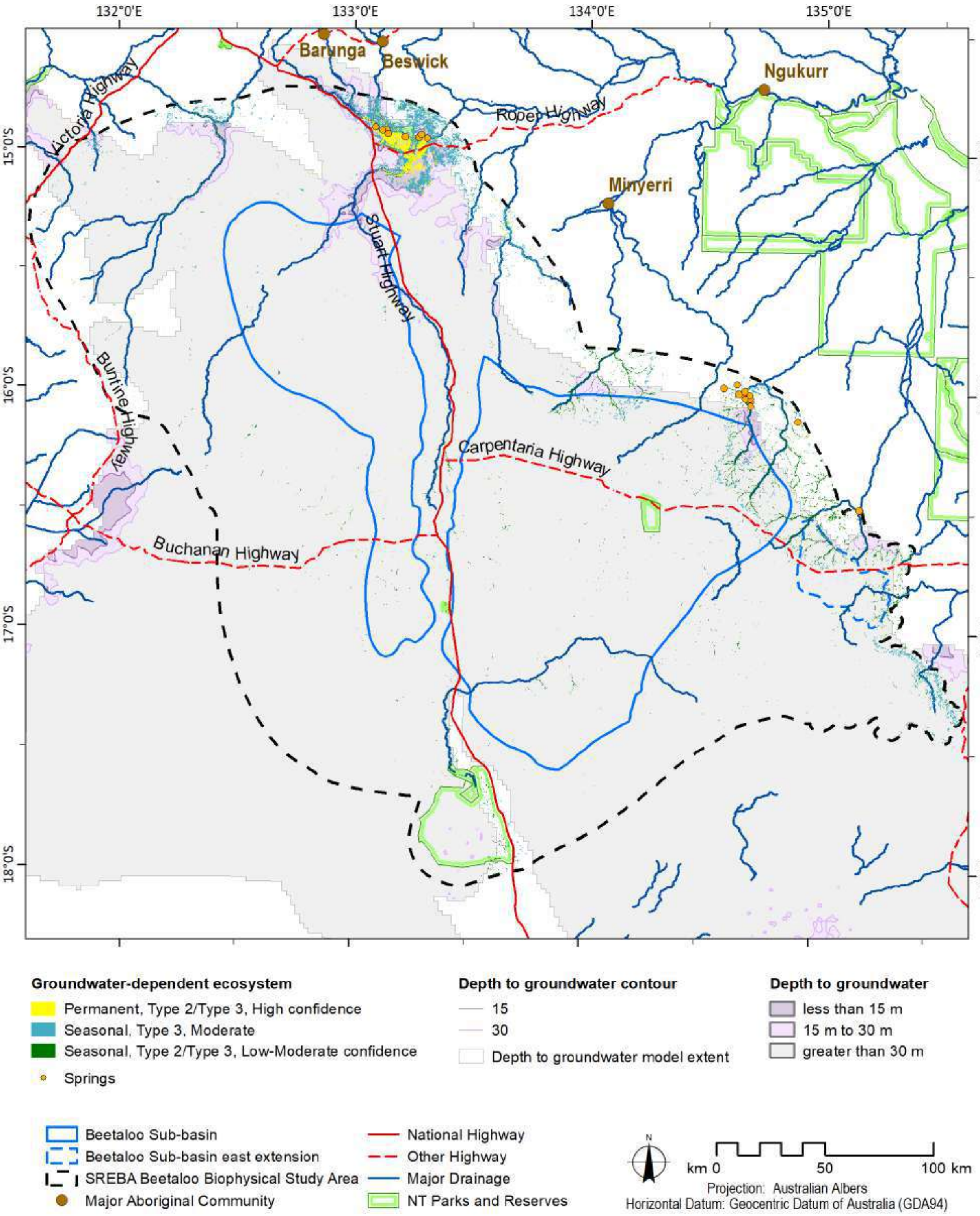

Figure 6-6. Potential groundwater-dependent ecosystems mapped across the study area.

6.4. Regional fauna surveys

6.4.1. Background

The Scientific Inquiry identified the need for regional assessments of the biodiversity of a region prior to the development of any onshore shale gas industry, and stressed the need for these to be comprehensive, both in terms of space (covering all major vegetation types across the region) and biota (including all groups of vascular plants and terrestrial vertebrates, and representative terrestrial invertebrates).

Comprehensive assessment of the faunal biodiversity of a region requires systematic survey using a range of sampling techniques appropriate to the target biota, as well as careful site selection to include the regional range of habitats and other environmental drivers of species and assemblage distribution.

There are well-established techniques for vertebrate fauna survey that have been applied and refined in the Northern Territory over decades (e.g. Woinarski *et al.* 2010; Einoder *et al.* 2018), as well as for some invertebrate groups (e.g. Andersen 1991). At the broadest scale, rainfall gradients in the Northern Territory are a key determinant of fauna assemblages, but at a regional scale rainfall also interacts with the physical environment (especially soil and landform) to influence the distribution patterns of the major fauna groups (Whitehead *et al.* 1992; Woinarski *et al.* 1999; Andersen *et al.* 2015).

Additional drivers of habitat suitability, including vegetation structure and hollow abundance, influence the patterns of faunal diversity at a finer scale than the broader climatic, edaphic and topographic drivers. Thus, fauna assemblage patterns need to be examined at multiple scales to adequately characterise their major environmental associations.

The objectives of the regional fauna surveys were to:

- document the vertebrate and (selected) invertebrate fauna of the study area
- test the ability of major habitat categories to summarise patterns of fauna richness, abundance and assemblage composition
- describe finer-scale patterns of fauna richness, abundance and assemblage
- identify habitats of high biodiversity value.

It is not feasible to systematically sample all elements of the terrestrial fauna. Target taxa were chosen on the basis of factors described in the SREBA Framework, most notably that there must be established sampling methods for that group, with adequate detection probabilities; sampling methods must not have excessive resource constraints given the geographic scope of the SREBA; the group should not be subject to high stochastic variability in distribution and abundance; and groups must be taxonomically tractable and/or the taxonomic expertise be available to consistently resolve taxa. Consequently, the following fauna groups were sampled during the regional fauna surveys:

- birds
- mammals (other than bats)
- bats (considered separately as sampling methods and site selection are distinct from other mammals)
- reptiles
- ants.

6.4.2. Methods

An *a priori* classification of the landscape was constructed to summarise major gradients in rainfall, soil type, topography and vegetation structure. Eleven categories were defined to represent the range of fauna habitats occurring in the study area. Survey sites were then allocated across these eleven habitat classes, in proportion to the distribution and extent of the habitat type in the study area and the variability within that habitat type (Figure 6-7). There was a minimum of five sites allocated to each habitat type.

Site locations were chosen by interrogating the draft regional ecosystems map and natural colour satellite imagery and through on-ground validation. Survey sites were selected to be a minimum of 2 km apart, except where restricted habitats could only be found in closer proximity. Logistical consideration required some clustering of sites; the minimum distance between sites in the same cluster being surveyed at the same time was 1.3 km and the maximum distance was 10 km. Ninety-eight fauna inventory sites were surveyed between May 2021 and May 2022. An additional 15 sites were sampled, using camera traps only, between June and August 2020 for the GBA Program (Davis *et al.* 2021).

A variety of survey methods were applied at each site, and these are described in detail in the Baseline Report and summarised in Table 6-3.

Any vertebrate animals captured had their species, sex and age class recorded. If there was uncertainty about the species' identification, photographs, measurements and a tissue sample for genetic analysis were collected. Any observations of additional or significant fauna species that were made on a survey site but were outside of formal survey times, or detected off-site, were recorded as incidental observations. For these incidental observations, information on location, species identification and number of individuals was recorded.

Images collected on camera traps were processed using Camera Photo Warehouse version 4 (CPW). Two observers identified any fauna observed in images, with identification to species level where possible, otherwise to the greatest taxonomic resolution possible.

Bats recorded by the passive detectors were identified through their characteristic echolocation call structure. Bat calls were only used if three consistent echolocation pulses were present. Twenty species of echolocating bat are known to occur in, or within 50 km of, the study area. Thirteen of those can be identified to species using this method while an additional eight species are grouped into three species groups.

Invertebrate samples that were collected during fauna inventory surveys were provided to Charles Darwin University researchers for sorting and identification. All ant specimens were sorted to species and named where possible. Where naming was not possible, ant specimens were identified to species group following Andersen (2000) and were given species codes. Species-level delimitation was informed by the CO1-barcoding of approximately 4,000 specimens from the Beetaloo region, as well as thousands of species from elsewhere in northern Australia.

At each fauna inventory site, habitat attributes that were expected to influence the composition of faunal assemblages were recorded, as well as a full floristic description.

Community patterns of fauna occurrence and abundance were assessed separately for birds, reptiles, non-volant native mammals (hereafter 'mammals'), bats and ants.

Generalised linear models (GLMs) were used to analyse environmental drivers of species richness and abundance in each fauna group. Biogeographic patterns were also examined by testing the relationship between fauna composition and a set of environmental variables, as detailed in the Baseline Report.

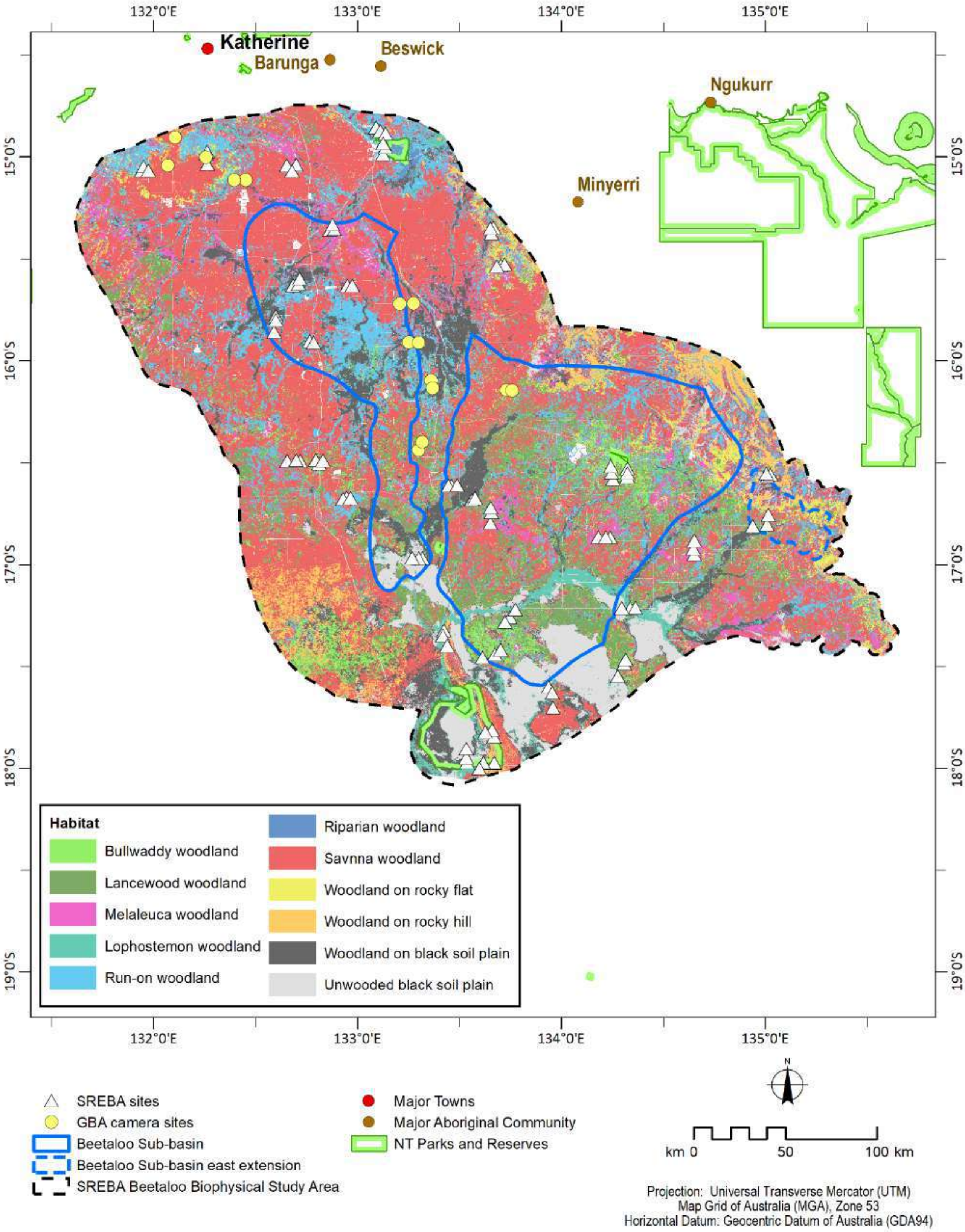

Figure 6-7. Distribution of habitat types in the study area and location of terrestrial fauna inventory sites.

Table 6-3. Summary of regional fauna survey methods.

Method	Detail	Target fauna
Live trapping	• 8 cage traps, 16 Elliot traps, 3 drift fences each with a pit and 4 funnel traps • Four days/nights • 50 x 50 m quadrat	Mammals Reptiles
Invertebrate wet traps	• 24 specimen vials (4.5 cm) containing ethylene glycol • Four days/nights • Adjacent to edges of live trapping quadrat • Invertebrates > 2 mm long that were found in the live-trapping pitfall buckets were also collected	Ants
Bird census	• Seven 20 minute visual and aural census • 2 ha area centred on trapping quadrat • Within 3 h of sunrise and sunset during 4 day survey period	Birds
Nocturnal search	• Four 10 min searches • 2 ha area centred on trapping quadrat • Evenings during 4 day survey period	Birds Reptiles Mammals
Camera trapping	• 5 Reconyx cameras • Three camera models with different focal length, sensitivity and distance to bait station • Centre and four corners of trapping quadrat, central camera with drift fence and cork board • Deployed for 31 to 69 days	Mammals Reptiles
Bat detectors	• One Anabat Swift detector per site, within ~100 m of centre point of trapping quadrat • One Anabat Swift detector per cluster of sites, on a bat 'flyway' • c. 1.5 m from ground, 45° from vertical • for 2 h after sunset and 2 h before sunrise • 4 nights	Bats

6.4.3. Results

During the SREBA surveys, 234 vertebrate species and 639 ant species were recorded at fauna inventory sites. Vertebrate species recorded included 109 bird species, 88 reptile species (including one introduced species), 28 non-volant (non-flying) mammal species (including seven introduced species) and at least twelve microbat species.

Species accumulation curves show that a greater number of sites are required to capture the full suite of bird, reptile, non-volant mammal and, particularly, ant species in the region (Figure 6-8). The species accumulation curve for microbats suggests all bat species were sampled, but there are likely to be additional bat species that cannot be detected by passive detectors.

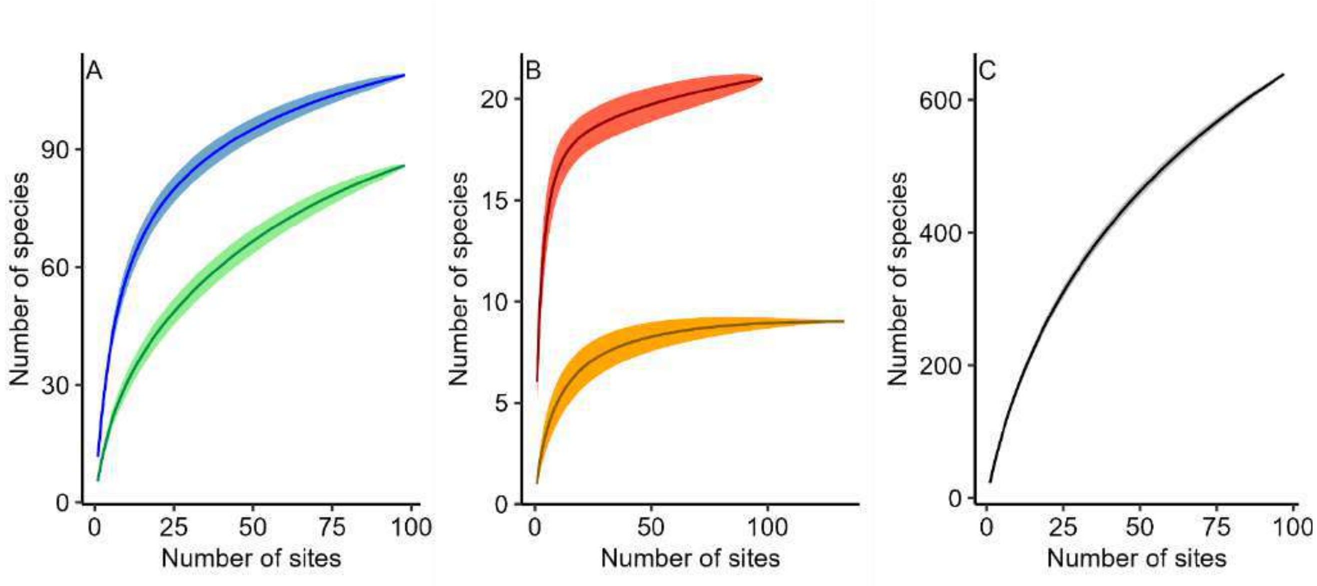

Figure 6-8. Rarefied species accumulation curves for A) birds (blue line) and reptiles (green line), B) native non-volant mammals (red) and microbats (orange) and C) ants. Lines represent rarefied mean number of species. Shading represents standard deviation.

Three-hundred and fifty-three vertebrate species were recorded from all surveys and incidental observations during the SREBA and GBA studies, including 14 amphibian species, 202 bird species, 39 mammal species and 99 reptile species. Including additional records from the *Fauna Atlas NT*, a total of 512 vertebrate species have been recorded in the study area. SREBA surveys recorded thirteen vertebrate species that were not previously documented in the *Fauna Atlas NT* as occurring in the study area.

No terrestrial vertebrate species are endemic to the study area.

Of the 748 ant species now known from the Beetaloo region (incorporating the GBA pilot survey and previous collections), only 39 (5%) can be confidently named. More than half of these species are only known from the Beetaloo region, which includes hundreds of species for which the collections from the SREBA are the first ever records.

Thirteen introduced species (one reptile, one amphibian, eight mammal and three invertebrates) are known from the study area and all but one (House Mouse *Mus musculus*) were recorded during GBA and SREBA surveys.

6.4.3.1. Birds

Bird species richness at the site level ranged from zero to 32 (mean: 12.8 ± 7.1). The bird species recorded at the greatest number of sites were Rufous Whistler (77 sites), Willie Wagtail (67) and Peaceful Dove (47). Nineteen bird species were recorded at just one survey site each and 44 species were recorded at < 5 survey sites each.

Bird species richness showed a unimodal response to rainfall, with a peak in species richness near the 850 mm isohyet. Bird species richness was lowest in unwooded black soil plain; low in bullwaddy and lancewood woodlands, *Melaleuca* woodlands, and woodlands on blacksoil plains; and highest in riparian and *Lophostemon* woodlands. Unwooded black soil plain, woodland on black soil plain, Lancewood woodland and Bullwaddy woodland also supported distinct bird communities. However, there were no species that were diagnostic of the Lancewood and Bullwaddy woodland habitats, indicating that these habitat types support a subset of the bird fauna found in other woodland habitat types, rather than more restricted habitat specialists.

Multivariate analyses of bird composition separated plain, hill and drainage depression landforms in the south of the study area from the southern stream channel/bank landforms. The latter clustered more closely with the northern landforms and swamps. These relationships are similar to those described across the northern Northern Territory, with many species typical of higher rainfall areas extending into lower rainfall areas only or mainly along riparian strips (Woinarski *et al.* 2000).

Another environmental variable that influenced bird species composition in the study area was total number of hollows. Hollows were most abundant in riparian woodland, *Lophostemon* woodland, woodland on rocky flat and Bullwaddy woodland, but the size of hollows differed between habitat types.

6.4.3.2. Reptiles

Reptile species richness at the site level ranged from zero to 15 (mean: 5.2 ± 3.0). The reptile species recorded at the greatest number of sites was *Ctenotus spaldingi* (50 sites). Twenty-nine reptile species were recorded at just one survey site each. Reptile species richness also showed a unimodal response to rainfall, with a peak in species richness between the 750 and 800 mm isohyets. Reptile species richness was highest in woodland on rocky flat, savanna woodland and *Melaleuca* woodland, and lowest in unwooded black soil plain, although richness was quite variable within habitats. There was relatively poor patterning of reptile species composition between habitat types, with unwooded blacksoil and woodlands on rocky hills having the most distinct composition.Reptile composition in the study area was more strongly related to substrate, specifically soil type, rockiness, and ground cover attributes such as the frequency of hummock grass and leaf litter.

6.4.3.3. Native (non-bat) mammals

Mammal species richness at the site level ranged from one to seven (mean: 3.18 ± 1.48). The mammal species recorded at the greatest number of sites was the Agile Wallaby *Notamacropus agilis* (66 sites). Four mammal species were recorded at just one site each.

Mammal species richness showed a similar unimodal response to average annual rainfall as reptile species richness, with a peak between 750 and 800 mm isohyets. There was little difference in mammal species richness between habitat types, although the frequency (abundance) of mammals was high in unwooded blacksoil. Mammal species composition in unwooded black soil plain, woodland on black soil plain and woodland on rocky hill was relatively distinct, but poorly differentiated between other habitat types. Multivariate analyses indicated a broad influence of soil type across landforms, with the composition of mammal species differing between all pairwise soil type combinations except clay loam and sandy loam. Vegetation structure and ground cover had a lesser influence than rainfall, landform and soil type. However, there is a difference in mammal composition between hills with vegetation dominated by *Eucalyptus*/*Corymbia* and hummock grass understorey and those dominated by Lancewood, which had little ground vegetation.

6.4.3.4. Ants

Ant species richness at the site level ranged from four to 53 (mean 23.5 ± 12.4). The ant species recorded at the greatest number of sites were *Iridomyrmex* sp. anc1 (anceps complex) (64 sites) and *Iridomyrmex sanguineus* (63), and these two species accounted for 9.9% and 9.2% of all individual ants collected, respectively. Two-hundred and eighty-eight ant species were recorded at just one site each and 505 ant species were recorded at < 5 sites each. The richest ant genera sampled were *Monomorium* (121 species), *Melophorus* (106 species), *Tetramorium* (66 species), *Rhytidoponera* (57 species), *Meranoplus* (50 species), *Iridomyrmex* (45 species), *Camponotus* (44 species) and *Pheidole* (42 species).

Ant species richness was highest at the lowest annual rainfall and declined with increasing average annual rainfall, before increasing slightly at the highest rainfall sites. Ant species richness was very low in unwooded black soil plain and wooded black soil plain, and highest in savanna woodland and woodland on rocky flats. Ant species composition was markedly different in woodland on rocky hills from all other habitats, and composition in savanna was distinct from woodland on black soil plain, unwooded black soil plain and riparian woodland.

The multivariate analyses indicated that substrate and landform were major drivers of ant community composition. The compositional gradient correlated with the gradient from the well-drained or higher elevation landforms (hill, rocky flat) to landforms subject to inundation and characterised by clay soil types (swamp, stream channel/bank and black soil plain). Ground cover attributes and vegetation structure had a lesser but still significant influence on ant assemblage composition.

6.4.3.5. Bats

A total of nine species of bat that could be identified from calls to a single species were detected in the study area, and calls from three species groups were also detected, so the total number of species is at least 12 and potentially as many as 16. The most commonly detected species was *Chalinilobus gouldii* (56 sites), while the rarest was *Vespadelus caurinus* (3 sites), with this species recorded only within Elsey National Park. One species (*Nyctophilus walkeri*) was only detected at flyway sites.

Mean site richness (for bats that could be identified to species level) ranged from 0 to 6 (mean 1.1 ± 1.2). Site richness had a strong positive relationship with average annual rainfall, but there no significant relationships with any other habitat attributes. All the species for which the probability of occurrence was positively related with rainfall are cave-dwelling species (*Rhinonicteris aurantia*, *Taphozous georgianus*, *Vespadelus caurinus* and *Vespadelus finlaysoni*) associated with sandstone and limestone outcrops, which are only found in the northern portion of the study area. The *a priori* habitat classification was not a significant predictor of bat species or guild occurrence in the study area, with bats found to be using all habitat types. Habitat complexity was also not found to be a predictor of species richness overall, but it was important for predicting the presence of particular species.

6.4.4. Discussion

Including SREBA and GBA survey data and records from the *Fauna Atlas NT*, a total of 512 vertebrate species have been recorded in the study area, which is greater than that recorded in the *Fauna Atlas NT* for the Sturt Plateau (463 species), Mitchell Grass Downs (430 species), and Daly Basin bioregions (506 species), but fewer than recorded in the Gulf Fall and Upland bioregion (572 species). The greater total number of species in the study area compared to the number of species recorded in the Sturt Plateau bioregion reflects the incorporation of parts of adjacent bioregions and their component fauna into the margins of the study area. For example, the Carpentarian Antechinus (*Pseudantechinus mimulus*) was only detected in the Gulf Fall and Upland bioregion and the Pygmy Mulga Monitor (*Varanus gilleni*) was only detected in the Mitchell Grass Downs bioregion during SREBA surveys.

At the scale of the Northern Territory, the study area has relatively high vertebrate species richness, being closer to the bioregion with the greatest species richness (Darwin Coastal: 652 species) than the bioregion with the lowest species richness (Central Ranges: 237 species). This high richness can be partly attributed to the study area encompassing a transition from a tropical to arid fauna. It also reflects both the large total area of the region and the now relatively high intensity of systematic fauna survey effort.

Patterns of fauna diversity and composition relating to the climatic gradient, and landscape and habitat attributes were apparent across all fauna groups sampled. There was higher richness of birds, reptiles and mammals in the middle compared to the lower and higher ends of the rainfall gradient, and fauna assemblages differed between habitats on the black soil plain, rocky hills and other woodland types, independently of the rainfall gradient. Analyses also described further nuance in the way each group responded to rainfall, habitat type and other environmental attributes, and interactions amongst them, across the study area.

Riparian and swamp habitats were found to be of high value for birds, likely facilitating the occurrence of more tropical bird assemblages into lower rainfall areas and the maintenance of bird diversity in the study area during dry periods. Hollow abundance, in addition to vegetation structure and ground cover attributes, influenced bird species composition, highlighting the importance of hollows for bird communities. Reptile, mammal and ant assemblages responded to substrate and ground cover attributes. Clay soils and black soil plains, along with rocky hills, supported distinct reptile, mammal and ant assemblages compared to the other habitat and landform types. While these habitats contributed strongly to the organisation of reptile, mammal and ant assemblages, they are widespread within the study area and/or in adjacent bioregions. These habitats are important for the maintenance of regional fauna diversity but are not identified as ecosystems of high conservation value.

This study added to the knowledge of microbat species and their use of habitat in the Stuart Plateau and resulted in range revisions for six bat species, extending known ranges southward from between 5 km and 60 km. In addition, this study adds to the limited literature (Milne *et al.* 2005) on the influence of habitat features on bat species in the Top End.

Fourteen vertebrate species were recorded during SREBA surveys that were not previously recorded from the study area in the *Fauna Atlas NT*. New records for these species clarified the extent of the species' distribution or provided additional resolution within the known distribution.

6.4.4.1. Values and risks

a) Riparian zones, ephemeral swamps and Lophostemon woodlands

The riparian woodland and *Lophostemon* woodland habitat types were identified as being important for bird diversity, particularly in the southern half of the study area. The richness and frequency of bird species was higher in these habitats than all other habitat types. These habitats were not compositionally distinct from other woodland habitats, suggesting they support numerous species that use multiple habitats rather than a strictly unique bird assemblage. The positioning of the southern stream channel/bank landform with the northern landforms in the distance-based redundancy analysis ordinations suggests that these higher-productivity habitats are even more important in the southern, more arid part of the study area as they provide refuges for more widespread species when the rest of the landscape is dry and provide a conduit for more tropical species into lower rainfall regions.

Similarly, but to a lesser degree than the riparian and *Lophostemon* woodlands, run-on woodlands may help to maintain regional diversity particularly during dry periods. Due to its run-on position in the landscape, this habitat is more productive than the surrounding woodlands and may provide a more stable resource base for fauna.

The riparian and *Lophostemon* woodland habitats occur throughout the study area and Sub-basin but occupy only a small proportion of their total area (study area: riparian woodland = 0.89%; *Lophostemon* woodland = 3.12%; Sub-basin: riparian woodland = 0.59%; *Lophostemon* woodland = 2.9%). They therefore have low redundancy at a landscape scale and are potentially more sensitive to disturbance and cumulative impacts.

b) Hollows and large trees

In addition to particular habitats, there are a suite of habitat attributes that are important to faunal biodiversity across the landscape. Results showed that large trees and the presence of hollows provide high-quality habitat for some fauna. The value of large trees can relate to their height, diameter at breast height or the other habitat attributes that they provide (e.g. hollows). While these attributes can occur across all habitats where there are trees, they were most prominent in Lancewood woodland, run-on woodland, Bullwaddy woodland, *Lophostemon* woodland, riparian woodland, and woodland on rocky flat. The size of available hollows differed between habitat types and the maintenance of hollows in a range of size classes across the landscape is likely to be important for maintaining the diversity of fauna species that rely on hollows for nesting and/or roosting.

c) Disturbance

Disturbance modifies the quality and suitability of habitat for fauna species across the landscape. There are well-known impacts to native faunal assemblages related to disturbance from inappropriate fire regimes, and introduced herbivores, predators, and plant species. Introduced herbivore activity was highest in riparian woodland, and moderately high in *Lophostemon* woodland and woodland on black soil plain. Observed predator activity was highest in *Melaleuca* woodland and riparian woodland, and fire frequency was highest in the savanna woodland, *Lophostemon* woodland, woodland on rocky flat and woodland on rocky hill.

Weed occurrence was greatest in the more mesic vegetation types (run-on woodland, riparian woodland, woodland on black soil plain, *Lophostemon* swamps, *Melaleuca* woodland), as well as Bullwaddy woodland. While various disturbance factors were found to be greater in certain habitats, they were observed to be operating across the landscape. In general terms, management that reduces the intensity of disturbance is likely to improve habitat quality, help retain biodiversity values and increase resilience against the longer-term impacts of climate change. Priorities for management are where disturbance most severely impacts habitat types important for biodiversity (e.g. minimising grazing impacts and weed incursion in riparian woodlands and other run-on habitat), or negatively impacts important habitat attributes (e.g. frequent and extensive late-dry season fires that reduce hollow availability in affected woodlands).

Threatened species recorded during the regional biodiversity surveys, and the identification of areas of high conservation value, are discussed in more detail in Sections 6.5 and 6.6.

6.5. Significant fauna species

6.5.1. Background

The regional biodiversity surveys described in Sections 6.3 and 6.4 provide an account of the fauna and flora present across the region, the environmental factors affecting patterns of species distribution and assemblages, and may identify ecosystems of particularly high value to biodiversity. However, regional surveys are generally not effective for providing detailed information about the distribution of individual species that are rare, have highly restricted distribution, or are poorly detectable by standard survey methods. Consequently, targeted surveys were undertaken for a selected set of significant fauna species. Targeted surveys for threatened plant species were not undertaken because at the start of the project no threatened plant species were known to occur, or considered likely to occur, within the study area.

Of the 512 terrestrial fauna species recorded in the study area, nine birds, one invertebrate, six mammals and four reptiles are listed as threatened under the *Territory Parks and Wildlife Conservation Act 1976* (TPWC Act), the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) or both (Table 6-4). Twenty species are listed as migratory under the EPBC Act, including one that is also listed as threatened (Curlew Sandpiper). A further 21 species are listed as Near Threatened and three as Data Deficient under the TPWC Act.

The Beetaloo GBA Stage 2 report identified priority species that were considered potentially at risk from unconventional gas development in the region. Of these species, it was determined that priority during stage 3 of the Beetaloo GBA and subsequently during the Beetaloo SREBA should be given to undertaking targeted surveys for the Crested Shrike-tit (Northern) (*Falcunculus frontatus whitei*), Gouldian Finch (*Erythrura gouldiae*), Greater Bilby (*Macrotis lagotis*) and Ghost Bat (*Macroderma gigas*). Targeted surveys for the Plains Death Adder (*Acanthophis hawkeii*) were also determined to be feasible and were undertaken during the SREBA study. These species were selected because it was feasible to significantly improve the current knowledge base about their distribution and habitat use in the study area through targeted survey.

Surveys for the remaining priority species identified in the GBA Stage 2 report were determined to either not be feasible or for the species to be adequately covered under survey effort for other taxa. Targeted surveys for the Grey Falcon (*Falco hypoleucos*), Bare-rumped Sheath-tailed Bat (*Saccolaimus saccolaimus*), Masked Owl (*Tyto novaehollandiae kimberli*), Night Parrot (*Pezoporus occidentalis*) and Australian Painted Snipe (*Rostratula australis*) were considered to be impractical due to these species' cryptic nature and/or their unpredictable and irregular occurrence in the region. Methods used to detect the Curlew Sandpiper (*Calidris ferruginea*) are the same as those used for targeting waterbirds. Methods targeting the Northern Brushtail Possum (*Trichosurus vulpecula arnhemensis*), Pale Field-rat (*Rattus tunneyi*), Mertens' Water Monitor (*Varanus mertensi*), Mitchell's Water Monitor (*Varanus mitchelli*) and Yellow-spotted Monitor (*Varanus panoptes*) were covered by methods used for the regional fauna surveys during the SREBA (with additional data for *V. mertensi* and *V. mitchelli* proved by the Aquatic Ecosystem surveys).

The aims of targeted surveys for the selected significant species were to:

- clarify their occurrence and distribution in the study area
- predict the distribution of suitable habitat for each species across the study area
- identify mapped broad vegetation groups (BVGs) that are likely to represent habitat for each selected significant species.

Additionally, opportunistic records were collected for species listed as Near Threatened and Data Deficient, and for significant species not amenable to targeted survey.

Many waterbirds can be considered to be significant species, and these are discussed in Section 6.6.

Table 6-4. Terrestrial threatened species previously identified in the study area in *Fauna Atlas NT*, with conservation status under the *Territory Parks and Wildlife Conservation Act 1976* (TPWC Act) and *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The table also shows the most recent date for a regional record of each species in the *Fauna Atlas NT*, as well as whether the species was recorded during the GBA and SREBA surveys in 2021-2022.

Class	Common name	Scientific name	TPWC Act	EPBC Act	Recent record	SREBA
Birds	Australian Painted Snipe	*Rostratula australis*	Endangered	Endangered	3/06/2001	Y
	Crested Shrike-tit (northern)	*Falcunculus frontatus whitei*	Near Threatened	Vulnerable	7/03/2018	Y
	Curlew Sandpiper	*Calidris ferruginea*	Critically Endangered	Critically Endangered	22/09/1993	N
	Gouldian Finch	*Erythrura gouldiae*	Vulnerable	Endangered	4/06/2019	Y
	Grey Falcon	*Falco hypoleucos*	Vulnerable	Vulnerable	24/11/2015	Y
	Painted Honeyeater	*Grantiella picta*	Vulnerable	Vulnerable	no date	N
	Partridge Pigeon (eastern)	*Geophaps smithii smithii*	Vulnerable	Vulnerable	30/11/1976	N
	Princess Parrot	*Polytelis alexandrae*	Vulnerable	Vulnerable	30/11/1976	N
	Red Goshawk	*Erythrotriorchis radiatus*	Vulnerable	Vulnerable	29/08/2012	Y
Mammals	Greater Bilby	*Macrotis lagotis*	Vulnerable	Vulnerable	26/11/2011	Y
	Common Brushtail Possum (north-western)	*Trichosurus vulpecula arnhemensis*	Near Threatened	Vulnerable	13/07/2002	Pending DNA analysis
	Common Brushtail Possum (central and south-eastern)	*Trichosurus vulpecula vulpecula*	Endangered	Least Concern	1968	Pending DNA analysis
	Ghost Bat	*Macroderma gigas*	Near Threatened	Vulnerable	11/09/1987	Y
	Northern Quoll	*Dasyurus hallucatus*	Critically Endangered	Endangered	no dates	N
	Pale Field-rat	*Rattus tunneyi*	Endangered	Least Concern	11/06/1999	N
Reptiles	Mertens' Water Monitor	*Varanus mertensi*	Vulnerable	Least Concern	22/09/2019	Y
	Mitchell's Water Monitor	*Varanus mitchelli*	Vulnerable	Least Concern	1/12/1996	N
	Plains Death Adder	*Acanthophis hawkei*	Vulnerable	Vulnerable	8/09/2019	N
	Yellow-spotted Monitor	*Varanus panoptes*	Vulnerable	Least Concern	19/2/2019	Y

6.5.2. Methods

Different survey methods were implemented for each species, depending on existing information about the species' ecology and selection of survey techniques that would maximise detection probability. Methods are described in detail in the Baseline Report and are summarised below.

6.5.2.1. Crested Shrike-tit

Call-playback surveys were undertaken at 58 sites between June and July 2020 (as part of the GBA program), at 39 sites between September and October 2021, and at 12 sites between March and April 2022 (totalling 109 sites). Surveys were undertaken in a range of potentially suitable woodland habitats across the northern two-thirds of the study area, within the geographic limits of known Crested Shrike-tit records. At each site, call-playback surveys were undertaken over two days on two mornings, within 3 h of sunrise, and on two afternoons, from 3 h prior to sunset.

6.5.2.2. Gouldian Finch

Surveys for the Gouldian Finch were undertaken between June 2020 and April 2022 at small, persistent water sources (e.g. pools in creeks, pastoral dams) at 26 sites between Mataranka in the north and Lake Woods in the south of the study area. Sites were selected using satellite imagery and then assessed on-ground to confirm the presence of standing water. Surveys were undertaken for 2 h on two consecutive mornings beginning at sunrise, and on two consecutive afternoons beginning at 4 pm. Additional observations of Gouldian Finch were made at multiple waterbodies during reconnaissance for waterhole sites, as well as during regional surveys and incidentally while traversing the study area.

6.5.2.3. Greater Bilby

Aerial and on-ground tracking surveys were undertaken for the Greater Bilby on Murranji Station in June 2020 and on Karlantijpa North Aboriginal Land Trust, Tandyidgee, Newcastle Waters and Powell Creek Stations in May 2021 and June–July 2022. These areas were selected based on proximity to recent records and them having likely suitable habitats with sandy substrate. Greater Bilby surveys were designed to detect sign (e.g. burrows, scats, tracks and/or diggings) rather than the animals themselves. Aerial surveys were undertaken using an R44 helicopter that was flown along transects oriented east-west at 3 km spacing over potentially suitable habitat. Potential sign was ground-truthed when the helicopter could land nearby. Ground-based surveys for the Greater Bilby were undertaken using 2 ha (200 m x 100 m) plot-based tracking surveys, with two observers searching for any sign of Greater Bilby (e.g. tracks, scats, burrows, diggings).

6.5.2.4. Ghost Bat

Ghost Bats have specific habitat requirements, so survey locations were stratified at the landscape scale to include areas that have potential roosting sites. There are no records of the Ghost Bat in the Sub-basin, nor geology that would be considered to be suitable (sandstone or limestone outcrop), but there is potential habitat within the broader SREBA study area (Figure 6-9). The Tindall Limestone geological formation that occurs in the extreme north of the study area is the most likely to have cave, fissure and crevice formations that may provide roosting habitat for the Ghost Bat. There are two main areas of outcropping Tindall Limestone in the study area: in the vicinity of Mataranka on Elsey National Park and Mangarrayi Aboriginal Land Trust (east side), and to the south of Katherine on Manbulloo, Nenen and Dry River Stations (west side).

An array of 17 (east) and 13 (west) sample sites at c. 5 km spacing was established over these two areas. Ghost Bats were sampled at each site using a broadcast of their 'squabble' social vocalisation, and passing bats were illuminated by an infra-red lamp and recorded on a video camera. Sampling occurred for a 2 h period from 30 minutes after sunset, with sampling on two nights per site. Technical issues for some sites meant that presence/abundance of ghost bats may have been underestimated at some sites.

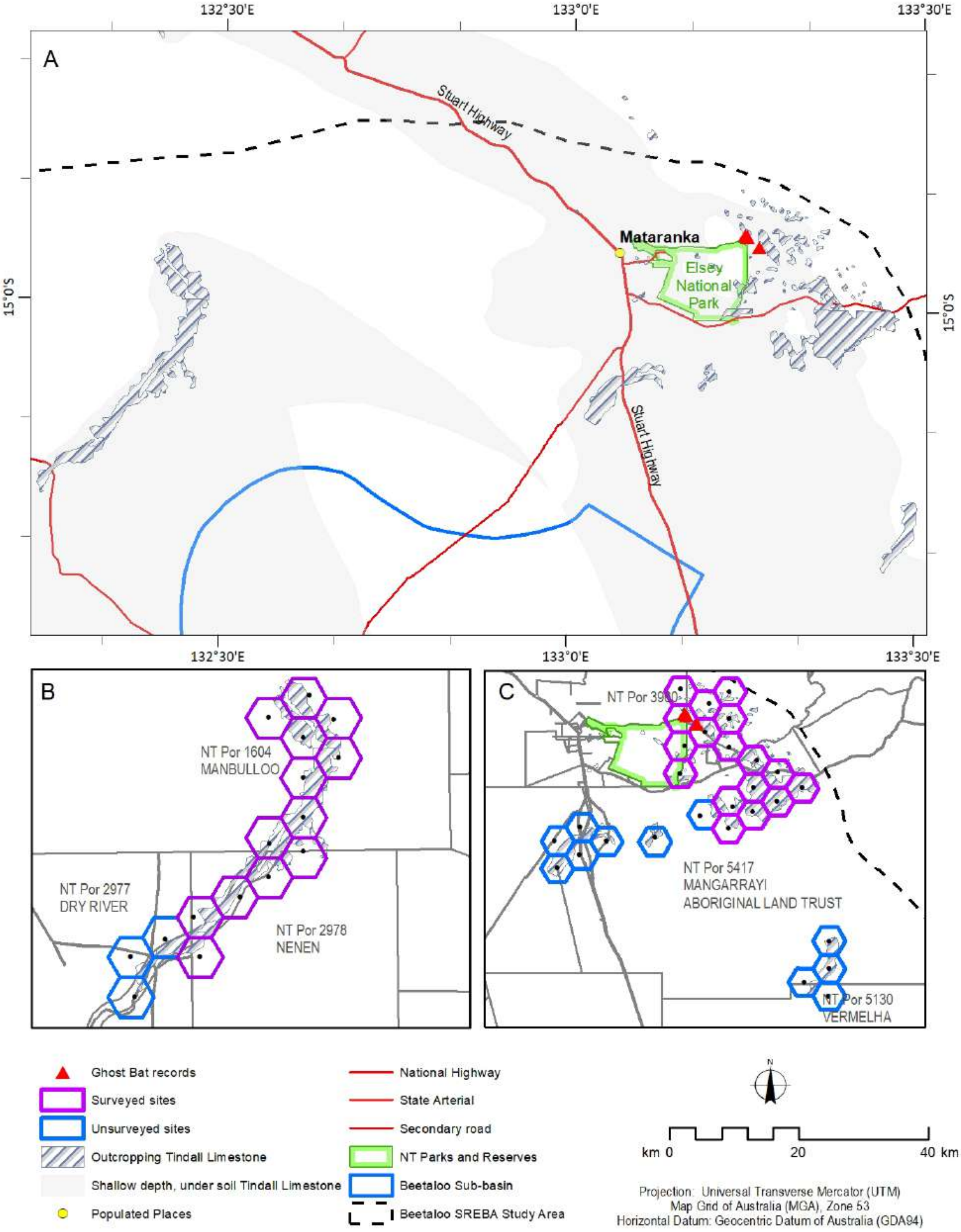

Figure 6-9. A) Areas of outcropping Tindall Limestone geology in the northern-most part of the SREBA study area, including previous records of the Ghost Bat from *Fauna Atlas NT* (DEPWS 2019); and survey area for the Ghost Bat on the B) west; and C) east side of the northern study area.

6.5.2.5. Plains Death Adder

Sampling was undertaken in the late wet season to coincide with warm, humid conditions likely to be favourable for nocturnal reptile activity. In March 2022, three 10 km transects, and one 42 km transect were selected for 'road-cruise' sampling targeting the Plains Death Adder along existing station tracks on Beetaloo Station. These transects ran through some of the largest areas of treeless cracking clay grasslands in the SREBA study area, which are potentially suitable habitat for the Plains Death Adder. Each transect was driven at 30–45 km/h once (two transects) or twice (two transects) in a 4WD vehicle fitted with driving lights, commencing shortly after dusk.

6.5.2.6. Species distribution modelling

There were sufficient records of the Gouldian Finch, Crested Shrike-tit, Greater Bilby and Yellow-spotted Monitor in the study area to model habitat suitability using available and relevant spatial data. Species distribution models (SDMs) for all species were run using the Maxent algorithm in the 'SDMtune' package in the software program 'R'. Records collected during the SREBA surveys for each species were supplemented with records in the *Fauna Atlas NT* and *Atlas of Living Australia* that were collected after 1970 and that had a locational accuracy better than 2 km. The spatial covariates used in the SDMs are described in detail in the Baseline Report, but included variables related to climate, topography, vegetation structure, hydrology, fire indices and soil type. To delineate areas with the highest likelihood of suitable habitat, the final predictive model was thresholded using maximum sensitivity plus specificity (Bean *et al.* 2012).

6.5.3. Results

6.5.3.1. Crested Shrike-tit

There were 22 unique locations for the Crested Shrike-tit in the *Fauna Atlas NT* from 1980–2015 and six undated records, prior to the GBA and SREBA surveys. During the latter surveys, the Crested Shrike-tit was recorded at 26 out of the 109 call-playback survey sites, at ten locations incidentally and at one fauna inventory site (Figure 6-10).

Extensive areas of woodland habitat on the plains throughout the northern half of the study area are predicted by the SDM to be suitable for the species (Figure 6.12). High-quality habitat occurs across 17.1% of the study area and 11.3% of the Sub-basin, particularly in BVG 1 (*Corymbia*/*Eucalyptus* open woodland on sandy loam).

6.5.3.2. Gouldian Finch

There were 37 unique locations for the Gouldian Finch from 1970–2019 in the *Fauna Atlas NT*, prior to the GBA/SREBA projects. During the latter surveys, the Gouldian Finch was recorded at ten of the 26 waterhole survey sites, at four Crested Shrike-tit call-playback sites, eight regional survey sites and a further 30 incidental locations (Figure 6-11).

The model for predicted habitat suitability for the Gouldian Finch indicates that there is generally a higher likelihood of suitable habitat in the northern two-thirds of the study area, and highest likelihood surrounding waterways and close to hills and ranges (Figure 6-13). High-quality habitat occurs across 21.6% of the study area and 14.8% of the Sub-basin, including in a broad variety of vegetation communities. The SDM for the Gouldian Finch does not distinguish foraging habitat from nesting habitat, which may be far more spatially restricted.

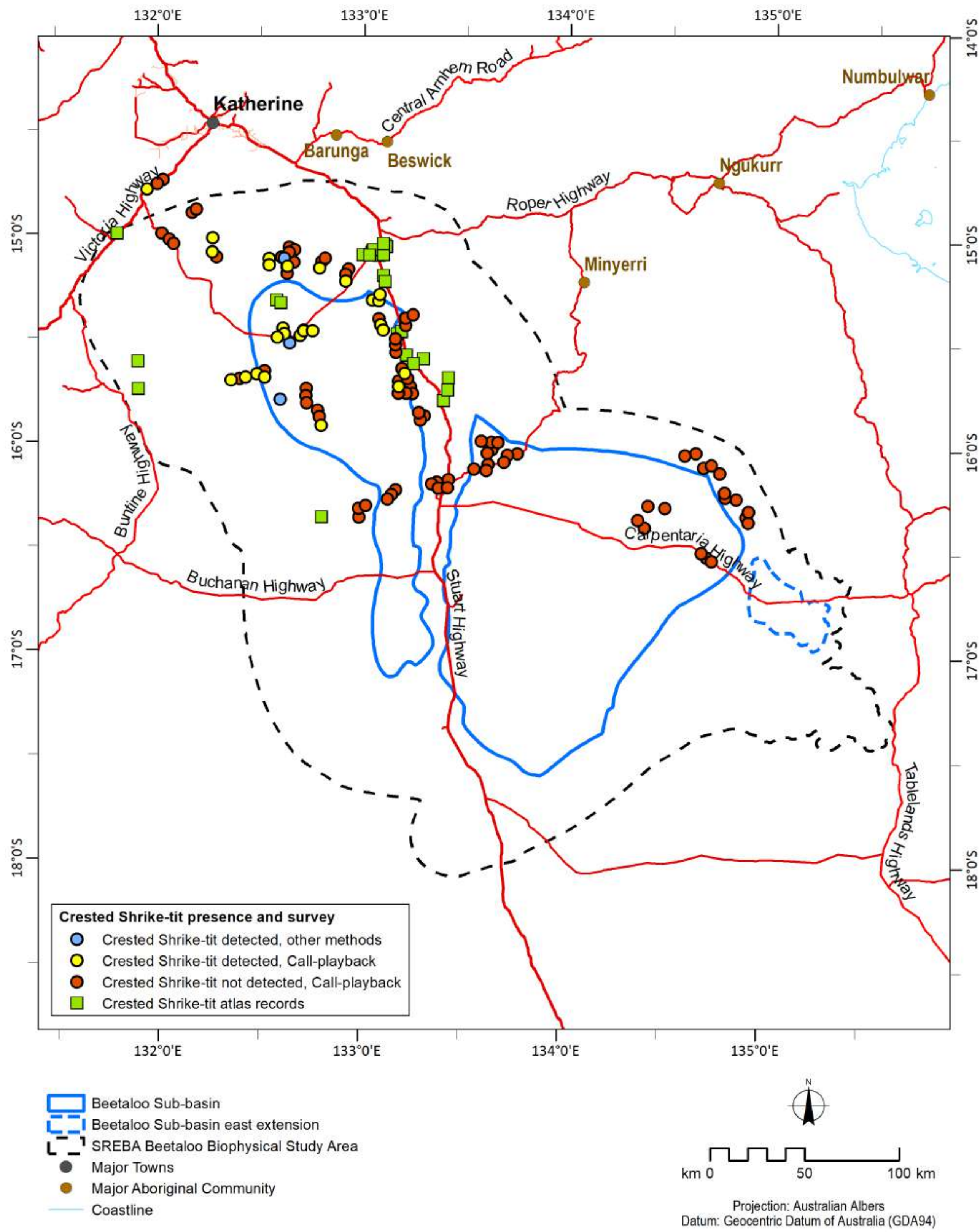

Figure 6-10. Location of sites surveyed for the Crested Shrike-tit during GBA and SREBA studies and previous records in the *Fauna Atlas NT* (DEPWS 2019).

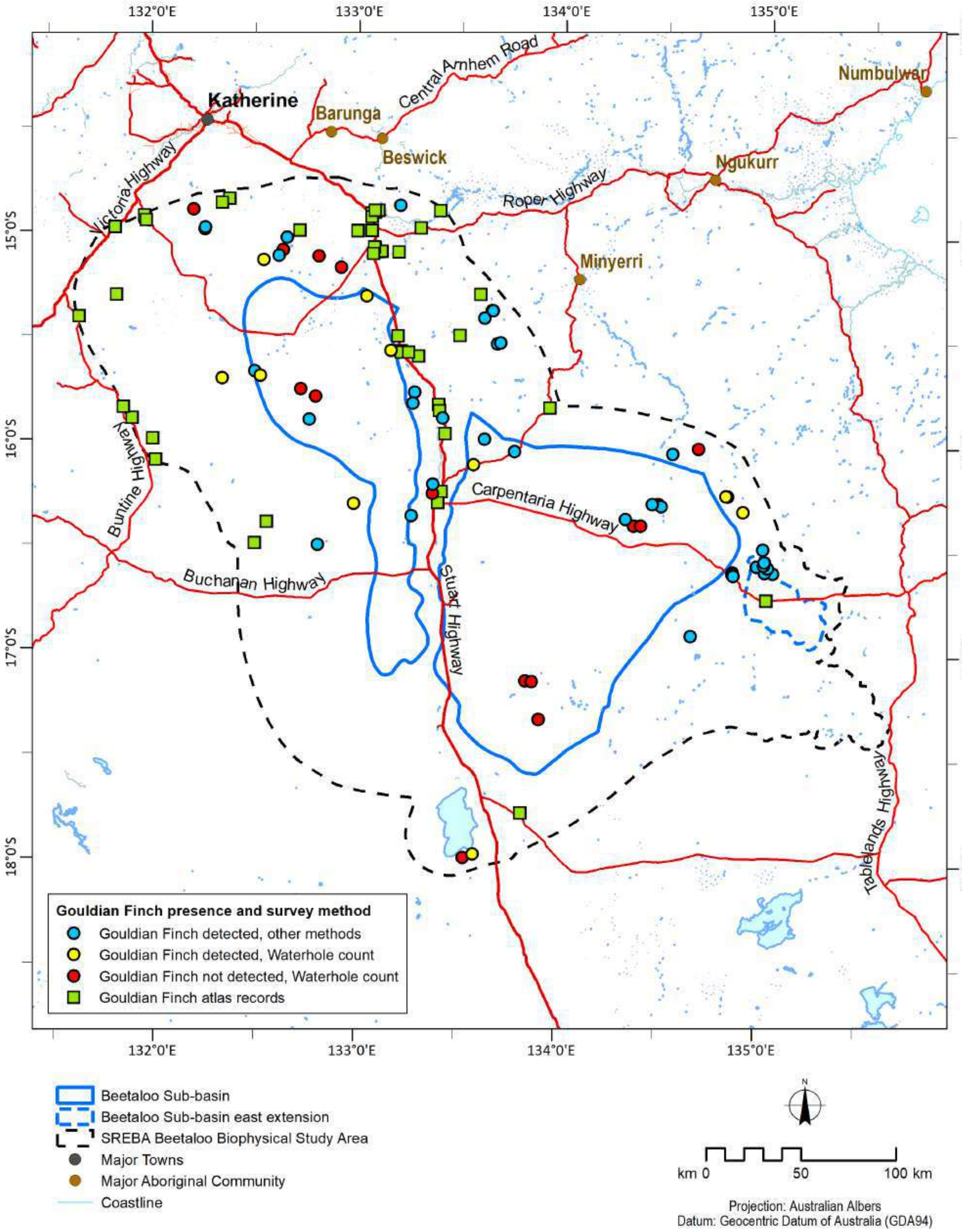

Figure 6-11. Location of sites surveyed for the Gouldian Finch during GBA and SREBA surveys and previous records in the *Fauna Atlas NT* (DEPWS 2019).

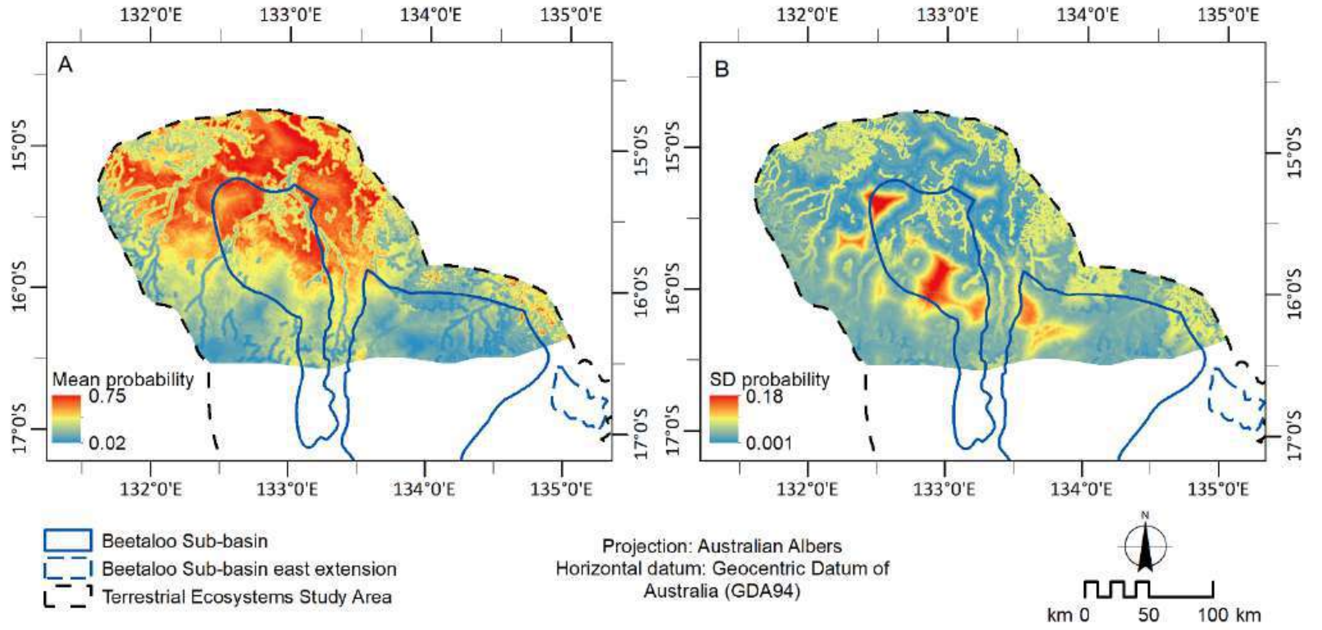

Figure 6-12. Predicted A) mean and B) standard deviation (uncertainty) of the probability of occurrence for the Crested Shrike-tit within the predicted climatically-suitable area.

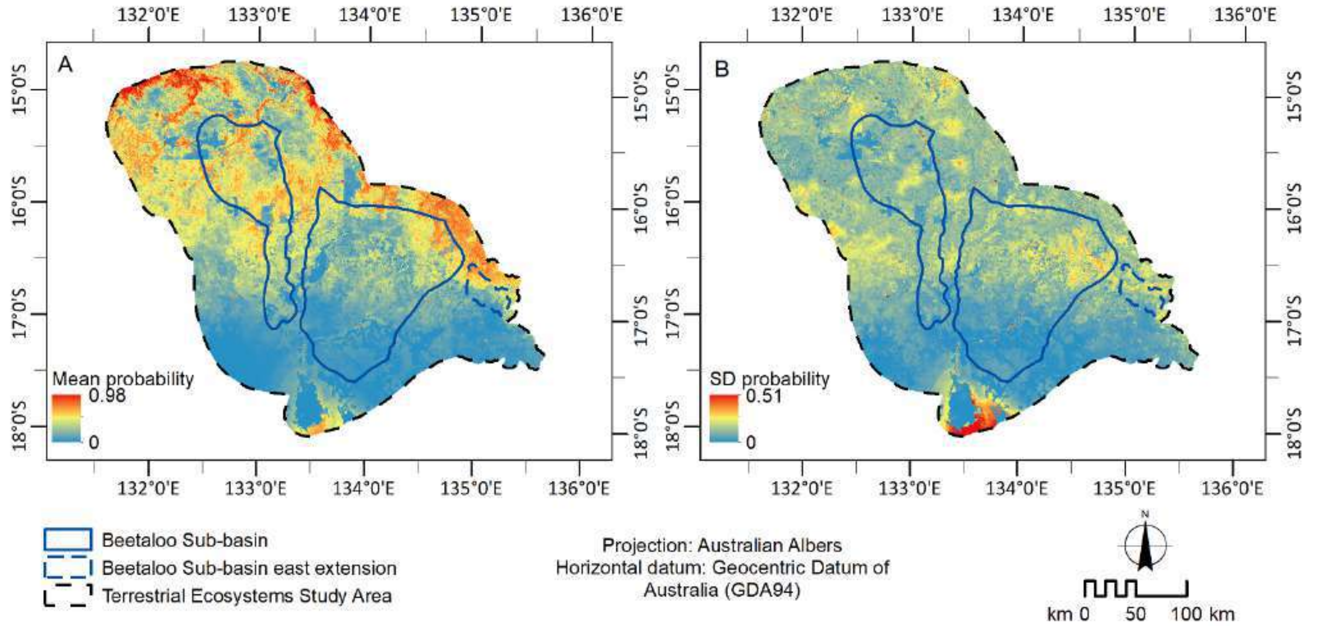

Figure 6-13. Predicted A) mean and B) standard deviation (uncertainty) of the probability of presence for the Gouldian Finch within the study area.

The Snappy gum low open woodland BVG, which is likely to have suitable breeding habitat for the Gouldian Finch, occupied only 4.53% of the predicted high-quality habitat. The most common dominant overstorey tree species in the woodland on rocky flat habitat is a snappy gum species, *Eucalyptus leucophloia*, which is known to readily form hollows and to provide breeding habitat for the Gouldian Finch. Survey sites in this habitat had the highest number of hollows of >0-10 cm diameter.

6.5.3.3. Greater Bilby

There were 19 unique post-1970 locations for the Greater Bilby in the *Fauna Atlas NT*, collected between 1983 and 2011. Sign of the Greater Bilby was detected at 15 locations (> 1 km apart) during GBA and SREBA aerial surveys. No sign of the Greater Bilby was detected during on-ground track plot surveys.

Habitat suitability was predicted to be highest in the south-west margin of the study area (Figure 6-14). There were also small areas of predicted high-quality habitat within the Sub-basin boundary, comprising 1.1% of the Sub-basin area. Additional survey is required to confirm the presence or absence of Bilby in this area, which is outside the species' known range.

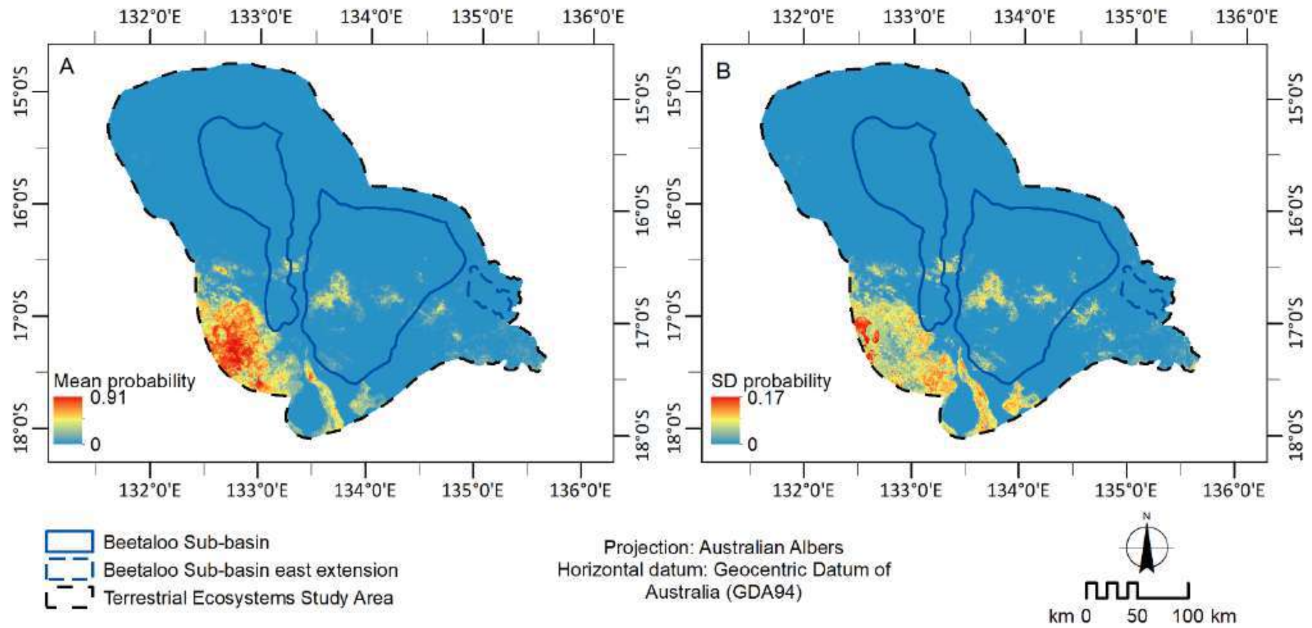

Figure 6-14: Predicted A) mean and B) standard deviation (uncertainty) of the probability of occurrence of the Greater Bilby in the study area.

6.5.3.4. Ghost Bat

The Ghost Bat was detected at 12 of the 17 eastern survey sites and two of the 13 western survey sites. There was a hotspot of activity to the east of Elsey National Park that suggests the Ghost Bat is roosting in this area and additional surveys and on-ground searches for roost sites are required to confirm this. Detections at the western sites may reflect local roosting or long-range foraging from roosts to the north, such as in the vicinity of Cutta Cutta Caves.

6.5.3.5. Plains Death Adder

No Plains Death Adders were detected during the targeted road sampling, and there are only two prior records of the Plains Death Adder within the study area in the *Fauna Atlas NT*. Cane Toads, a key threat to the Plains Death Adder, were detected patchily at dams, leaking cattle troughs and tanks along the southern transects but not along the long northern transect. While the Plains Death Adder was not detected during targeted surveys, areas of grasslands on cracking clay plains should be considered potentially suitable habitat. Patches of mixed tussock grassland > 100 ha in size occupy 4.8% of the study area and 4.3% of the Sub-basin.

6.5.3.6. Yellow-spotted Monitor

There were eight records of the Yellow-spotted Monitor in the *Fauna Atlas NT* prior to the GBA and SREBA surveys. Yellow-spotted Monitors were detected at 16 regional fauna inventory sites and there were a further six incidental records.

The model predicted areas of high-quality habitat throughout the study area (Figure 6-15), comprising 48.1% of the study area and 59.7% of the Sub-basin, and including a variety of broad vegetation groups.

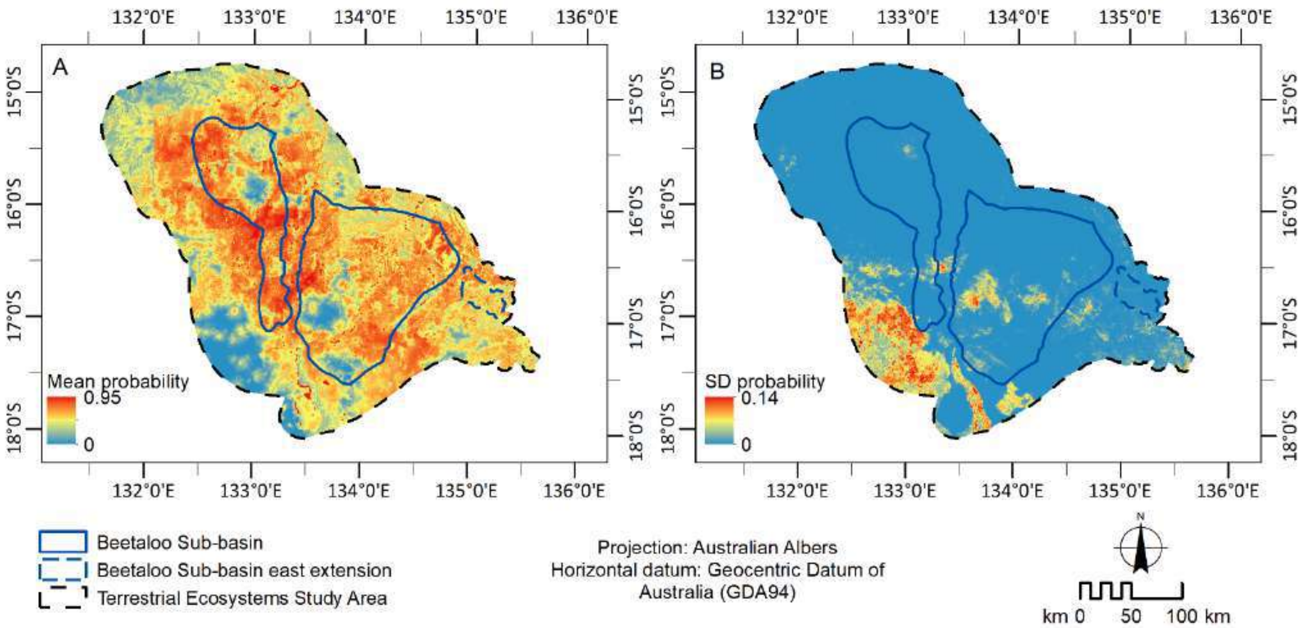

Figure 6-15. Predicted A) mean and B) standard deviation (uncertainty) of the probability of occurrence of the Yellow-spotted Monitor in the study area from the habitat model.

6.5.3.7. Additional threatened fauna species

Additional threatened species recorded during SREBA and GBA surveys included the Australian Painted Snipe (one record in the north of the study area), Grey Falcon (two records in the south of the study area), Red Goshawk (one record in the north of the study area), Common Brushtail Possum (12 records across the study area) and Mertens' Water Monitor (four records from the north of the study area) (Figure 6-16).

Records for the Common Brushtail Possum were of particular interest. Two sub-species of the Common Brushtail Possum occur within the Northern Territory: *Trichosurus vulpecula vulpecula* (southern sub-species) and *T. vulpecula arnhemensis* (northern sub-species). Eleven records of the Common Brushtail Possum (*Trichosurus vulpecula*) were collected during camera-trapping and nocturnal surveys, and one scat was collected during surveys for the Greater Bilby. Records obtained through camera trapping and nocturnal surveys cannot be classified lower than species level. The scat has been sent to Charles Darwin University for DNA analysis for clarification of sub-species identity. Other Northern Territory records suggest that the distributional limit of each sub-species occurs in the study area. As such, the records from the SREBA may represent either sub-species, although records in the vicinity of Mataranka appear likely to be *T. vulpecula arnhemensis*.

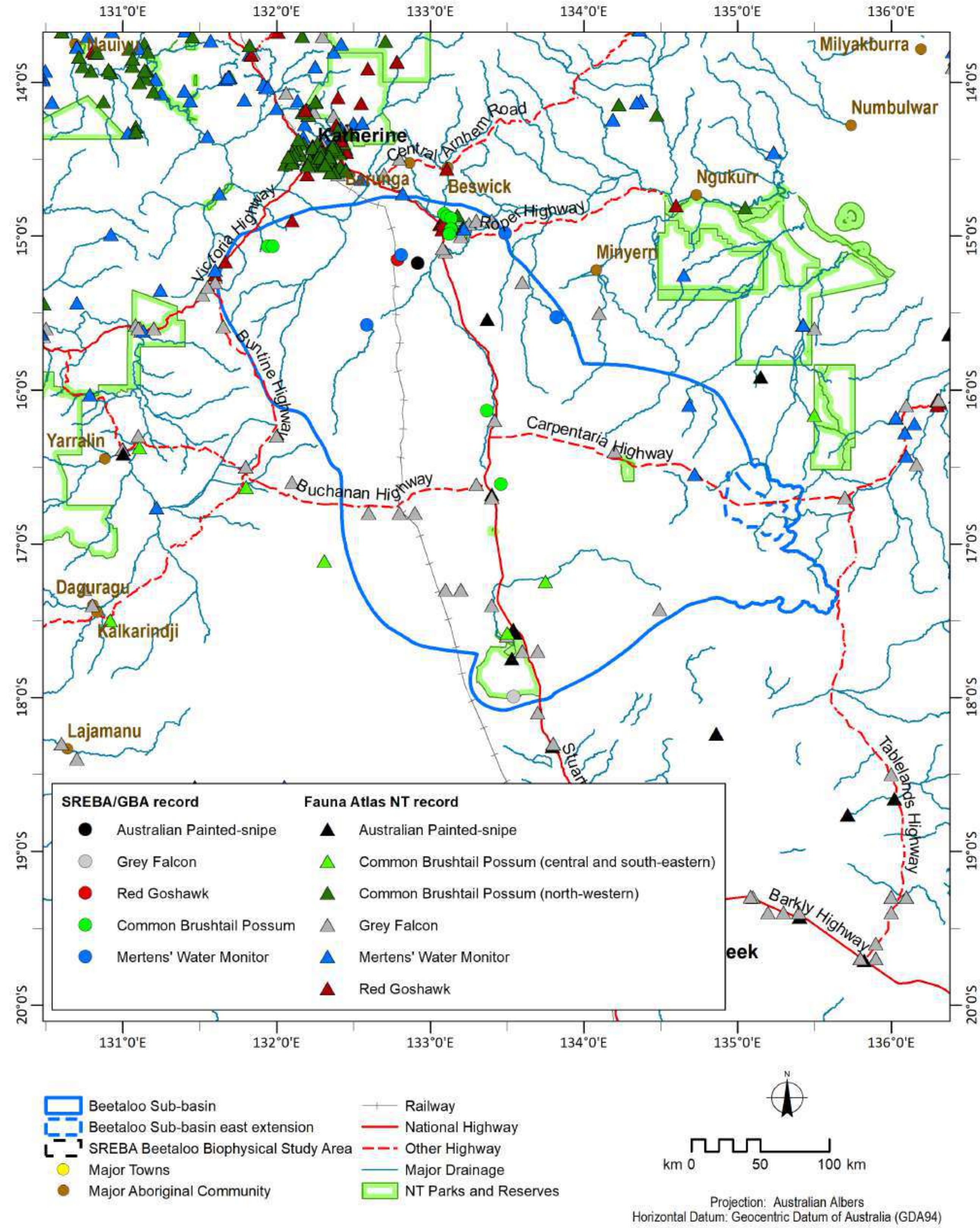

Figure 6-16. Location of additional threatened species recorded during SREBA and GBA surveys and existing locations in the Fauna Atlas NT (DEPWS 2019).

6.5.3.8. Near threatened and Data Deficient species

Ten bird, eight mammal and two reptile species listed as Near Threatened and three species listed as Data Deficient under the TPWC Act (but not also listed as threatened under the EPBC Act) were recorded during the GBA and SREBA surveys (Table 6-5; Figure 6-17). The Central Pebble-mouse

(*Pseudomys johnsoni*) and the Carpentarian Pseudantechinus (*Pseudantechinus mimulus*) had not previously been recorded in the study area. Records of the Carpentarian Pseudantechinus and Purple-crowned Fairy-wren (Eastern; *Malurus coronatus macgillivrayi*) increased the known extent of occurrence of these taxa, although these two species are likely to occur only on the margins of the study area where suitable habitat exists. New records for the remaining 16 species listed as Near Threatened and three species listed as Data Deficient are within known ranges but help to clarify distribution at more local scales.

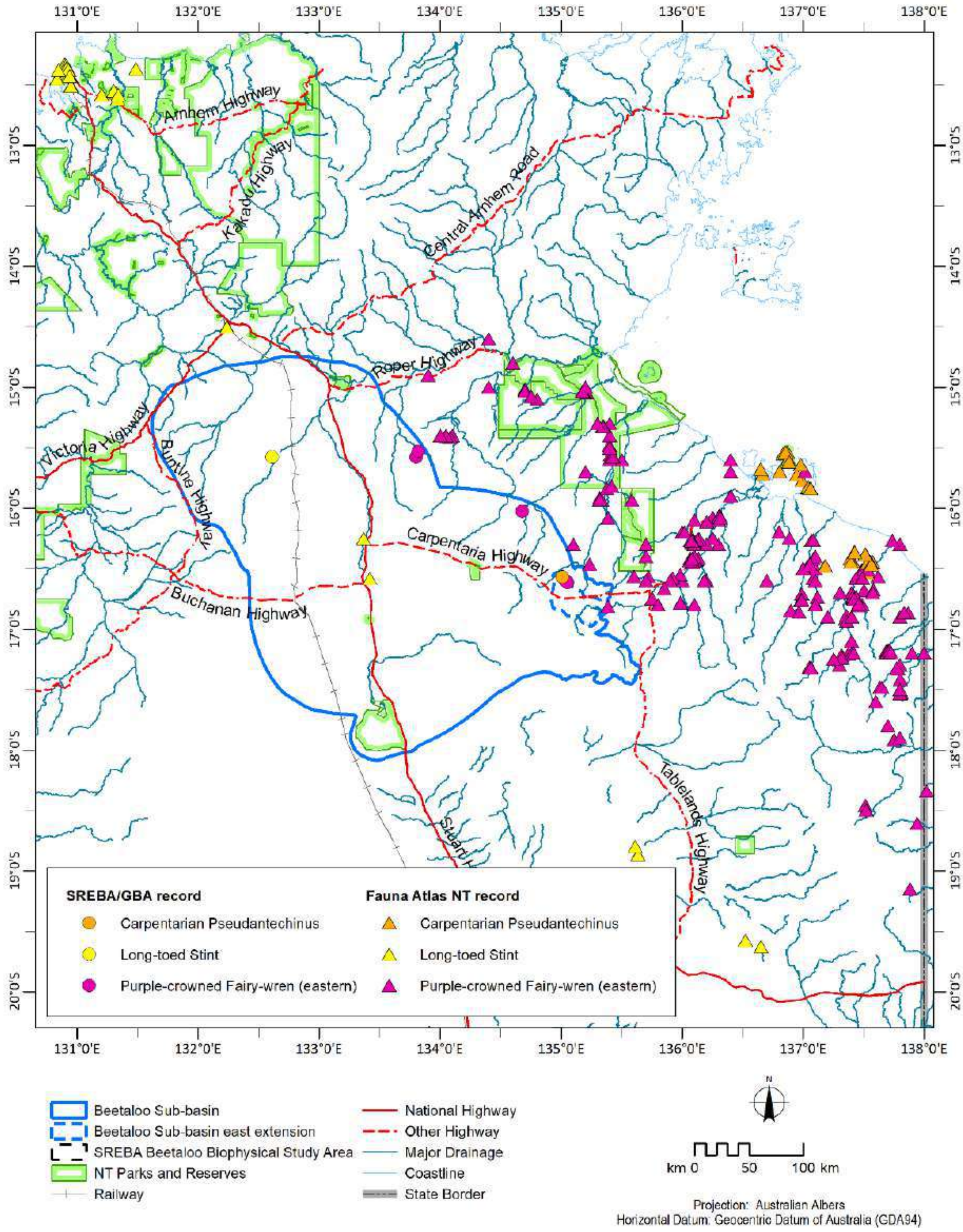

Figure 6-17. Records of Near Threatened and Data Deficient species recorded during SREBA and GBA surveys for which new records increase the Extent of Occurrence of the species and/or for which new records are > 100 km from previous records in the *Fauna Atlas NT* (DEPWS 2019).

Table 6-5. Species recorded during the GBA and SREBA surveys that are listed as Data Deficient (DD) and Near Threatened (NT) under the *Territory Parks and Wildlife Conservation Act 1976* (TPWC Act). Also reported is the presence of records within the *Fauna Atlas NT* prior to surveys, whether new records occurred within the known Extent of Occurrence (EOO) and distance (km) to closest *Fauna Atlas NT* record.

Class	Common name	Scientific name	TPWC Act	*Fauna Atlas NT*	Within existing EOO	Closest record (km)
Birds	Australian Bustard	*Ardeotis australis*	NT	Yes	Yes	1.4
	Buff-sided Robin	*Poecilodryas cerviniventris*	NT	Yes	Yes	76
	Bush Stone-curlew	*Burhinus grallarius*	NT	Yes	Yes	6.0
	Emu	*Dromaius novaehollandiae*	NT	Yes	Yes	20
	Flock Bronzewing	*Phaps histrionica*	NT	Yes	Yes	3.9
	Hooded Parrot	*Psephotellus dissimilis*	NT	Yes	Yes	3.4
	Long-toed Stint	*Calidris subminuta*	DD	Yes	Yes	110
	Pictorella Mannikin	*Heteromunia pectoralis*	NT	Yes	Yes	11
	Purple-crowned Fairy-wren (Eastern)	*Malurus coronatus macgillivrayi*	NT	Yes	No	24
	Star Finch	*Neochmia ruficauda*	NT	Yes	Yes	84
Mammals	Carpentarian Pseudantechinus	*Pseudantechinus mimulus*	NT	No	No	201 (island) 232 (mainland)
	Central Pebble-mouse	*Pseudomys johnsoni*	NT	No	Yes	25
	Northern Brown Bandicoot	*Isoodon macrourus*	NT	Yes	Yes	25
	Northern Nailtail Wallaby	*Onychogalea unguifera*	NT	Yes	Yes	0.6
	Orange Leaf-nosed Bat	*Rhinonicteris aurantia*	NT	Yes	Yes	5
	Spectacled Hare-wallaby	*Lagorchestes conspicillatus*	NT	Yes	Yes	1.8
	Western Chestnut Mouse	*Pseudomys nanus*	NT	Yes	Yes	22
Reptiles	Chameleon Dragon	*Chelosania brunnea*	NT	Yes	Yes	67
	Common Blue-tongue	*Tiliqua scincoides*	DD	Yes	Yes	11
	Mulga Snake	*Pseudechis australis*	NT	Yes	Yes	11
	Sombre Whipsnake	*Demansia quaesitor*	DD	Yes	Yes	36

6.5.4. Discussion

In combination, the SREBA and GBA surveys contributed new records for eleven threatened fauna species, 18 fauna species listed as Near Threatened, and three fauna species listed as Data Deficient. Of the eleven threatened species, there were sufficient records to model predicted habitat suitability in the study area for four species: Crested Shrike-tit, Gouldian Finch, Greater Bilby and Yellow-spotted Monitor. These models predict likely high-quality habitat, which can be used in development planning, impact assessment and to guide further survey or monitoring. With the exception of the Greater Bilby, these threatened species are widely distributed within the study area and have relatively generalist habitat requirements.

Despite access to previous records and targeted efforts to collect more data, the number of records available to model the distributions of some species across the study area remains relatively low. While efforts were made to produce distribution models that align with species' known distributions and habitat requirements, model uncertainty should be considered when assessing requirements for future surveys in the study area. The distribution of the Ghost Bat and Plains Death Adder within the study area could not be modelled; however, spatial information relating to geological features (Ghost Bat – outcropping Tindall Limestone) or vegetation communities (Plains Death Adder – mixed tussock grasslands) is available to help direct any future targeted survey effort or evaluate likely impacts to potentially important habitat from development.

Areas of high biodiversity value and potential sensitivity to development of an onshore gas industry are discussed further in Section 6.7.

6.6. Waterbirds

6.6.1. Background

Waterbirds include a diverse assortment of species from different bird families, including ducks, which are typically associated with open water; egrets and ibis that forage in grasses and sedges near the water's edge; and resident and migratory waders or shorebirds that feed in the shallows or along the shoreline. Waterbirds are all tied to waterbodies and wetlands for a significant part of their life history and require such wetlands in order to persist in the landscape.

The availability of surface water in the study area is highly variable between seasons and years, due to variability in annual rainfall and the ephemeral nature of a high proportion of the region's wetlands. Following periods of high rainfall, wetlands in the study area can support large numbers of resident and migratory waterbirds; this includes supporting breeding events. Lake Woods is one of the most important ephemeral inland wetlands for waterbirds in the Northern Territory and lies within the study area. Lake Woods supports a large number and high diversity of waterbirds when flooded and is recognised as a Key Biodiversity Area (BirdLife International 2022b). Within the study area, permanent water is scarce, and persistent and permanent wetlands such as Longreach Waterhole are important refuges for water-dependent fauna.

During the Geological and Bioregional Assessment study for the Beetaloo Sub-basin, data from multiple sources were compiled and over 7,000 records of 81 waterbird species were identified from the study area (Davis *et al.* 2021). Several large-scale waterbird surveys across the Barkly and Sturt Plateau bioregions, as well as several targeted surveys, have previously been undertaken; however, no regular, long-term monitoring of waterbirds has been conducted in the study area.

Additional waterbird surveys were undertaken during the SREBA to:

- assess patterns and drivers of waterbird occurrence across the study area
- identify important wetlands for waterbirds, including: drought refuges; important sites for breeding and large congregations; wetlands with high waterbird richness/abundance; and sites that have clusters of records of threatened, migratory or managed species
- evaluate sampling methods to assess adequacy of surveys and inform future monitoring.

6.6.2. Methods

Wetlands were selected to represent geographical extent, river catchments and the range of wetland sizes and types in the study area (Table 6-6). Access to some wetlands was restricted due to logistical, environmental and cultural reasons.

Table 6-6. Wetland size and classification used for site selection following wetland ecosystem classification by Kingsford *et al*. (2016).

Class	Category	Description / Sub category
Size class	Very small	1-10 ha
	Small	10-50 ha
	Medium	50-1000 ha
	Large	>1000 ha
Classification	Riverine	Flowing river
		Non-flowing river/waterhole
		Riverine floodplain
		Billabong
	Lacustrine	Lake
		Dam/pond
	Palustrine	Marsh
		Swamp

A total of 55 wetland sites was surveyed for waterbirds (Figure 6-18), with 44 sites surveyed in the late dry season of 2021 and 40 sites surveyed in the late wet season of 2022, and 28 sites surveyed in both seasons. Across the study area, there was low wet season rainfall preceding the late wet season survey, resulting in large ephemeral lakes and swamps — notably Lake Woods and Shenandoah Swamp — not filling or remaining wet for the surveys. As such, no large-sized wetlands were available for survey in the study area. There are, however, relatively large amounts of existing waterbird data for Lake Woods.

Waterbird surveys were undertaken as aerial surveys using a Robinson R44 helicopter, and as on-ground surveys, where sites were accessed by 4WD vehicle from roads / station tracks and by walking. Both survey types used two experienced observers and established methods, ensuring independent observations. Information on wetland habitat and condition, including on-ground and GIS-derived data, was collected for 40 sites for use in analyses of drivers of waterbird richness, abundance and assemblages.

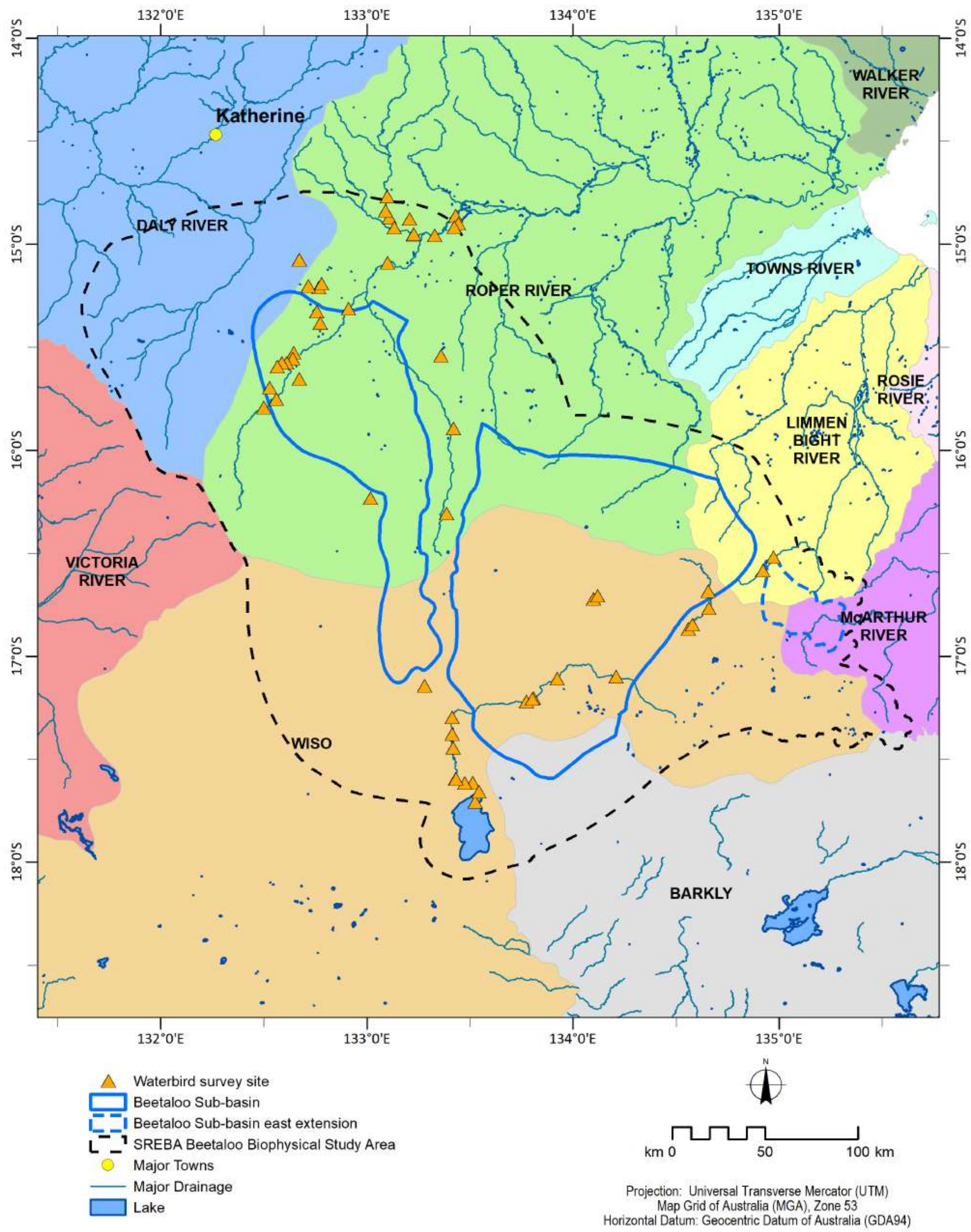

Figure 6-18. Location of all 55 waterbird survey sites across the study area. Coloured regions indicate the river catchments where sites are located: Blue = Daly River; Green = Roper River; Yellow = Limmen Bight River; Tan = Wiso.

Important places in the study area for waterbirds were identified using the following values:

- drought refuges
- breeding records
- large congregations
- sites with higher richness or abundance.

Records of significant waterbird species, including threatened species (listed under the EPBC and TPWC Acts), migratory waterbirds and Northern Territory managed species, were compiled from the *Fauna Atlas NT* and SREBA waterbird surveys and mapped for visual inspection of spatial patterns.

6.6.3. Results

The surveys identified 53 waterbird species representing 19 families from seven orders (see the Baseline Report for details). No large aggregations of breeding waterbirds were observed during the SREBA surveys. However, there were some instances of nesting or waterbirds with recently fledged juveniles, indicating breeding occurred at that site.

A number of factors influencing waterbird richness and abundance were identified, and these differed between different waterbird groups. Overall, waterbird richness increased with increasing persistence of surface water. Waterbird composition varied according to river catchment and wetland systems. In particular, Roper-channel sites had low commonality with the other systems, being relatively species poor and lacking characteristic waterbird groups. Composition also varied by season, with a strong catchment / season interaction, suggesting a high level of movement within and between regions according to season.

Analysis of satellite imagery revealed the areas with the most persistent surface water across the study area (Figure 6-19) and, although these were not all sampled, they are all considered potentially important drought refuges for waterbirds. In the north, persistent wetlands are rare on the Sturt Plateau and were mostly limited to the spring-fed Roper River and its tributaries. Throughout the semi-arid central and southern parts of the study area, persistent surface water comprises the widely-spaced waterholes of the Newcastle Creek drainage system, including Longreach Waterhole. Other persistent surface water occurs along the north-eastern edge of the study area, in the headwaters of the Gulf of Carpentaria drainages.

All large-scale waterbird breeding events recorded from the study area are from Lake Woods and nearby waterholes on Newcastle Creek, with 24 species recorded breeding and, for some species, in colonies ranging from several hundred to several thousand birds. Most breeding has been recorded in flooded woodland and lignum in the north-eastern part of the lake, associated with the outflow from Newcastle Creek.

During the SREBA surveys, small-scale breeding observations (< 50 juveniles) were made for ten waterbird species (Figure 6.20). Similar small-scale breeding events (1-8 broods) were recorded in wetlands throughout the Sturt Plateau in 2001 for 11 species. There is also a possible Australian Painted Snipe breeding record from 2001 at an unnamed swamp on the Sturt Plateau (Jaensch 2003).

Large congregations of waterbirds have also been recorded during aerial surveys of Lake Woods when it is in flood, including 120,000 birds in September 1993. The largest waterbird counts during the SREBA fieldwork were 3,400 Plumed Whistling-ducks at Bloodwood Homestead Dam; 1,220 Magpie Geese at Marlinja Waterhole on Newcastle Waters Station; and 850 Plumed Whistling-duck on Newcastle Creek on Powell Creek Station.

During the SREBA surveys, wetlands with relatively high numbers of waterbirds were concentrated in the central northern parts of the Sturt Plateau and throughout the Newcastle Creek drainage system. Beetaloo homestead billabong was the only wetland that ranked highly for both waterbird abundance and species richness.

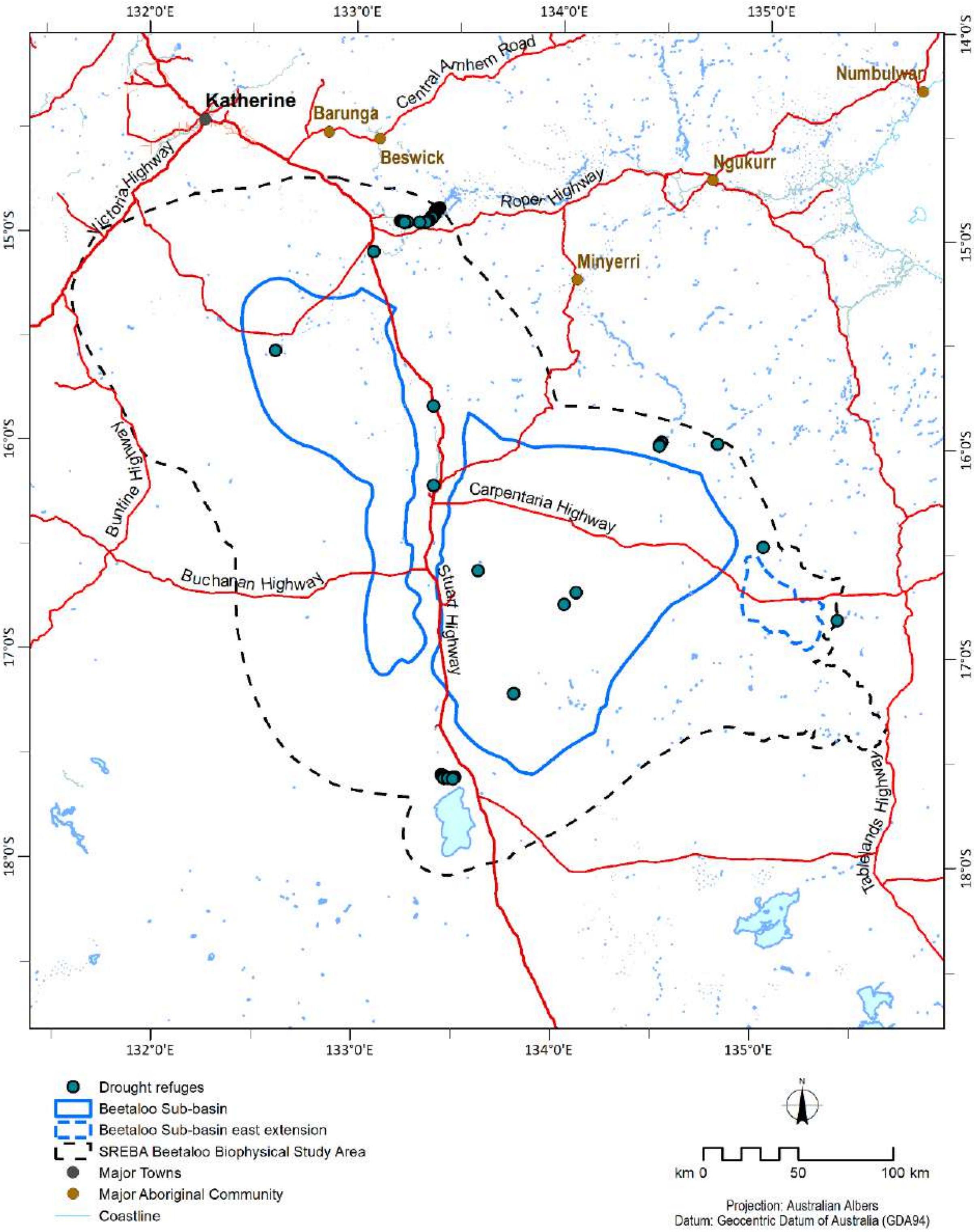

Figure 6-19. Potential drought refuges for waterbirds in the study area, calculated using a surface water model from Landsat imagery 1986-2021, using a threshold at index value of 0.8.

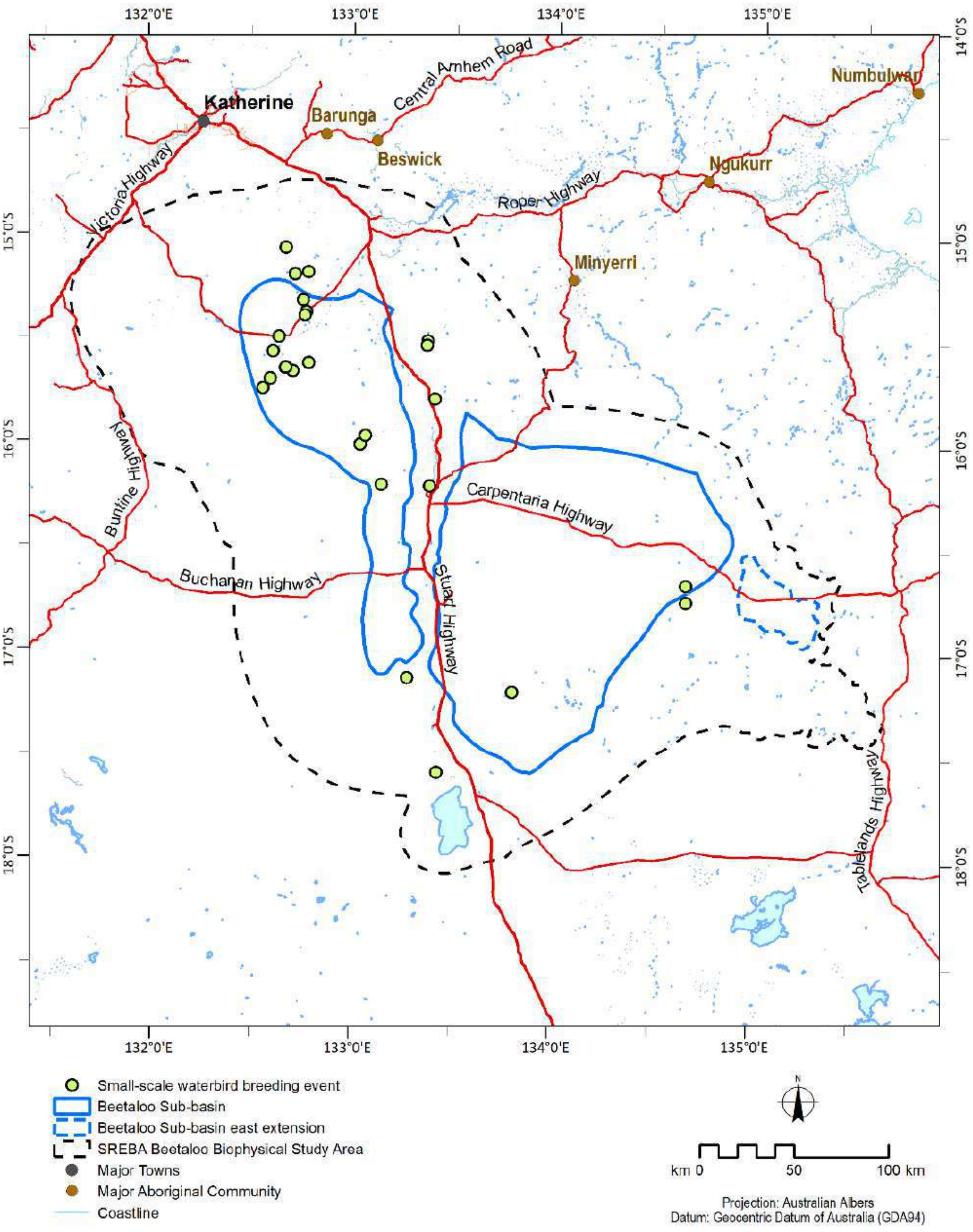

Figure 6-20. Small-scale waterbird breeding observations made during the SREBA surveys in 2021-22 and during waterbird surveys on the Sturt Plateau in 2001 (R. Jaensch unpublished data).

6.6.3.1. Significant species

Two waterbird species listed as threatened under the EPBC Act and TPWC Act are known to occur in the study area (Australian Painted Snipe *Rostratula australis* and Curlew Sandpiper *Calidris ferruginea*). Furthermore, eighteen waterbird species recorded from the study area are listed under the EPBC Act as migratory species (Table 6-7) and records of most of these species are concentrated on Lake Woods and nearby Newcastle Creek waterholes (Figure 6-21). The Magpie Goose, which is a managed species under the TPWC Act, occurs periodically at wetlands throughout the study area but records are particularly clustered in the Roper River systems in the extreme north and, in the south, at Lake Woods and nearby waterholes in the Newcastle Creek system. Congregations of up to 1,200 Magpie geese were observed during SREBA surveys in March 2022.

Table 6-7. Waterbirds listed as migratory that have been recorded in the *Fauna Atlas NT* as occurring in the SREBA study area (A2H: species is a member of a family listed in Bonn Convention Appendix 2; A2S: species listed explicitly in Bonn Convention Appendix 2).

Common name	Scientific name	Bonn	CAMBA	JAMBA	ROKAMBA
Black-tailed Godwit	*Limosa limosa*	A2H	Listed	Listed	Listed
Caspian Tern	*Hydroprogne caspia*			Listed	
Common Greenshank	*Tringa nebularia*	A2H	Listed	Listed	Listed
Common Sandpiper	*Actitis hypoleucos*	A2H	Listed	Listed	Listed
Curlew Sandpiper	*Calidris ferruginea*	A2H	Listed	Listed	Listed
Glossy Ibis	*Plegadis falcinellus*	A2S			
Little Curlew	*Numenius minutus*	A2H	Listed	Listed	Listed
Long-toed Stint	*Calidris subminuta*	A2H	Listed	Listed	Listed
Marsh Sandpiper	*Tringa stagnatilis*	A2H	Listed	Listed	Listed
Oriental Plover	*Charadrius veredus*	A2H	Listed	Listed	Listed
Oriental Pratincole	*Glareola maldivarum*		Listed	Listed	Listed
Pacific Golden Plover	*Pluvialis fulva*	A2H	Listed	Listed	Listed
Pectoral Sandpiper	*Calidris melanotos*	A2H		Listed	Listed
Red-necked Stint	*Calidris ruficollis*	A2H	Listed	Listed	Listed
Sharp-tailed Sandpiper	*Calidris acuminata*	A2H	Listed	Listed	Listed
Swinhoe's Snipe	*Gallinago megala*	A2H	Listed	Listed	Listed
White-winged Tern	*Chlidonias leucopterus*		Listed	Listed	Listed
Wood Sandpiper	*Tringa glareola*	A2H	Listed	Listed	Listed

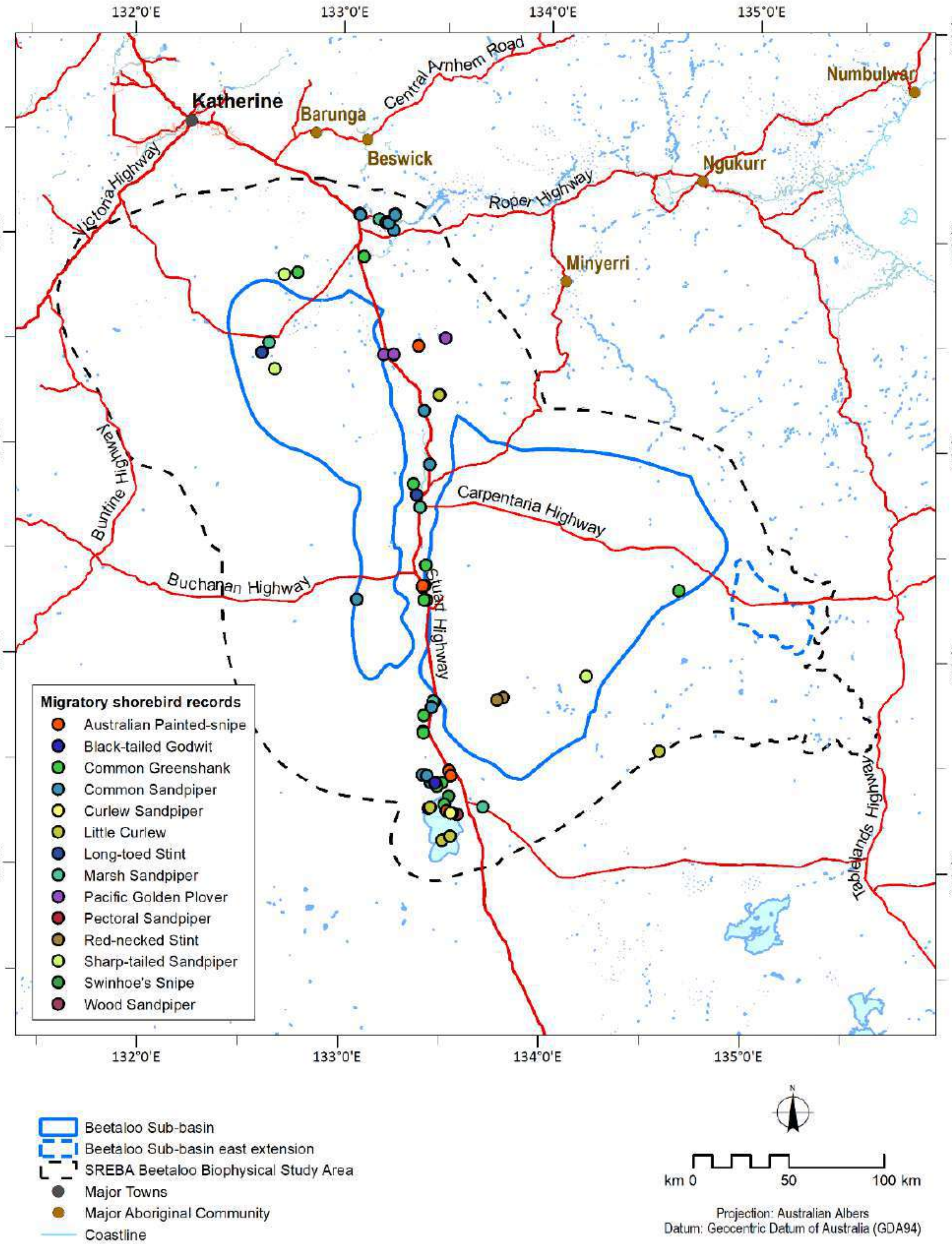

Figure 6-21. Migratory wader records from the SREBA surveys and *Fauna Atlas NT*.

6.6.3.2. Assessment of monitoring methods

The comparison of survey method (aerial or on-ground) using occupancy analysis showed species-specific differences in probability of detection.

On-ground surveys showed higher probability of detection for 39 of the 48 species, although this was only a significant effect ($P < 0.05$) for eleven species. The aerial survey method had a greater probability of detection for nine species, but only one species for which this was significant.

Analysis using abundance (N-mixture) data showed on-ground surveys had a higher probability of detection for 34 of the 49 species, and this was a significant effect for 17 species. The aerial survey method had a greater probability of detection for 15 species, and this was significantly greater for 13 species.

Only five (occupancy) or six (N-mixture) species had a probability of detection greater than 0.9 from a single survey, highlighting the requirement for multiple independent surveys to improve species detection and survey adequacy.

Some of these differences in detection can be attributed to the habits of individual species and how they may be obscured or evade detection. For example, the Straw-necked Ibis had significantly greater detection probability of individuals in abundance models from aerial counts, likely due to better visibility of these birds in deep grasses from above than laterally from the ground. Conversely, the Australasian Grebe had significantly greater detection probability in occupancy and abundance models from on-ground surveys, likely due to their small size and evasive diving behaviour to avoid aerial predators or, in this case, aerial observers. These results reinforce the principle that waterbird survey and monitoring approaches need to be tailored to the target species or include multiple methods.

6.6.4. Conclusions

There were two dominant themes from the waterbird survey results with particular relevance for waterbird conservation in the study area. Firstly, isolated wetlands with persistent surface water in the Newcastle Creek drainage system (Wiso-channel system) and on the Sturt Plateau support greater waterbird species richness compared to the more ephemeral wetlands and those on the Roper River. These persistent wetlands enable small-scale waterbird breeding events through dry conditions and are likely to be refuges for waterbird persistence during drought. Secondly, Lake Woods and nearby waterholes on Newcastle Creek stand out in supporting large waterbird breeding events and congregations when they are in flood. Additionally, this terminal section of the Newcastle Creek system has the largest cluster of migratory shorebird and threatened waterbird records in the study area, the only record of the Critically Endangered Curlew Sandpiper in the study area, and one record of the Endangered Australian Painted Snipe. Lake Woods, together with Longreach and South Newcastle Waterholes, is listed as a ‘Key Biodiversity Area’, ‘Important Bird Area’ and a ‘NT Site of Conservation Significance’.

While predictors of waterbird richness and abundance varied across waterbird groups, there were some common themes. Surface water persistence was an important predictor of overall waterbird species richness, as well as of the presence, abundance or richness of several waterbird groups. In all cases, the relationship of waterbirds to persistent surface water was positive, highlighting the necessity of these wetlands for waterbird occurrence in the study area.

Persistent wetlands are likely to be especially important in the dry season and through drier conditions, as prevailed during the SREBA fieldwork. Small-scale waterbird breeding observations were recorded at wetlands throughout the study area during the relatively dry conditions, reinforcing the importance of surface water persistence for waterbirds in this system. Wetlands with persistent surface water are widely spaced across the study area and include ten mapped wetlands that, while not sampled during SREBA fieldwork, are predicted to be important for waterbirds.

A combination of occupancy and abundance models should be considered for any future survey or monitoring of waterbirds in the study area. Results from this study can be used to guide the number of surveys required for survey or monitoring of waterbirds, and whether aerial or ground-based surveys are most suitable. Most waterbird species showed imperfect detection (e.g. detection probability < 0.9) and will require multiple independent surveys at each site to improve estimates of occupancy and abundance. The value of each waterbird sampling visit is increased by having more than one independent observer. The occupancy and N-mixture analysis results provide a basis for future power analysis, using simulation to determine the survey methods, number of surveys and number of sites to detect change in waterbird occupancy and abundance over time.

6.7. Terrestrial biodiversity values and risks

A key aim of the terrestrial vegetation and fauna surveys presented in previous sections was to identify and describe the distribution of terrestrial species and biological communities in the study area, and identify the most important biodiversity values, particularly those that may be sensitive to potential impacts from the development of an onshore gas industry. This was achieved by systematically assessing the extent and condition of terrestrial vegetation, riparian vegetation and wetlands, as well as the distribution of important fauna habitat and focal threatened fauna species, including waterbirds.

Spatially discrete biodiversity values are associated with broad vegetation groups of high ecological value and with the habitat of threatened species and waterbirds. The vegetation types associated with river channels and the surface expression of groundwater have high species richness, are important habitat for fauna and have known sensitivities to land management and resource extraction activities. The riparian channels and potential groundwater-dependent ecosystems (GDEs) have additional value and sensitivity due to their high connectivity to the broader landscape and to groundwater basins.

The main terrestrial biodiversity values within the study area are summarised as follows.

- Sites of Conservation significance (SoCS)
    - Mataranka Thermal Pools
    - Lake Woods and Longreach Waterhole
- High-value vegetation
    - Monsoon forest and thicket
    - *Melaleuca* forest (springs, river channels)
    - Riparian woodland (ephemeral streams)
    - Ephemeral wetland
    - Lignum shrubland
- Habitat for waterbirds and threatened species.

Additionally, the following broad vegetation groups were assessed to be of moderate ecological value, but are generally much more extensive in the study area and may be less sensitive to impact:

- Coolabah low open woodland on clay
- Coolabah, *Lophostemon* and Gutta Percha swamps
- *Melaleuca* low open woodland on floodplains and drainage depressions

- *Corymbia/Eucalyptus* woodland (run-on areas and heavier soils)
- *Corymbia bella* woodland on alluvial plains.

6.7.1. Sites of conservation significance (SoCS)

The Cambrian Limestone Aquifer underlies much of the study area and groundwater in the Roper flow path discharges to the surface at the Mataranka Thermal Pools and surrounding areas. This area has vegetation types with a high likelihood of groundwater dependence — including *Melaleuca* forests, monsoon rainforests, swamps, sedgelands and riparian vegetation — and acts as a seasonal refuge for species in an otherwise seasonally dry environment. The biodiversity values of this area were also highlighted by the SREBA Aquatic Ecosystems baseline studies.

Lake Woods is a Site of Conservation Significance of international value, primarily due to its importance for waterbird aggregations and breeding. This site encompasses Lake Woods and the lower reaches of Newcastle Creek, including the Longreach and southern Newcastle Waterholes. During periods of inundation, Lake Woods is a vast flooded area comprising diverse wetland habitat dominated by open water, with substantial areas of lignum shrubland and woodland at the lake margins. Longreach Waterhole is a near-permanent waterhole located on the northern edge of Lake Woods that provides refuge habitat for flora and fauna.

6.7.2. High-value vegetation

Five broad vegetation groups (comprising 25 vegetation communities) were identified as having high ecological value. Three broad vegetation groups predominantly occurring in the north of the study area are classified as significant vegetation and groundwater-dependent ecosystems: *Monsoon forest and thicket*, *Melaleuca forests (springs, river channels)* and *Riparian woodland (ephemeral streams)*.

Groundwater-dependent ecosystems are also associated with sandstones ranges and escarpments on the eastern margin of the study area, where the Sturt Plateau and Gulf Fall & Uplands bioregions converge. *Riparian woodland (ephemeral streams)* and *Melaleuca forests (springs, river channels)* were the dominant broad vegetation groups mapped along streams in this area. The *Ephemeral wetland* and *Lignum shrubland* broad vegetation groups were also identified as having high ecological value.

6.7.3. Significant groups and species

6.7.3.1. Waterbirds

Two dominant conservation management themes emerged from the SREBA studies in relation to waterbirds. The first was the importance of isolated wetlands with persistent surface water in the Newcastle Creek drainage system and on the Sturt Plateau (Wiso-channel system). These sites support greater waterbird species richness compared to more ephemeral wetlands and to those on the Roper River. They are critical as they enable small-scale waterbird breeding events through dry conditions and are likely to be important refuges for waterbird persistence during years with low rainfall. Second, Lake Woods and nearby waterholes on Newcastle Creek support large-scale waterbird breeding events and major congregations when in flood. This terminal section of the Newcastle Creek system also has the largest cluster of migratory shorebird and threatened waterbird records in the study area.

6.7.3.2. Crested Shrike-tit

Four of the mapped broad vegetation groups each occupied > 5 % of the predicted high-quality habitat threshold for Crested Shrike-tit. At a finer-scale, this species is most likely to occur in association with the tallest trees. The Crested Shrike-tit is a sedentary species that occupies small home ranges and has a patchy distribution across the landscape. This makes the species vulnerable to habitat loss, degradation and fragmentation. Fire and grazing are identified as potential threats, though further work is required to quantify this threat level.

6.7.3.3. Gouldian Finch

Species Distribution Modelling (SDM) predicted the occurrence of suitable habitat for the Gouldian Finch across much of the study area. The Gouldian Finch has discrete habitat requirements for different parts of its life-cycle: snappy gum (*Eucalyptus leucophloia/Eucalyptus umbrawarrensis*) woodland for breeding; persistent water sources at which to drink regularly, and a variety of seed resources at different times of the year throughout the landscape. The woodland BVGs listed above likely reflect foraging habitat for the species. Threats to the Gouldian Finch include introduced herbivores and inappropriate fire regimes. The restricted range of snappy gum vegetation and the limitation in persistent water sources in the landscape makes this species sensitive to habitat degradation, fragmentation and loss. Surface water contamination or a reduction in surface water availability may also be detrimental to this species.

6.7.3.4. Greater Bilby

In the study area, the Greater Bilby is most likely to occur west of Lake Woods within the *Eucalyptus/Corymbia* woodland, *Acacia* shrubland and hummock grassland, and Bullwaddy shrubland and woodland broad vegetation groups. As suitable habitat for the Greater Bilby is unlikely to exist in the Sub-basin, there is a low likelihood that the species will be impacted directly by onshore gas development. However, other development activities related to onshore gas development (e.g. sand mining) may occur in Greater Bilby habitat. The most likely potential impacts to this species would be from introduced predators, inappropriate fire regimes, habitat degradation, fragmentation and loss, and direct mortality.

6.7.3.5. Ghost Bat

Within the study area, outcropping Tindall Limestone that occurs within the distribution of the Ghost Bat (Australasian Bat Society - BatMap 2022) should be considered suitable roosting habitat for the species, and this occurs in the north-east of the study area but not in the Sub-basin. Degradation of foraging habitat and loss of roosts are the equal highest-ranked threats to the Ghost Bat, and collision with barbed wire fences is also a significant threat.

6.7.3.6. Australian Painted Snipe

The Australian Painted Snipe has been recorded sparsely throughout the study area. This species occurs irregularly at shallow ephemeral wetlands and is difficult to detect. Given its dependence on wetland habitat, degradation, fragmentation and loss of wetlands, and the sedimentation, contamination and reduction of the availability of surface water threaten the persistence of the species. The Australian Painted Snipe is also potentially impacted by increased introduced predator and herbivore abundance.

6.7.3.7. Common Brushtail Possum

The Common Brushtail Possum has been recorded in a variety of woodland habitat types within the study area. Known threats to the Common Brushtail Possum include habitat fragmentation, degradation and loss as a result of land clearing, the introduction of invasive grasses, and inappropriate fire regimes.

6.7.3.8. Threatened and significant flora species

Two threatened flora species, *Eleocharis retroflexa* and *Carex fascicularis*, are known from a single record each within the study area and both species are associated with streams and swamps. Three additional plant taxa that, due to their restricted range, are considered significant species are also known from the study area. The wetland habitat of most of these significant species reinforces the high conservation value of these restricted parts of the landscape. Habitat degradation, fragmentation and loss, inappropriate fire regimes, reduction in surface water availability, surface water contamination, and soil contamination, erosion and sedimentation will potentially impact the persistence of significant flora species.

6.7.4. Risks to biodiversity values

Major risks to terrestrial biodiversity from onshore gas development are comprehensively assessed in the impact assessment for the Beetaloo GBA region (Huddlestone-Holmes *et al.* 2021).

This SREBA study provides support for the following as potential risks to the biodiversity values identified in the study area:

- habitat degradation, fragmentation and loss
- inappropriate fire regimes
- reduction in surface water and/or groundwater availability
- contamination of surface water and/or groundwater
- soil contamination, erosion and sedimentation
- competition and predation from introduced species
- mortality of native species.

Many of these threats are already present in the landscape (e.g. habitat degradation, fragmentation and loss, competition and predation from introduced species) and could be exacerbated by onshore gas development. Others are more specific to major onshore gas development and may also interact with existing threats (e.g. reduction in surface water and/or groundwater availability).

Additionally, changes that are predicted under climate change scenarios — particularly an increasing number of very hot days and increasing evapotranspiration rates — may reduce the resilience of terrestrial biodiversity in the study area, particularly of those species with a requirement for persistent water or climate-buffering habitats. Additional pressures on fauna and fauna under these conditions may enhance the likelihood of significant impacts.

The SREBA studies have enabled habitats with high ecological value to be identified and mapped throughout the study area. Habitat degradation, fragmentation and loss associated with clearing of native vegetation within these habitats can be minimised through the application of measures outlined the *NT Land Clearing Guidelines* (Northern Territory Government 2021b) and *Code of Practice: Onshore Petroleum Activities in the Northern Territory* (Northern Territory Government 2021a).

The cumulative effects of clearing and fragmentation can be precisely calculated at the scale of broad vegetation groups that have been mapped within the study area, potentially allowing thresholds for acceptable change to be implemented.

The relevance of each potential risk to the biodiversity values identified in the study area is described in more detail in the Terrestrial Ecosystems Baseline Report.

6.8. Indicators and methods for regional monitoring

Monitoring the impact of any major onshore gas development on identified biodiversity values in the Beetaloo region is important to test whether the assessment of risks was accurate, that mitigation measures are effective, and to trigger and inform appropriate corrective measures if unacceptable impacts occur. However, monitoring programs can only be effective if they have the power to detect change in the value or indictor of interest, are feasible to implement and maintain over time, and are informative about causality. These criteria were used in considering the potential to effectively monitor the potential impacts arising from the development of an onshore gas industry on the various terrestrial ecological values in the study area, as described above.

Monitoring was assessed as being effective and feasible for:

- the spatial extent of high- and moderate-value broad vegetation groups
- the condition of waterbird habitat
- bird fauna of riparian and swamp habitats
- landscape-scale fire regimes
- vegetation clearing and fragmentation.

There are established methods for monitoring these attributes that would be likely to provide sufficient data for monitoring of change over time in relation to potential impacts from onshore gas development.

Monitoring of the other broad vegetation groups and threatened species was assessed as not feasible. In most cases, key risks attributed to these values are not specific to the potential impacts associated with onshore gas development, and ascribing causality would be very difficult. Additionally, in many cases, the amount of data required to distinguish directional change due to development impacts from the natural variability at a regional scale is prohibitively large.

Ants are recognised as being valuable indicators of ecosystem function and are recommended for monitoring site rehabilitation. However, regional monitoring of the ant fauna is not recommended.

The spatial extent of significant vegetation can be effectively monitored through remote sensing. Remote sensing techniques can also be used to assess directional change in canopy cover and to determine the effects of fire, both of which are known to influence vegetation condition.

Monitoring of vegetation clearing using remote-sensing techniques enables evaluation of the cumulative impacts of land clearing, both in terms of the total extent of clearing for each vegetation community, and metrics of fragmentation at various scales. This allows for the assessment of the impact of individual clearing applications, enables the strategic design of clearing footprints to minimise impacts, and facilitates the application of regulatory thresholds if these are required.

Landscape-scale fire is amenable to management, including where land is managed by the gas industry and potentially through offset requirements (that may, for example, support local ranger groups). Time series monitoring of fire scars mapped from satellite imagery is a cost-effective tool for determining if fire-related metrics (e.g. fire extent, fire frequency, fire severity) have improved or declined over a focal period, relative to a preceding baseline period. Fire-scar mapping is available for the study area, and online tools are available to monitor for changes in fire regime elements at multiple scales. Habitat-specific performance thresholds in relation to fire frequency and severity can be developed to inform and guide fire management.

Due to the spatial and temporal fluctuations of waterbird occurrence in the study area, direct monitoring of waterbirds is not likely to provide sufficient data to detect changes in populations that can be attributed directly to impacts from onshore gas development. Monitoring of water quality and a sub-set of aquatic fauna at a set of regionally important wetlands may provide an indication of the quality of habitat for waterbird species.

Amongst the vertebrate fauna, birds are the most amenable to monitoring, although monitoring of the bird fauna across the entire study area or Sub-basin is unlikely to be feasible or informative. However, monitoring of the bird fauna of riparian systems and swamp habitats should be considered. Riparian and swamp habitats were identified as high value for birds in the study area, are restricted in the landscape and are sensitive to the impacts of onshore gas development.

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7. Methane and greenhouse gases baseline studies

7.1. Background

The Methane and Greenhouse Gas studies for the Beetaloo Sub-basin SREBA were undertaken in line with the approach set out in the SREBA Framework and the Scope of Work. The Methane and Greenhouse Gas studies aimed to address the following:

1. Assess the ambient methane concentrations across the region (including natural and anthropogenic sources).
2. Develop a conceptual model of the Sub-basin to identify areas of higher risk of geogenic emissions.
3. Identify all of the potential methane sources contributing to the observed methane levels.
4. Locate these sources.
5. Determine the emission rates of each source.
6. Examine any seasonal or annual variation.
7. Identify indicators and methods relevant for an ongoing monitoring program.

This study builds on a project conducted by CSIRO through GISERA for methane baseline monitoring in the Beetaloo Sub-basin in 2019, which established a platform for longer-term monitoring (Ong *et al.* 2019).

The SREBA greenhouse gas study consisted of three elements:

1. Baseline mobile surveys to establish the baseline methane concentrations across three different seasons.
2. Identification of geological seeps and reference sites.
3. Collation of information produced by Northern Territory and national programs and researchers to estimate the emission rates of the current main sources of emissions.

7.2. Regional mobile surveys

Mobile greenhouse gas surveys, which use optical gas analysers fitted to a vehicle driven across the landscape to continuously measure ambient methane concentrations, are one of the best-developed methods to provide information on the regional variation in methane levels and identify sources of methane within the landscape. Large areas of a region can be mapped during a field campaign, enabling broad-scale trends and variations to be visible. It is also possible to conduct more localised, detailed surveys in order to locate and investigate methane sources.

The mobile survey approach allows other equipment to be carried in the vehicle, such as flux chambers to measure the flux from possible geologic seeps or small portable greenhouse gas analysers to conduct walking surveys. Mobile surveys are limited in coverage depending on road and track networks, rely on the vehicle being downwind of the methane source for the source to be detectable, and can only provide periodic data rather than monitoring how methane concentrations or emissions vary over time.

7.2.1. Methods

Three portable gas analysers with different capabilities were mounted in the rear seat of a dual cab Toyota HiLux utility vehicle. These were coupled to a GPS sensor that streamed position, time and date information to the instruments and was recording concurrently with the methane data. A small 12 V diaphragm pump was used to pump air at approximately 9 L/min via a ¼ inch tube from the top of the vehicle aerial at the front of the vehicle, to the instruments in the rear seat.

Data from the gas analysers was recorded onto a laptop and could be monitored in real time and additional observations added (such as possible sources for the methane). A Gill Maximet GMX500 Compact Weather Station was fitted to the frame between the cabin and utility tray; this enabled local meteorological data (wind speed and direction, temperature and humidity) to be measured and also recorded to the laptop. Wind speed and direction measurements were collected only when the vehicle was stationary, particularly when larger elevated methane concentrations were detected. Initial and periodic calibration checks of the gas analysers were made in the CSIRO Kensington laboratories in Perth. Calibration checks were also performed each day in the field on the analysers using two reference gases; these checks were also used to calculate the level of uncertainty in the measured data.

During processing, the data were manually inspected and, for each visible peak above baseline, these data were categorised into "fire", "cattle", "fuel station/town", or "unknown", using field observations.

Three mobile survey campaigns totalling more than 14,000 km were completed during October 2021 to June 2022.

- In the first mobile survey campaign representing the fire season, approximately 5,700 km were traversed from 19–26 October 2021 (Figure 7-1).
- The mobile survey representing the wet season was conducted from 22–25 of February 2022. This survey covered a smaller distance of approximately 2,350 km, including the return trip from Darwin to Daly Waters (Figure 7-2). The survey length was shorter because of rain, which caused many unsealed roads and tracks on cattle stations to be impassable or off-limits.
- The dry season regional mobile survey was conducted from 14–21 of June 2022 (Figure 7-3). The distance and area surveyed were similar to the October 2021 survey.

The area of coverage for all the surveys was guided by the previous surveys conducted as part of the GISERA project and by areas being accessible to the field team. The routes traversed were selected to cover as much of the area within the SREBA biophysical boundary as possible. Typically, between about 200 km and 600 km was covered each day.

7.2.2. Results

The spatial distribution of methane concentrations recorded during the three mobile survey campaigns are shown in Figure 7-1, Figure 7-2 and Figure 7-3. The mode (most common value) background methane concentrations were 1.863 ppm and 1.868 ppm for the dry and fire seasons, and the wet season had the lowest background methane concentration at 1.845 ppm. A lower value in the wet season aligns with the findings of the GISERA study. The background methane concentrations in 2018/2019 were between 33–42 ppb lower than those recorded for this study, but very similar differences of 35–43 ppb in methane concentrations between the years were measured at the Kennaook/Cape Grim Baseline Air Pollution Station. Overall, the background methane concentration measured within the Beetaloo SREBA study area in different seasons is closely aligned with the national reference trend in Australia.

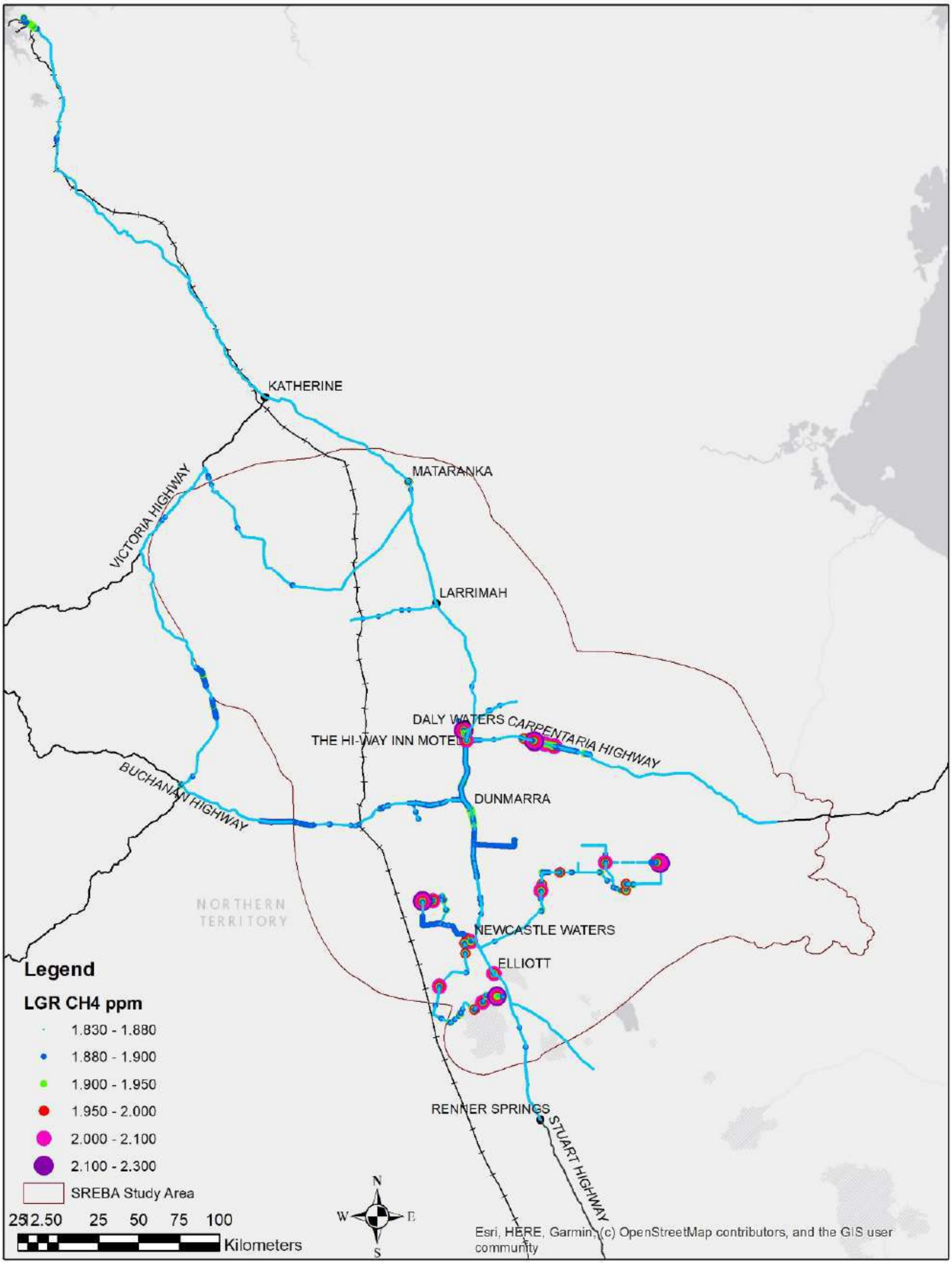

Figure 7-1. Map of October 2021 survey with recorded methane concentrations (ppm).

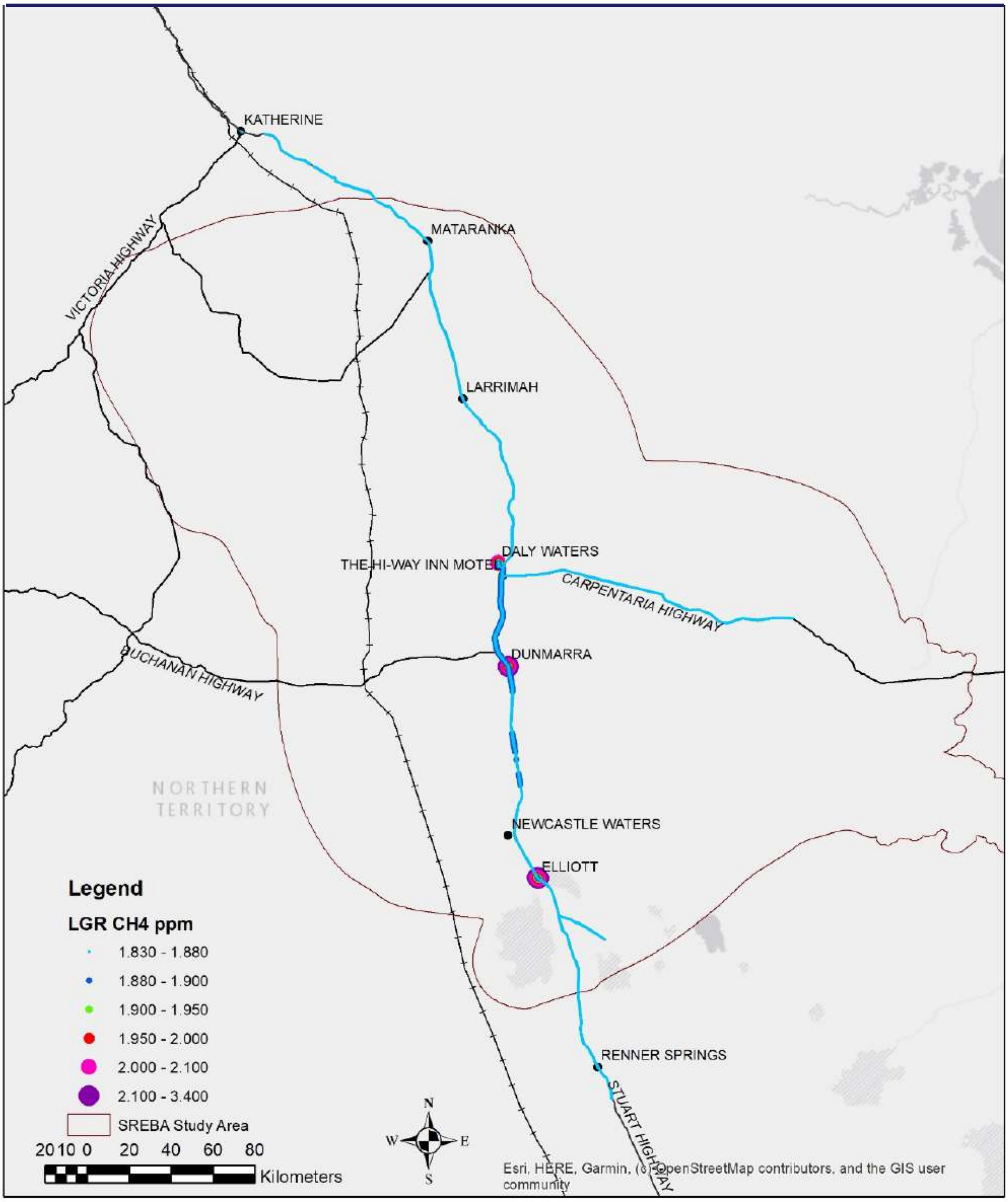

Figure 7-2. Map of February 2022 mobile survey with recorded methane concentrations (ppm).

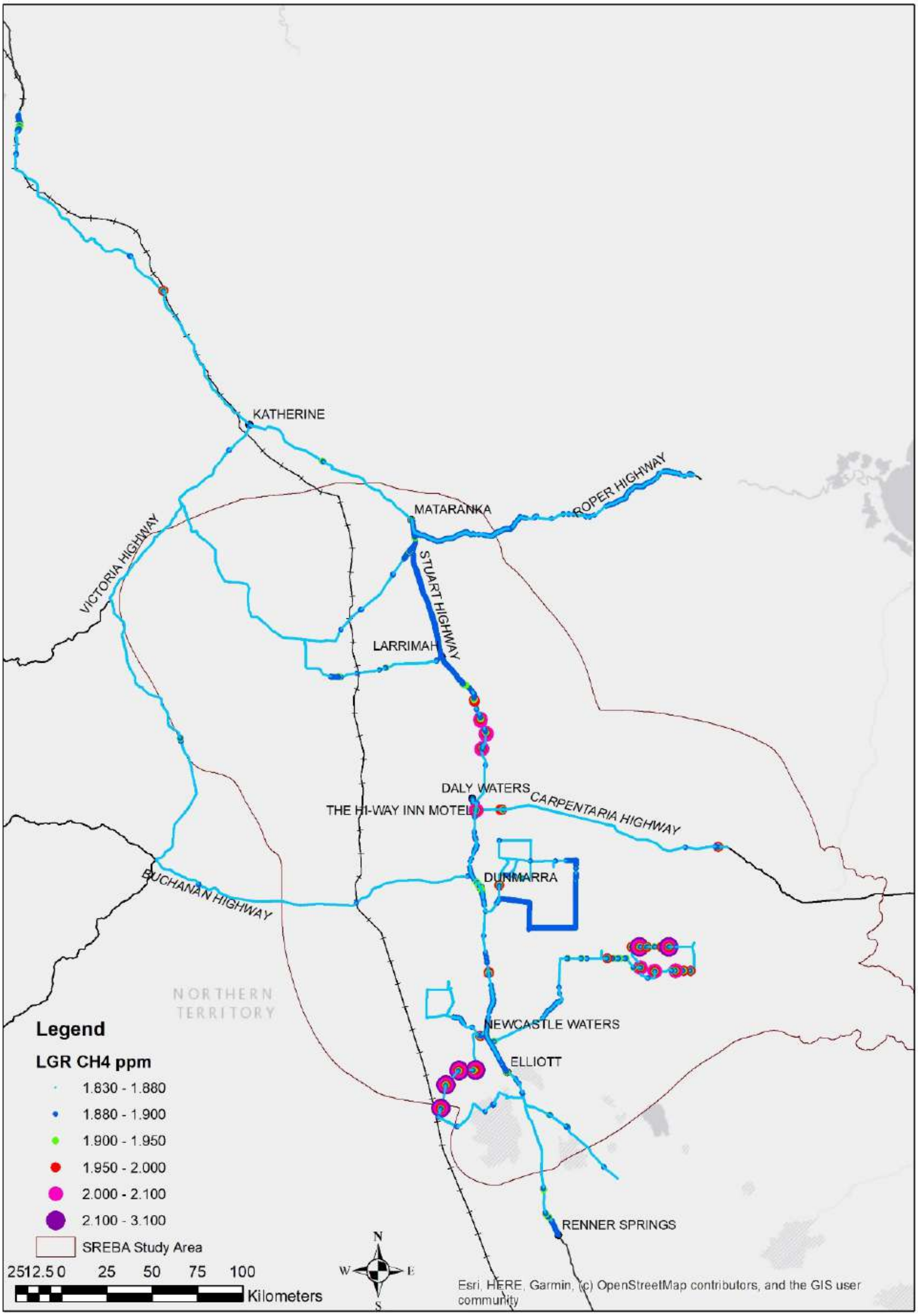

Figure 7-3. Map of June 2022 survey with recorded methane concentrations (ppm).

Between 88.3% and 91.7% of the methane concentration data for each surveys were below 1.88 ppm. The remaining 10% of data are mostly slightly elevated levels, with a long tail out to the maximum concentrations of 2.286 ppm, 3.06 ppm and 3.397 ppm for the fire, dry and wet season respectively. The main sources of elevated methane concentrations detected during this study were cattle, fires and towns/fuel stations, as illustrated in Figure 7-4, Figure 7-5, and Figure 7-6. In addition, emissions from the gas power station at Elliott were detected, with methane concentrations as high as 3.397 ppm were detected on the Stuart Highway around 50 m downwind of the station in February 2022.

During the survey, the field team investigated some gas infrastructure in the south-east of the study area, including the drill rig pad for the Shenandoah 1 exploration well and the much older Balmain 1 exploration well. Both wells are plugged and abandoned, and there is also a water bore on the pad. The field team observed low-level methane peaks on the pad. Since there were cattle nearby at the time, most of these peaks were likely to be caused by cattle. However, two of the methane peaks were correlated with peaks in ethane concentration, possibly indicating a thermogenic origin. More thorough investigation of this site is warranted.

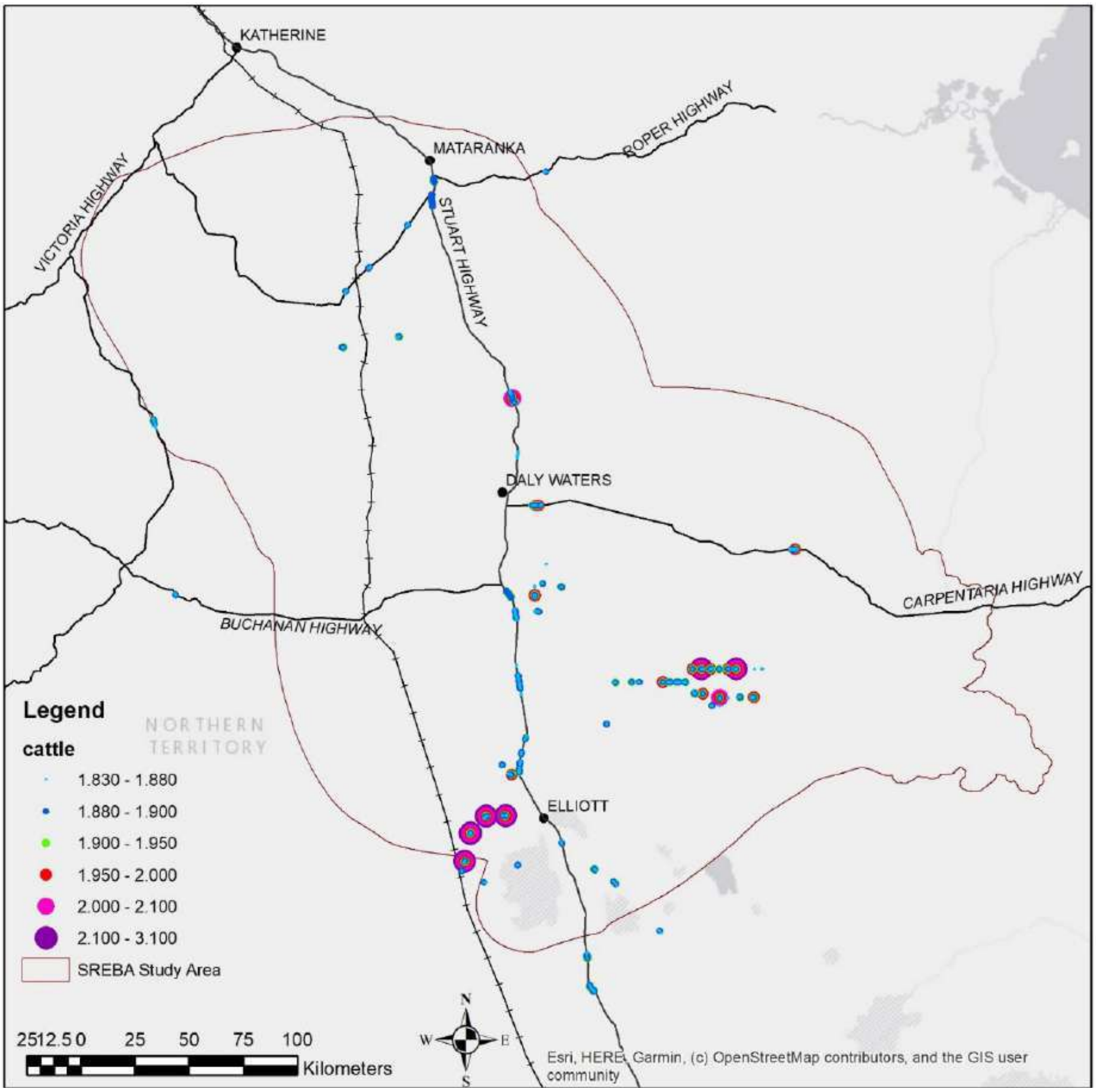

Figure 7-4. Map of June 2022 survey, showing methane concentrations (ppm) that were identified as related to cattle.

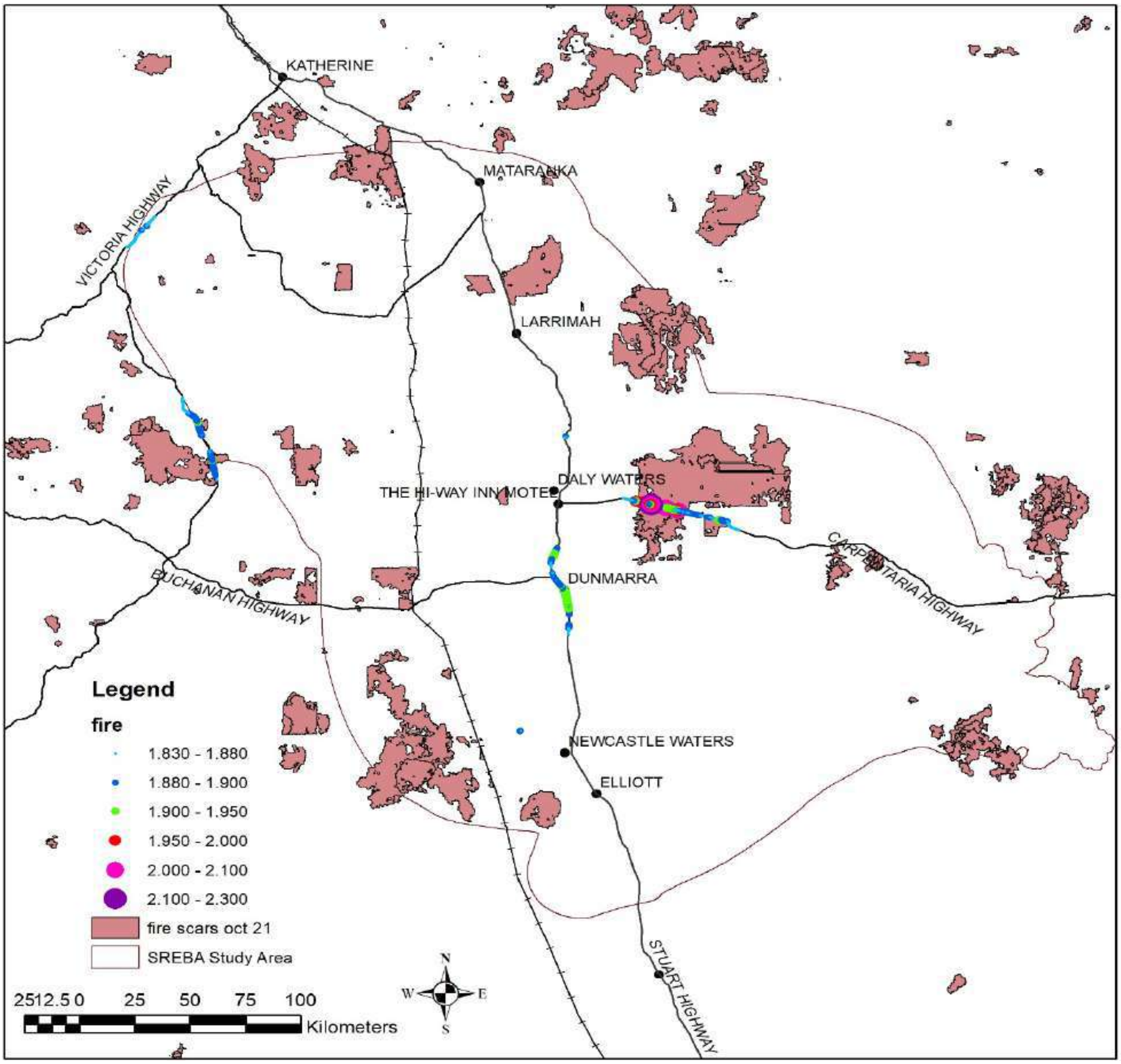

Figure 7-5. Map of October 2021 survey, showing methane concentrations (ppm) that were identified as being due to fire. Also shown are fire scars derived from satellite images for October 2021 (NAFI, 2021).

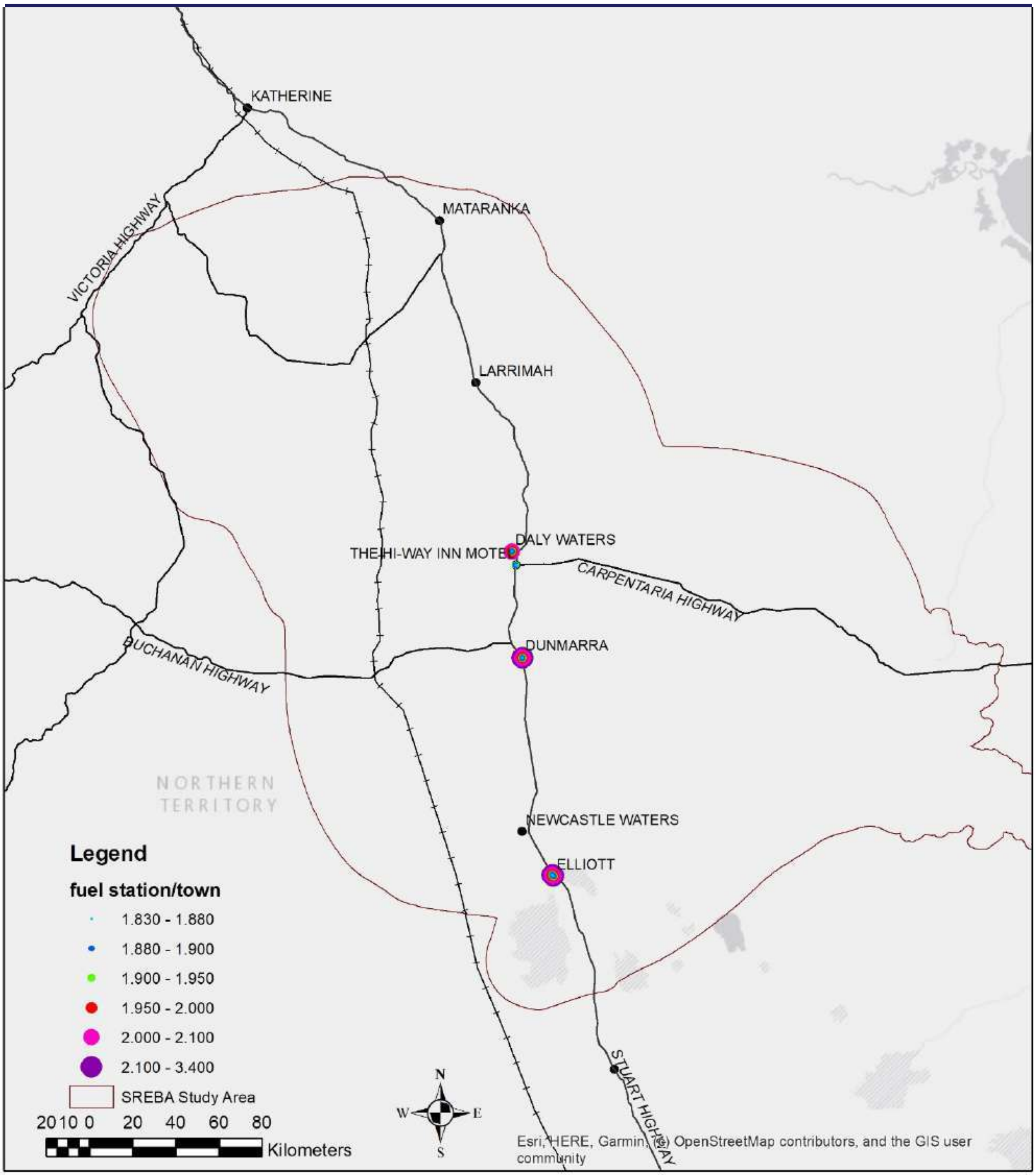

Figure 7-6. Map of June 2022 survey, showing methane concentrations (ppm) that were identified as related to fuel station/town sources.

7.3. Autonomous emission monitoring station

An alternative approach to monitoring greenhouse gas emissions is the use of fixed sites, where sensors continuously monitor concentrations over extended periods. While this does not provide regional-scale data, it can provide detailed information about temporal variation in emissions.

As part of this study, a prototype mobile autonomous emission monitoring station (AEMS) developed by CSIRO was trialled. This is specifically designed to tolerate extreme climates while providing laboratory-grade measurements in real-time at locations where there is no access to grid power and standard telecommunications. The AEMS collected continuous methane, ethane and meteorological conditions from a 9 m mast, recording one measurement per minute.

The AEMS was deployed at Elsey National Park following the end of the October 2021 mobile survey and collected methane, ethane, water vapours, carbon monoxide and meteorological data from November 2021 through to September 2022. No geological seeps where the AEMS could be usefully deployed were identified until near the end of the project.

7.4. Identification of geological seeps

7.4.1. Target identification

Geological, geophysical and geofluid data from the Beetaloo GBA reports were interpreted in an integrated manner to determine the potential presence of geological seeps.

The criteria for determining the potential presence of geological seeps included:

- the presence of bubbling springs along major active faults, such as the Mataranka Springs and other springs
- the presence of active seismic faults
- potential recent fault escape features visible on seismic reflection 2D profiles
- record of high helium content in groundwater
- potential paleo-leakage indicator on non-seismic datasets such as localised demagnetisations.

The final ranking was categorised into seven levels of potential geological seeps targets; this ranking also took into consideration access constraints. The location of potential seep targets are shown in Figure 7-7. Where vehicle access to the vicinity of these sites was possible, data from mobile surveys were examined to investigate whether there was any evidence of elevated methane levels attributable to seeps. Measurements were collected in the vicinity of Mataranka Springs during the GISERA project. Springs at Clint's Gorge in the north-east of the study area were visited and sampled in September 2022.

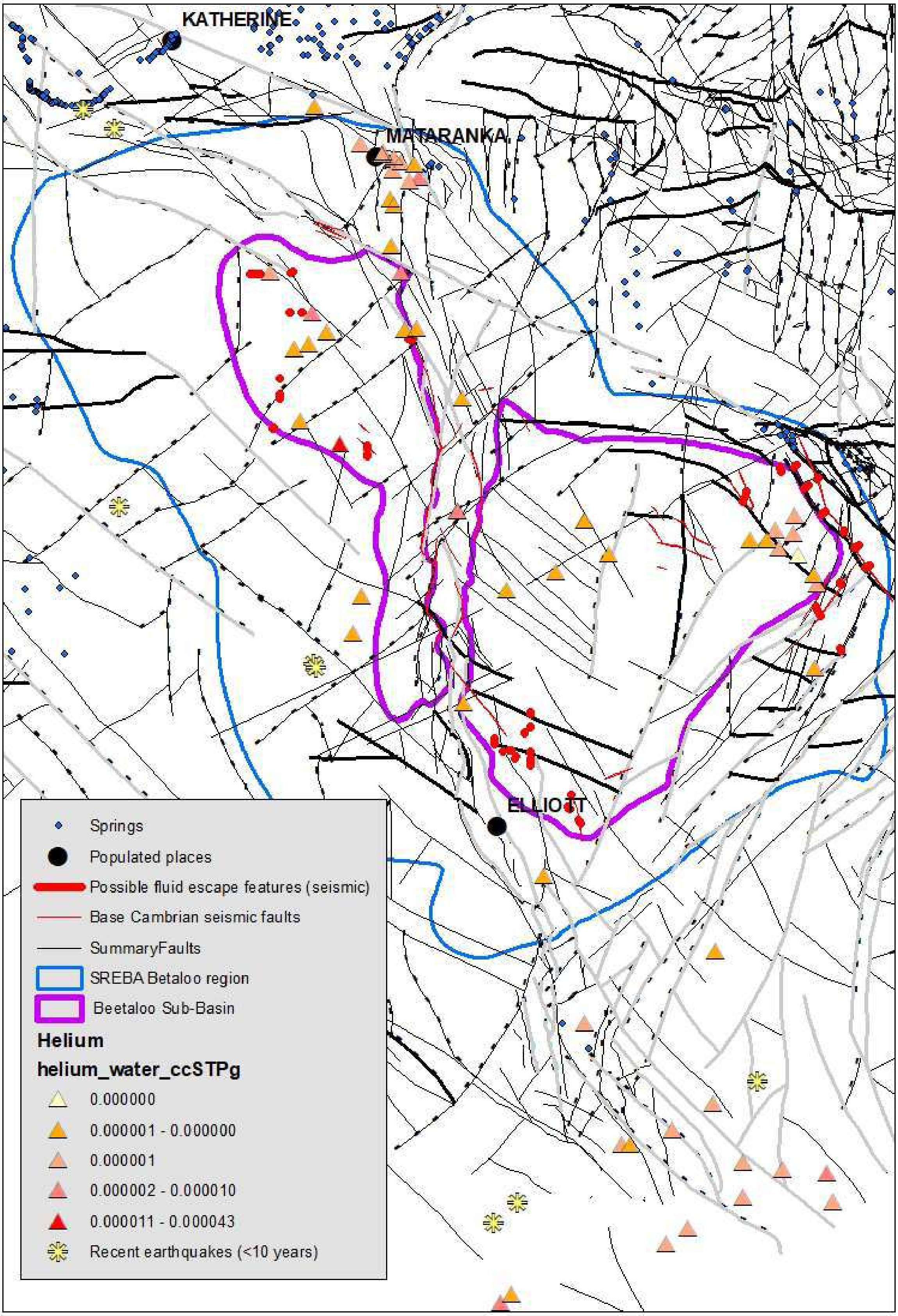

Figure 7-7. Geological, geophysical and geofluid datasets used to define the potential geological seeps to target for further on-ground investigations. These datasets were extracted from the Geological and Bioregional (GBA) assessment stage 2 report (Huddlestone-Holmes *et al.* 2020) and GBA structural review (Frery *et al.* 2022).

7.4.2. Results

Springs near Clints Gorge have the highest temperature recorded in the Northern Territory and bubbles of gas are visible at a number of locations along the creek. These springs and the associated geology are described in more detail in the Baseline Reports for Water Quality and Quantity, and Methane and Greenhouse Gas. The site was accessed by helicopter in September 2022 and methane and ethane concentrations were collected at locations with visible bubbles along the creek. Methane concentrations were up to 1.5 ± 0.02 ppm above the background levels and the ethane concentrations were up to 50 ± 20 ppb above background levels. Concentrations of the two gases were correlated.

Correlated methane and ethane concentrations have been associated with thermogenic sources and have been used to discriminate fossil fuel sources. However, other studies have also found evidence of biogenic methane and ethane in similar environments. The field visit near Clints Gorge provided only a limited opportunity to examine the bubbles from the hot springs, and further, more comprehensive investigations including isotopic studies of methane, ethane and sampling for other gases such as helium are recommended to provide more conclusive information related to the source of these gases.

In contrast, the measurements collected at Mataranka Spring and Rainbow Springs examined during the GISERA project only showed elevated methane concentrations. These were not correlated to the ethane concentrations, suggesting a biogenic source.

There was no evidence from mobile survey data of elevated methane levels associated with other potential geological seep targets, although it could be challenging to pinpoint any potential sources as there were generally no visible above-ground indicators. In a few cases, there were very low-level unidentified elevated methane concentrations detected near the potential targets during the June 2022 survey, but methane levels in the same locations were not elevated for the October 2021 survey.

7.5. Regional emissions inventory

An inventory of the estimated emission rates for each identified source and sink for the SREBA study area has been compiled (Table 7-1). The method and data sources for each estimate are detailed in the Methane and Greenhouse Gas Summary Baseline Report. Such inventories not only provide a useful baseline but can be helpful for targeting mitigation or reduction strategies for industrial facilities such as power stations.

Emissions from the power stations can only currently be calculated as CO_2 equivalents. The extension of routine stack testing to quantify methane would be helpful to provide a more accurate emission rate.

7.6. Recommendations for future monitoring and research

Currently, the most practical and effective method of characterising and monitoring the regional background methane concentrations for the Beetaloo region is the deployment of regional mobile surveys, with such monitoring programs/campaigns recommended to occur every 2 to 3 years. When gas wells are operational, the use of regular (yearly or 6 monthly) local-scale mobile surveys specifically to locate sources at wells may be beneficial. In combination with the local-scale surveys, investigating and updating methods for undertaking leak, detection and repair (LDAR) programs would enhance capabilities to detect lower-level sources and potentially quantify emission rates.

Table 7-1. An inventory of the sources and sink for methane within the SREBA study area.

Type		Emission Rate (tonnes CH_4 yr ^{1})	Emission Rate (tonnes CO_2e yr ^{1})	Method
Cattle	Source	51,650		Charmley *et al.* (2016)
Termites	Source	2,760		Jamali *et al.* (2011)
Fire	Source	5,360		SavBAT 2.2
Elliott Power Station	Source		2,155	National Greenhouse and Energy Reporting (NGER)
Daly Waters Power Station	Source		1,104	NGER
Soil	Sink	13,130		Jamali *et al.* (2011)

In conjunction with the regional mobile surveys, targeted deployment of long-term autonomous emission monitoring stations would be useful to augment regional mobile surveys and would capture the natural diurnal and temporal variations of methane and other greenhouse gas concentrations. The locations where autonomous emission monitoring stations may be useful include:

- at least one reference site away from settlements and where no developments are planned
- where new industrial developments are taking place
- where geological seeps are found.

A GISERA project is currently investigating the use of emission monitoring stations, together with either tracers and/or modelling methods, to characterise the magnitude of methane emissions during the development of wells at industrial development sites.

The SREBA work found elevated and correlated methane and ethane concentrations above the bubbles at the Clints Gorge. Further research is recommended to investigate and characterise the source of the emissions at this site and assess if the input of gas is local or regional. A strong pre-development baseline is particularly important for the industry to consider where such sites are found close to new developments.

There are now a range of new satellites sensors that specifically measure greenhouse gas and that are either in operation or will be launched in the near future (Neumeier *et al.* 2021). While they hold promise for detecting large sources (super emitters), currently they do not have sufficient sensitivities and adequately low detection limits to monitor relatively small and diffused sources such as found in the study area. However, the development of these technologies should be monitored as they could potentially be an important source of monitoring data in the future.

Additionally, the next generation of satellites and earth observation sensors will potentially offer advances in discrimination capabilities for vegetation mapping. They may also improve biomass characterisation, enhancing the estimation of greenhouse gas emissions from bushfires.

7.7. References

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Neumeier, V., Venturini, S., Davitt, A., Madiraju, H.V. and Ryan, B. (2021). GHG Monitoring from Space: A mapping of capabilities across public, private and hybrid satellite missions. Joint report by the Group on Earth Observations, Climate TRACE and the World Geospatial Industry Council. Available at: GHG Monitoring from Space_report final_Nov2021.pdf [accessed 17 November 2022].

Ong, C., Day, S., Maney, B., Mainson, M., Myers, M., & Down, D. (2019). Final Report for GISERA Project G5 - Pre-Exploration Measurement and Monitoring of Background Landscape Methane Concentrations and Fluxes in the Beetaloo Sub-Basin, Northern Territory. Report prepared for the Gas Industry Social and Environmental Research Alliance by CSIRO.

8. Environmental health baseline studies

The Environmental Health domain consists of a set of four studies: Population Health, Air Quality, Soil Quality and Water Quality.

- The Population Health study aimed to set a baseline of the current health status of the population in the region and identify relevant indicators for monitoring change over time.
- The Air Quality study aimed to establish a baseline of air quality at selected sites in the region, and to develop a methodology for a future monitoring program.
- The Soil Quality study reviewed and conducted a gap analysis of the studies undertaken through the GBA and GISERA programs and any other relevant work, and DEPWS data holdings, to establish a risk assessment framework and identify information gaps.
- The Water Quality study within the Environmental Health domain conducted a review and gap analysis, using a human health lens, of the water quality studies undertaken and data developed through the GBA program, GISERA research and the SREBA Water Quality and Quantity projects.

8.1. Population health

The Population Health study was framed by the following objectives.

- Define the boundary of the population health baseline and establish which populations are to be included in the baseline.
- Collate population health data for the Beetaloo Sub-basin using the following indicators over appropriate time periods:
    - respiratory diseases including rates of chronic obstructive pulmonary disease
    - notifiable infectious diseases, which may include melioidosis, Barmah Forest virus infection, Murray Valley encephalitis, chikungunya virus infection, dengue virus infection, and sexually transmitted infections.
- Determine any other relevant indicators and data sources for these indicators.
- Collate, analyse and interpret data to establish a baseline.
- Describe an appropriate long-term monitoring plan and methods for each indicator.

Matters of mental health and wellbeing are included in the Social, Cultural and Economic baseline studies for the Beetaloo Sub-basin, and the occupational health of workers directly involved in hydraulic fracturing activities will be addressed separately through work health safety requirements.

8.1.1. Methodology

The following approach was taken to establish a baseline understanding of the pre-development health status of identified population group(s) that reside within the Beetaloo Sub-basin area.

Stage 1 - Literature review of population health impacts of hydraulic fracturing

- A review of literature was undertaken to build on the understanding of evidence presented in the Final Report of the Scientific Inquiry in relation to health issues associated with onshore gas activity, including hydraulic fracturing.

- The literature review also addressed health matters of relevance to Aboriginal Australians, in an effort to understand if the health evidence can be generalised and applied to the Beetaloo Sub-basin context.
- The findings of the literature review were then used to identify other relevant indicators in addition to those set out in the Scope of Works, and to support recommendations for the monitoring plan.

Stage 2 – Baseline analysis of current disease burden in the community

- Data requests for baseline information on the relevant health indicators for the Beetaloo Sub-basin study area, which was defined as including people with residential addresses in Mataranka, Jilkminggan, Larrimah, Daly Waters, Dunmarra, Newcastle Waters and Elliott, were submitted to NT Health in August 2022.
- A desk-based review of online sources, such as the 2021 Census, was undertaken to collect data on the relevant health indicators. These data were analysed to provide an initial evaluation of the health profile in the study area.
- For reasons of data protection and the privacy of health data, more detailed, location-specific data involving a small population have been redacted. Available baseline health data from NT Health were used for analysis and developing the baseline; however, as the data are sensitive, they will be retained by NT Health and are available upon application to NT Health.

Stage 3 - Develop a monitoring plan for population health impacts

- An outline of a monitoring plan was developed for the relevant health indicators. It is recommended that stakeholders be engaged to refine and agree on the indicators prior to finalising an implementable monitoring plan.

Stage 4 – Recommendations and conclusions

- Recommendations for next steps have been set out, regarding how the monitoring plan should be agreed, planned and finalised.

8.1.1.1. SREBA Beetaloo Population Health study area

Health data were provided by NT Health for two different population areas (Figure 8-1):

- Statistical Area 1: Beetaloo Sub-basin communities, defined as those with residential addresses within Mataranka, Jilkminggan, Larrimah, Daly Waters, Dunmarra, Newcastle Waters and Elliott.
- Statistical Area 2: Mortality data provided by the Australian Bureau of Statistics' statistical area 2 (SA2) regions were reported (without identification of communities) for three encompassing SA2 regions of Elsey, Katherine and Barkly.

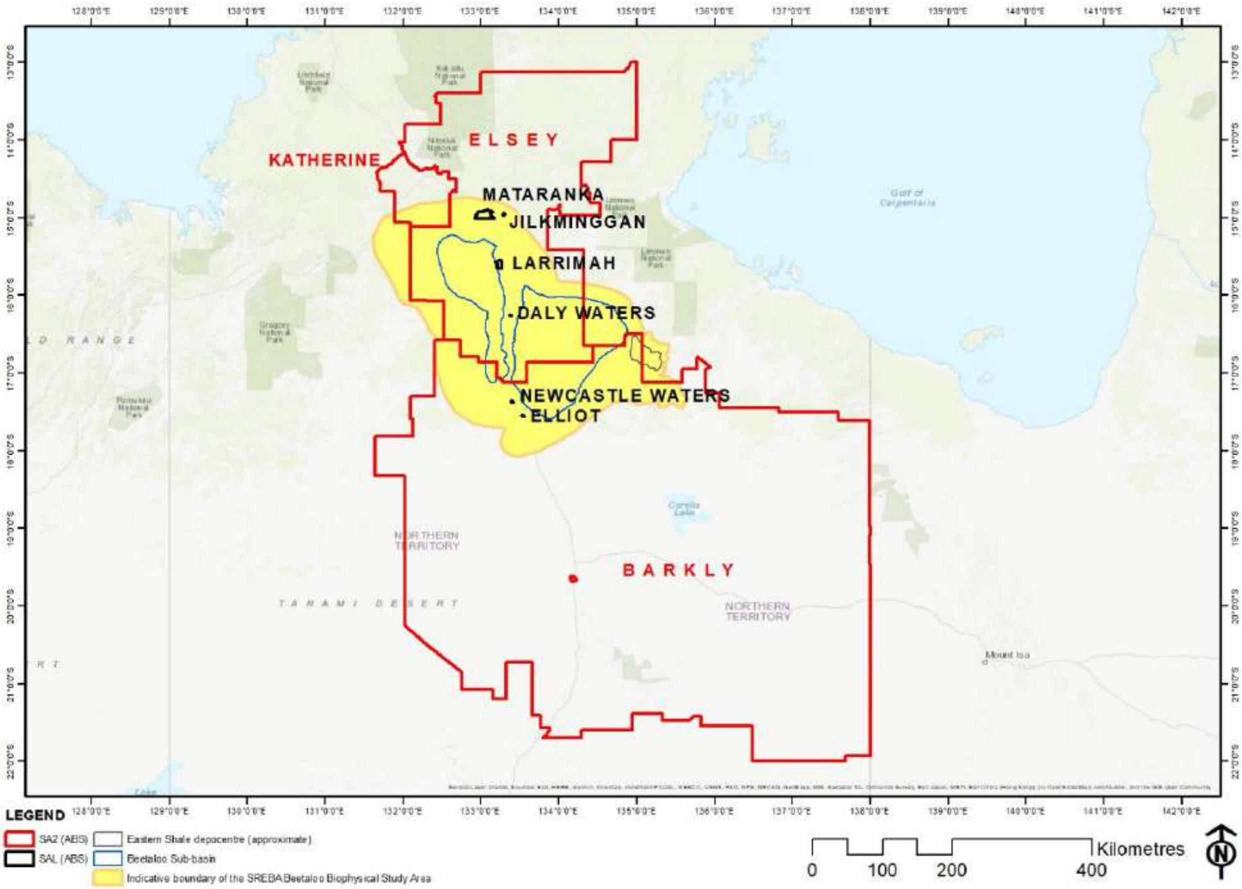

Figure 8-1. SREBA Population Health study areas for health data.

8.1.2. Data limitations

The study area for baseline data collection was set at a community or regional level, and therefore varies according to the spatial scale at which data were collected for each indicator.

A data request for baseline information on the relevant health indicators for the Beetaloo Sub-basin study area was submitted to the Department of Health (NT Health) in August 2022 and Sunrise Health Service in October 2022. Due to confidentiality constraints, no data could be obtained from Sunrise Health Service.

8.1.3. Results

A higher proportion of the population within the Beetaloo Sub-basin study area are Aboriginal when compared to the Northern Territory and Australia. The population is also significantly younger than the national average, with a median age of 30 years.

Generally, the population of the Northern Territory reports better health than the population of Australia across a range of health indicators. However, the trends in relation to health outcomes associated with lifestyle and behavioural factors in the Aboriginal population are consistent with those in Australia. Factors such as smoking result in an increase in prevalence of some cancers and are also associated with adverse foetal and birth outcomes, for which higher rates are recorded amongst the Aboriginal population. The leading causes of death among Aboriginal and non-Aboriginal people in the years 2004 to 2013 were similar; however, health conditions commonly associated with lifestyle and behavioural factors, including diabetes, liver disease, and alcohol use disorders, were higher amongst the Aboriginal population. Notably, lung cancer rates were lower among the Aboriginal population despite the significant prevalence of smoking.

The Mataranka Suburb and Locality (SAL; geographical boundaries used in the Australian Bureau of Statistics census data) and the Elliott SAL both have a mixed picture in terms of health conditions when compared to the Northern Territory and Australia as a whole. These SALs report a lower proportion of one or more long-term health conditions within the population, and lower levels of asthma. However, conditions commonly associated with lifestyle and behavioural factors, such as diabetes and heart disease, are more prevalent. These lifestyle and behavioural factors are more commonplace among the Aboriginal population than the non-Aboriginal population.

Rates of sexually transmitted infections are significantly higher for Aboriginal people than non-Aboriginal people. Many complex social determinants contribute to this disparity, such as education and health literacy, access to health services, racism (in the form of stigmatising social institutions), income and employment rates (Bell *et al.* 2020).

While the health data for the Beetaloo Sub-basin population and SA2 region provided by NT Health have substantial limitations, they do generally suggest that trends in health inequalities between Aboriginal and non-Aboriginal populations are reflected in the local community health profile. This appears to be the case for respiratory condition hospitalisations and deaths, cardiovascular condition hospitalisations and deaths, blood and immune disorder hospitalisations and deaths, neurological condition hospitalisations and sexually-transmitted infection notifications. Cases for cancers, foetal defects and adverse birth outcomes were too low to draw conclusions. Recorded cases of Ross River Virus among residents of non-Aboriginal status were more than double those of residents of Aboriginal status, although it should be noted that the case numbers were very low (19 cases in a 10 year period), which limits the value of this observation.

8.1.4. Recommended monitoring indicators

The Population Health Baseline Report sets out the recommended monitoring indicators and proposed collection methods (subject to confirmation of feasibility of data format and collection). The recommended indicators comprise the following types.

- Indicators for symptoms that are commonly associated with exposure to irritant substances.
- Indicators for chronic health outcomes associated with hazards presented by onshore gas production.
- Indicators for vector-borne and sexually transmitted diseases that are associated with natural and social environmental conditions respectively.

Indicators for risk factors that are associated with the health outcomes should also be monitored. It is proposed that two main sources of data be used for ongoing monitoring:

- Information provided by the health services (NT Health and Sunrise Health Service Aboriginal Corporation).
- Self-reported symptoms by members of the local communities.

8.1.4.1. Data Reporting

Frequency

Where suitable data can be provided for the baseline, it is anticipated that follow-up data can be provided at agreed intervals. For example, certain cancers have long latency periods between exposure and development, and therefore longer timeframes for reporting would be more appropriate. The use of a smart phone-based app would help acute symptoms to be recorded when or soon after they occur, allowing an ongoing form of monitoring.

Privacy

A protocol will need to be adopted to ensure privacy of individuals' health data. Stratification by age, gender and ethnicity may lead to very small numbers of cases, which increases the risk that individuals could be identified. Therefore, protocols such as not reporting numbers where there are fewer than five individuals would be implemented. It will also be appropriate to combine categories of health outcomes where case numbers are likely to be small. Broad age group categories as follows will also limit the likelihood of individuals being identified: <5 years, 5-14, 15-24, 25-44, 45-64, 65-74, >74 years. Expanded age groups (< 20 years, 20-45 years, > 45 years) could also be used. Any future study accessing and collecting data may require human research ethics approval from a recognised committee.

Language and Accessibility

The language and accessibility of reporting should be agreed to prior to commencement of monitoring and organisers thereof should take advice from the stakeholders listed in the Population Health Baseline Report.

8.1.5. Limitations

There are several limitations to the draft monitoring plan. The population size is too small to support robust epidemiological analysis and it will not be possible to measure effects with appropriate precision. Therefore, it is unlikely that significance can be drawn from any changes in health outcomes and associations with hydraulic fracturing activities, or any other risk factors. However, the data will support some trend analysis, will facilitate health service planning and will alert authorities to potentially unexpected changes from the health baseline that require further investigation.

Since patient identifiers have been restricted in the baseline data supplied by NT Health, any future analysis will not be able to track individuals over time. This again limits the ability to undertake robust epidemiological analysis.

Rates for certain health outcomes will be provided as crude rates. While this can allow a comparison in the same population over time, it will not allow comparison to other populations due to likely differences in age and gender structure (i.e. the rates will not be based on a standardised population). The indirect standardisation method may be appropriate to help overcome this issue to an extent.

Some data will be subject to various forms of bias. For example, the results of community health surveys may be subject to recall bias. The use of an app for self-reporting symptoms in real time may help overcome this risk to an extent. The use of an app-based approach to allow self-reporting has the potential to facilitate better monitoring of certain health issues; however, it is open to misuse. For example, people may over-report symptoms in the event they are anxious about hydraulic fracturing in their region. On the other hand, the ability to apply real-time responses to symptom reporting may enable an understanding of other potential environmental hazard exposures; for example, if there is a bushfire in the region.

Since the Population Health study area is covered by different health service providers, there is a risk that there will be differences in the method, classification and recording of health outcome measures; in turn, this would impact the understanding of the scale and geographical distribution of health outcomes.

8.2. Air quality

8.2.1. Background

There are three existing full ambient air quality monitoring stations in the Darwin region, and a recently installed station in Katherine collecting data for the NT EPA. The data collected by the pre-existing air quality stations are unlikely to be representative of the air quality within the study area due to their spatial separation.

Concentrations of nitrogen dioxide, sulphur dioxide and carbon monoxide will mainly be driven by the population and industrial activities in the Darwin region, as well as hazard reduction burning and bushfires. Observations indicate that these concentrations are well below the National Environment Protection Measure for Air (NEPC 2021) standards. The population and industrial activity in and around the Beetaloo Sub-basin are lower than that in the Darwin region; therefore, baseline concentrations of pollutants that are driven by urban-anthropogenic activities are expected to be materially lower in the study area than in Darwin.

Concentrations of particulate matter in Darwin regularly exceed the National Environment Protection Measure for Air standards, mainly due to burning of vegetation and associated smoke during the dry season. Over the last 10 years, fires were more frequent in the north near the Darwin region than in the Beetaloo Basin and study area.

8.2.2. Monitoring locations

Five air quality monitoring stations were installed in the study area as part of the SREBA (Figure 8-2). The locations were chosen to capture a representative baseline across the geographic extent of the Beetaloo Sub-basin, within logistical constraints. Monitoring equipment was installed and commissioned during September 2022. Monitoring will be undertaken for at least 12 months, which is considered the minimum required to characterise the baseline environment throughout all seasons. Monthly visits are made to each air quality monitoring station to collect samples for analysis, as well as to maintain and service the deployed equipment.

Figure 8-2. Location of SREBA air quality monitoring stations.

8.2.3. Air quality parameters

Air quality parameters for monitoring have been selected based on the expected emissions from onshore gas development in the area. The main types of emissions from unconventional onshore gas projects are dust from construction activities and gaseous emissions from onsite equipment and machinery. These align with the criteria pollutants defined in the National Environment Protection Measure for Air. The main sources of emissions from unconventional onshore gas developments are likely to be:

- fuel combustion, including flaring of gas at well pads and processing facilities, gas-powered engines used in production and processing infrastructure, and diesel-powered vehicles, equipment and plant used in well development and operations
- air pollutants present in produced gas and liquids that are intentionally (vented) or unintentionally (fugitive) released from gas infrastructure
- dust from construction activities and wheel-generated dust from movements of vehicles and equipment
- air pollutants from the transport, storage, handling, use and disposal of chemicals used in well development (e.g. drilling and hydraulic fracturing), production and processing activities.

The following parameters are being measured as part of the monitoring program:

- deposited dust – using dust deposition gauges (DDG)
- suspended particulate matter (PM2.5, PM10) – using a real time light-scattering device
- gases (NO_2, SO_2, H_2S, VOCs and aldehydes) – using passive sampling methods
- meteorological parameters (wind speed, wind direction, temperature, humidity and rainfall).

The methods for monitoring these parameters are outlined below.

8.2.4. Methods

8.2.4.1. Deposited dust

Baseline and ongoing measurements of dust deposition will provide information on changes in the 'dustiness' of the area and is a commonly used technique in mining and industry monitoring. Dust deposition gauges have been deployed at all air quality monitoring stations and sampling will be carried out with a sampling interval of approximately one month (30±2 days). Sampling is conducted in accordance with the Australian Standard AS/NZS 3580.10.1:2003. The assessment of the dust deposition gauge results is a daily rate on a monthly average basis, rather than against a total mass over a month-long period.

8.2.4.2. Suspended particulate matter

Continuous monitoring of airborne particle concentrations is being used to provide indicative information for comparison with National Environment Protection Measure for Air objectives. Due to the number of data collection locations and the remote nature of each location, measurement of particulate matter in accordance with the relevant Australian Standards was not practicable. The measurements are carried out using a light scattering particle sensor, which is portable, has a low power demand, does not require samples to be taken and does not have excessive maintenance requirements. An ATSI Instruments DustTrak™ DRX Aerosol Monitor has been deployed at all sites to measure suspended particles, $PM_{2.5}$ and PM_{10}.

There are limitations associated with use of this type of equipment and these are in part associated with the low sampling flow rate of the sensor. To overcome these limitations, the DustTrak has been co-located with 'E-BAM' instruments at the Daly Waters site for the entire monitoring period. This will allow for 'correction factors' to be developed and applied to the data collected by the DustTraks.

The E-BAM is a real-time beta attenuation monitor that can be supplied with either TSP, PM_{10} or $PM_{2.5}$ inlets. For this project, two E-BAMs are deployed with a PM_{10} inlet and $PM_{2.5}$ inlet, in accordance with Australian Standard AS/NZS 3580.9.11 and AS/NZS 3580.9.12.

8.2.4.3. Gases

Passive sampling of gases, including NO_2, SO_2, H_2S, VOCs and aldehydes, is being conducted using Radiello diffusive samplers. These samplers have a 'diffusive layer' that allows gaseous molecules to pass through, surrounding an 'adsorbing surface' that traps these molecules. The concentration, as mass, of the target gas on the adsorbing surface can then be calculated. Passive samplers require the sorbent cartridges (adsorbing surface) to be replaced at an interval of typically less than 14 days.

Due to the remote locations of the site, a 28-day sample schedule has been established and is considered appropriate due to the low concentrations of target gases expected. To investigate if this variation to the method is fit for purpose, a duplicate run of two consecutive 14-day periods was conducted alongside one 28-day period. The aim was to investigate the level of 'back diffusion' that might be expected over the longer sampling period. Back diffusion is a phenomenon that can occur when the absorbed mass of the compound exceeds the capacity of the adsorbent bed and concentrations are therefore under-reported. Other studies using passive Radiello samplers have also used this method of extending the sampling period for some samples past the 14-day recommendation, with acceptable results (Dunne *et al.* 2018).

Agreement between the average of the two 14-day samples and the concurrent 28-day samples was variable. The relative difference between the results from the different sampling periods is materially significant, with the 28-day sample producing results ranging from 50% to 350% of the standard sampling period for most pollutants, with an average of approximately 180%.

For five of the seven pollutants detected (NO_2, SO_2, toluene, m- and p-xylene, and o-xylene), there was both positive and negative variability. For formaldehyde and benzene, the 28-day exposure period had consistently less concentration than the 14-day periods, suggesting a potential underestimation using this method.

Noting a significant comparative difference between the two methods, the absolute difference in concentrations measured by the two methods is marginal, particularly when taking into account the relevant criteria for each gas. The differences in measured concentrations between the methods are potentially a consequence of observed concentrations being very low and close to the detection limits, which would exaggerate any method errors.

Based on the above, the method, whilst having some limitations, is considered appropriate for the purposes of a baseline assessment where ambient concentrations are low. However, a recommendation is for further work to be undertaken to improve understanding of the modified method.

8.2.4.4. Meteorology

A weather station is set up at each site to measure wind speed, wind direction, temperature, relative humidity and rainfall. Meteorology is measured in accordance with AS/NZS 3580.14, where possible, using the following instrumentation.

- wind speed and wind direction are measured at 10 m height by a Vaisala WXT532 ultrasonic sensor
- Temperature, barometric pressure, and relative humidity are measured by a Lufft WS300 sensor.
- Rainfall is measured by a TB7 tipping bucket rain gauge.

The Daly Waters site is co-located with an existing Bureau of Meteorology station, which will allow validation of meteorological observations from the air quality station.

8.2.5. Monitoring results

The monitoring period began in late September 2022 and this section provides results for the data available to date.

8.2.5.1. Dust deposition

The dust deposition gauge results are presented as the monthly average deposition rate in g/m²/month (Table 8-1). No criteria are stipulated by the National Environment Protection Measure for Air for deposited dust; however, many Australian state guidance documents provide a limit of 4 g/m²/month.. The results show that the dust deposition rates available to date at the sites are within the adopted objective level.

Table 8-1. Summary of dust deposition results.

Sample period	Limit (g/m²/month)	Monthly average dust deposition rate (g/m²/month)				
		Mataranka	Manbulloo	Bullwaddy	Daly Waters	Elliott
October 2022	4	0.60	0.90	1.0	0.40	0.70

8.2.5.2. Ambient particulate monitoring

Continuous particulate matter monitoring was carried out at the five monitoring locations for the entirety of the monitoring period to date. Correction factors for the DustTrack data have not been calculated at this stage; however, data collected at the Daly Waters site using the E-BAM and DustTrack have been compared and show a variation of less than 10%.

Plots show consistently low levels PM_{10} and PM_2 at Elliott and Bullwaddy Conservation Reserve, while the remaining three sites tend to experience some high peaks. Fires near the Mataranka and Manbulloo sites have been noted during late October and early November and are likely to account for some of the concentrations measured at these stations.

Table 8-2. Particulate concentrations for monitoring period, µg/m³. [1] indicates that annual averages are calculated using all available data to date.

Parameter	Averaging period	Limit	Mataranka	Manbulloo	Bullwaddy	Elliott	Daly Waters
PM_{10}	Annual average[1]	**25**	39	56	14	8.3	8.7
	24-hour maximum	**50**	156	199	31	23	27
$PM_{2.5}$	Annual average[1]	**8**	-	54	13	7.6	8.2
	24-hour maximum	**25**	-	195	30	21	27

8.2.5.3. Passive gas sampling

The results provide the average concentration for each pollutant over the sampling period and are presented with the same number of significant figures as provided by the laboratory. Criteria provided in the National Environment Protection Measure for Air are generally given as 1 h, 24 h or annual average values. Given the 28-day sample duration in the current study, direct comparison is not possible and values have been compared with the minimum (longest-term) criterion for each pollutant.

Nitrogen dioxide (NO_2)

The sampled NO_2 concentrations are presented in Table 8-3. The maximum 1-h NO_2 criterion, as per the National Environment Protection Measure for Air, is 164 μg/m^3 and the annual average criterion is 31 μg/m^3 (converted from ppm at 0°C). The passive sampling results indicate the maximum average NO_2 concentration observed was 3.4 μg/m^3 at Elliott during October 2022, which is slightly above the annual criterion.

Table 8-3. Summary of passive NO_2 sampling.

Sampling period	Annual criterion (μg/m³)	Average NO_2 concentration over the sample period (μg/m³)				
		Mataranka	Manbulloo	Bullwaddy	Daly Waters	Elliott
October 2022	31	3	3	2	2	3.4
November 2022		2	0.6	0.6	2	2

Sulphur dioxide (SO_2)

The sampled SO_2 concentrations are presented in Table 8-4. The maximum 1-hour SO_2 criterion, as per the National Environment Protection Measure for Air, is 286 μg/m^3 and the maximum 24-h criterion is 57 μg/m^3 (converted from ppm at 0°C). The passive sampling results indicate the maximum average SO_2 concentration observed was 2 μg/m^3 at Daly Waters during October 2022.

Table 8-4. Summary of passive SO2 sampling results.

Sample period	24 hour criterion (μg/m³)	Average SO_2 concentration over the sample period (μg/m³)				
		Mataranka	Manbulloo	Bullwaddy	Daly Waters	Elliott
October 2022	57	1	0.5	1	2	1
November 2022		0.8	1	0.6	0.3	1

Hydrogen sulphide (H_2S)

No criteria are specified in the National Environment Protection Measure for Air or the National Environment Protection Measure Air Toxics for hydrogen sulphide. Results for H_2S across all sample periods and sites were below the detectable limit of 0.5 μg/sample.

Aldehydes (formaldehyde)

The sampled formaldehyde concentrations are presented in Table 8-5. The maximum 24-h criterion for formaldehyde, as per the Air Toxics National Environment Protection Measure, is 54 μg/m^3 (converted from ppm at 0°C). The passive sampling results indicate the maximum average formaldehyde concentration observed was 0.9 μg/m^3 at Daly Waters during October 2022.

Table 8-5. Summary of passive formaldehyde sampling results.

Sample period	24 hour criterion (μg/m³)	Average formaldehyde concentration over the sample period (μg/m³)				
		Mataranka	Manbulloo	Bullwaddy	Daly Waters	Elliott
October 2022	54	0.6	0.3	0.4	0.9	0.2
November 2022		0.5	0.2	0.1	0.3	0.1

Volatile organic compounds

Sampling for volatile organic compounds produces results for a large suite of individual organic compounds. For the purposes of this baseline assessment, results are presented for those volatile organic compounds that are presented in the Air Toxics National Environment Protection Measure: benzene, toluene and xylene.

- **Benzene**

The sampled benzene concentrations are presented in Table 8-6. The annual average criterion for benzene, as per the Air Toxics National Environment Protection Measure, is 10 μg/m^3 (converted from ppm at 0°C). The passive sampling results indicate the maximum average benzene concentration observed was 0.03 μg/m^3 at Mataranka and Daly Waters during October 2022.

Table 8-6. Summary of passive benzene sampling results.

Sample period	Annual criterion (μg/m^3)	Average benzene concentration over the sample period (μg/m^3)				
		Mataranka	Manbulloo	Bullwaddy	Daly Waters	Elliott
October 2022	10	0.03	0.02	0.02	0.03	0.01
November 2022		0.02	0.02	0.01	<0.001	0.01

- **Toluene**

The sampled toluene concentrations are presented in Table 8-7. The maximum 24-hour criterion for toluene, as per the Air Toxics National Environment Protection Measure, is 4,110 μg/m^3 and the annual average criterion is 411 μg/m^3 (converted from ppm at 0°C). The passive sampling results indicate the maximum average toluene concentration observed was 0.21 μg/m^3 at Manbulloo during October 2022.

Table 8-7. Summary of passive toluene sampling results. Note that results, as reported by the laboratory, are an estimate.

Sample period	Annual criterion (μg/m^3)	Average toluene concentration over the sample period (μg/m^3)				
		Mataranka	Manbulloo	Bullwaddy	Daly Waters	Elliott
October 2022	411	0.10[1]	0.21[1]	0.06	0.07	0.07
November 2022		0.10[1]	0.16[1]	0.06	0.07	0.04

- **Xylene**

The sampled xylene concentrations are presented in Tables 8-8 and 8-9. The maximum 24-h criterion for xylene, as per the Air Toxics National Environment Protection Measure, is 1,184 μg/m^3 and the annual average criterion is 947 μg/m^3 (converted from ppm at 0°C). The passive sampling results indicate the maximum total m- and p-xylene concentration observed was 0.04 μg/m^3 at Manbulloo during October 2022, and the maximum total o-xylene concentration observed was 0.03 μg/m^3 at Manbulloo in October 2022 and at Daly Waters in November 2022.

Table 8-8. Summary of passive m- and p-xylene sampling results.

Sample period	Annual criterion (μg/m^3)	Average m and p xylene concentration over the sample period (μg/m^3)				
		Mataranka	Manbulloo	Bullwaddy	Daly Waters	Elliott
October 2022	947	0.01	0.04	0.01	0.02	0.02
November 2022		0.02	0.03	0.01	0.03	0.01

Table 8-9. Summary of passive o-xylene sampling results.

Sample period	Annual criterion (µg/m³)	Average o xylene concentration over the sample period (µg/m³)				
		Mataranka	Manbulloo	Bullwaddy	Daly Waters	Elliott
October 2022	947	0.009	0.03	0.007	0.01	0.01
November 2022		0.01	0.02	0.01	0.03	0.006

8.2.6. Ongoing monitoring

The baseline monitoring program is scheduled to continue for a further 10 months, with a total of 12 months of data to be collected. However, it is recommended that air quality monitoring continue beyond the 12-month baseline monitoring period. While compliance monitoring for industrial approvals is expected and would be the responsibility of the proponent, regional baseline monitoring in these areas is valuable for ensuring human health and environmental impacts are minimised and so that communities are aware of their air quality environment.

Air quality monitoring as part of an ongoing monitoring program is expected to be consistent with the current monitoring plan; however, some refinement may be applicable based on conclusions from this study. Refinement of the current monitoring program may include installation of a compliance-grade air quality monitoring station at one or more of the monitoring locations and may involve a reduction in the total number of satellite sites at which monitoring is conducted. The locations selected for ongoing monitoring would depend on various factors, including the outcomes of the SREBA study and the proximity of proposed industry to areas that are sensitive to air impacts.

A preliminary investigation was carried out into the adoption of a non-standard 28-day sampling period for measurement of gases by passive samplers. The results have identified some limitations with the 28-day sampling method; however, the method is considered appropriate for the purposes of this baseline study, as the ambient concentrations of gaseous pollutants are very low in comparison to the relevant air quality objectives. It is recommended that further investigation is carried out to better understand the implications of using a 28-day sampling period, in order to inform the most suitable method for any longer term regional air quality monitoring.

8.3. Water quality

The aim of this study was to review all available water quality data (surface water and groundwater) for the Beetaloo Sub-basin, and relevant literature, with a focus on water quality issues that may affect human health. A gap analysis should summarise existing knowledge gaps and recommend further sampling and/or monitoring activities to address these gaps.

The water quality component of the Environmental Health studies overlapped with the SREBA Water Quantity and Quality studies (Section 4) and also drew on information developed during the Beetaloo GBA Program, as well as other sources such as the drinking water quality reports published by Power and Water Corporation.

8.3.1. Literature review

An extensive list of reference documents already exists for guidance on assessing water quality in the Northern Territory and Beetaloo Sub-basin in relation to onshore gas activities (e.g. Wilkes *et al.* 2019). Key literature was reviewed from the following organisations: NT Government, CSIRO, NT Environment Protection Authority, Power and Water; and the key findings and knowledge gaps are tabulated in the Baseline Report. Much of the relevant information is also incorporated into the SREBA Water Quality and Quantity Baseline Report.

Of particular note, the GBA Program included a qualitative environmental risk assessment of drilling and hydraulic fracturing chemicals for the Beetaloo GBA region (Kirby *et al.* 2020). This considered 116 chemicals identified as being associated with drilling and hydraulic fracturing operations in the Beetaloo region; nine used during drilling chemicals, 99 during hydraulic fracturing, and eight for both activities. The assessment considered 42 chemicals to be of low concern and to pose minimal risk to aquatic ecosystems, 41 chemicals were of potential concern and 33 chemicals were of potentially high concern. Based on this assessment, chemicals that may be used during drilling and fracturing that are of potentially high concern because they are persistent in the environment, bioaccumulate and can exhibit high or acute toxicity to human health are presented in Table 8-10. It is noted that chemicals used in drilling and hydraulic fracturing are expected to change with time as the gas industry evolves and adapts to site-specific conditions, improves gas extraction efficiency, and endeavours to use 'greener-safer' options.

Table 8-10. Contaminants of potential concern that are used in drilling and fracturing. *CAS RN = Chemical Abstracts Services Registry Number. Adapted from Kirby *et al.* (2020).

Chemical	CAS RN	Use
Potentially High Concern (very high or acute toxicity, persistent and bioaccumulative)		
Dicoco dimethyl ammonium chloride	61789-77-3	Biocide surfactant
Decamethylcyclopentasiloxane (D5)	541-02-6	Defoaming agent surfactant
Silicone Oil (poly(dimethyl siloxane))	63148-62-9	Defoaming agent surfactant
Dodecamethylcyclohexasiloxane (D6)	540-97-6	Defoaming agent surfactant
Octamethylcyclotetrasiloxane (D4)	556-67-2	Defoaming agent surfactant
Potentially High Concern (harmful to very toxic and persistent or bioaccumulative)		
1,2,4-Trimethylbenzene	95-63-6	Solvent
1-Benzyl methyl pyridinium chloride	68909-18-2	Corrosion inhibitor
5-Chloro-2-methyl-4-isothiazolol-3-one	26172-55-4	Biocide

Chemical	CAS RN	Use
2-Mercaptoethyl alcohol	60-24-2	Surfactant
2-Methyl-4-isothiazol-3-one	2682-20-4	Biocide
Acrylamide	79-06-1	Friction reducer/gelling agent
Alcohols, C10-16, ethoxylated propoxylated	69227-22-1	Surfactant
Alcohols, C12-C16, ethoxylated	68551-12-2	Surfactant
Amines, tallow alkyl, ethoxylated	61791-26-2	Surfactant
C12-18-alkyldimethylbenzylammonium chlorides	68391-01-5	Biocide
Coco alkyldimethyl oxide	61788-90-7	Surfactant
Dipentene terpene hydrocarbon by-products	68956-56-9	Friction reducer and gelling agent
Naphthalene	91-20-3	Friction reducer and gelling agent
Naphthenic acids, ethoxylated	68410-62-8	Friction reducer and gelling agent
Polyethylene glycol monohexyl ether	31726-34-8	Non emulsifier
Pontacyl carmine 2B (acid violet 12)	6625-46-3	Tracking dye
Heavy aromatic solvent naphtha (petroleum)	64742-94-5	Friction reducer and gelling agent
Hydrotreated light distillate (C13-C14 isoparaffin)	64742-47-8	Friction reducer and gelling agent
Potentially High Concern (very toxic but not persistent or bioaccumulative)		
2-Bromo-2-nitro-1,3-propanediol	52-51-7	Biocide
Chromium (VI)	18540-29-9	Breaker
Cupric sulfate	7758-98-7	Biocide and breaker
Glutaraldehyde	111-30-8	Biocide
Hydrochloric acid	7647-01-0	Scale remover
Sodium chlorite (NaClO2)	7758-19-2	Biocide and breaker
Sodium hypochlorite	7681-52-9	Biocide and breaker
Sodium iodide	7681-82-5	Breaker and breaker
Tetrakis (hydroxymethyl) phosphonium sulfate	55566-30-8	Biocide
Tributyl-tetradecylphosphonium chloride	81741-28-8	Biocide

8.3.2. Groundwater quality

Groundwater data were collected from primary data custodians, including the Northern Territory Government, Power and Water, petroleum industry, Geoscience Australia and CSIRO. A small portion of groundwater results were from pastoral lease holder production bores. These provide groundwater quality data for five aquifers (Table 8-11). Parameter sampled, quality assurance and quality control were highly variable amongst locations.

Table 8-11. Aquifers for which groundwater quality data was assessed. *N* indicates the number of locations from which some relevant data are available, noting that reliable data for most groundwater quality parameters are only from a much smaller sub-set of these.

Identifier	*N*	Aquifer/Aquitard	Aquifer Formation
Aquifer 1	201	Cambrian Limestone Aquifer (Upper)	• Anthony Lagoon Formation • Jinduckin Formation
Aquifer 2	2130	Cambrian Limestone Aquifer (Lower)	• Gum Ridge Formation • Montejinni Limestone • Tindall Limestone
Aquifer 3	67	Carpentaria Basin	• Cretaceous
Aquifer 4	145	Antrim Plateau Volcanics Aquitard	• Basalt
Aquifer 5	130	Jamison Sandstone Aquifer	• Proterozoic

Analyses of groundwater quality parameters from each aquifer are detailed in the Baseline Report and average values are summarised below.

- pH generally ranges from lower neutral to a slightly acidic pH.
- Electrical conductivity generally ranges from fresh to brackish conditions.
- Sulfate concentration was highest within the Upper Cambrian Limestone Aquifer (CLA) and lowest in the Jamison Sandstone Aquifer.
- Field and laboratory pH generally range from lower neutral to a slightly acidic pH, apart from Antrim Plateau Volcanics aquitard, which has a neutral pH.
- Metal concentrations are generally low and remain below the health and aesthetic guidelines across the study area except for iron, for which average concentrations were reported above aesthetic guideline values in all aquifers, except for Antrim Plateau Volcanics Aquitard.
- Nutrient concentrations were generally low and remained below the health and aesthetic guideline values across the study area, except for sulfate and chloride. Sulfate exceeded the health and aesthetic guideline values in the Upper CLA and aesthetic guideline values in the Lower CLA. Chloride concentrations exceeded the aesthetic guideline values in the Upper CLA, Lower CLA and Carpentaria Basin. Additionally, fluoride exceeded health guidelines in the Upper CLA.

Evaporative minerals such as gypsum are commonly found in the Upper CLA, which can lead to groundwater having high sulfate concentrations. Another source of sulfate could be stock grazing and pastoral activities. However, the groundwater is brackish and unsuitable for potable or stock water supply and unlikely to pose a risk to human health.

The mean baseline values for groundwater parameters that may be indicators of release of anthropogenic chemicals from onshore gas activities into groundwater are shown in Table 8-12.

Table 8-12. Mean baseline values for groundwater parameters relevant to potential release of chemicals into groundwater from onshore gas activities. TDS = total dissolved solids; EC = electrical conductivity. *Note that there are only very limited data for methane.

Aquifer ID	TDS (mg/L)	Chloride (mg/L)	EC (µS/cm)	Strontium (mg/L)	Barium (mg/L)	Methane (mg/L)*
Aquifer 1	2,074	537.4	1,916	1.3	0.05	0.019
Aquifer 2	1,290	293.1	1,455	0.77	0.1	0.029
Aquifer 3	1,916	312.6	1,371	0.95	0.09	-
Aquifer 4	584	86.3	780	0.19	0.4	1.48
Aquifer 5	499	125.1	1,456	0.59	0.1	3.72

8.3.3. Township water quality

Routine groundwater quality monitoring data collected from water supplies at relevant townships (Daly Waters, Elliott, Larrimah, Mataranka and Newcastle Waters) and Aboriginal communities (Jilkminggan and Marlinja) serviced by Power and Water have been sourced (Power and Water 2016; 2021). The most recent data were compared to Australian drinking water guidelines for health and aesthetic criteria (NHMRC & NRMMC 2011).

No township within the study area has water data that exceed Australian drinking water health guidelines, except for aesthetic guidelines. Hardness as $CaCO_3$ and chlorine (free) exceeded the criteria in all townships, while Daly Waters exceeded chloride, sodium, turbidity and total dissolved solids; Elliott and Larrimah exceeded total dissolved solids; and Jilkminggan exceeded chloride iron, manganese, sodium and total dissolved solids. Exceeding aesthetic guidelines is not seen as a risk to human health; rather an indication of water palatability for the community.

Local communities within the Beetaloo Sub-basin that have been identified as having no water quality data are Jomet (Urpalarwn), Lily Hole and Jingaloo. Other communities without water quality data that are outside of the Sub-basin but within the broader study area are Elliott North Camp, Elliott South Camp, Lija Mukumparla, Dillinya, Mulggan and Mataranka Town Camp.

8.3.4. Private entities

There are a variety of private entities in the study area likely undertaking potable and non-potable groundwater use, including some from sites with potential pre-existing contamination (hydrocarbon spills etc.):

- BP and The Elliott Store NT (3 Lewis Street, Elliott NT 0862)
- Shell (13729 Stuart Hwy, Dunmarra NT 0852)
- Pump Service Station (Corner Stuart Hwy and Carpentaria Hwy, Daly Waters 0852)
- BP (10-14 Rider Terrace, Mataranka NT 0852)
- United (13 Roper Terrace, Mataranka NT 0852)
- Daly Waters Pub Outback Servo (24 Stuart St, Daly Waters NT 0852)
- Daly Waters Aerodrome (Daly Waters NT 0852)
- Private Station owners (cattle grazing, horticultural enterprises).

There are currently no water quality data or registered contaminated land status for these sites, with the exception of some bores on pastoral stations.

8.3.5. Surface water quality

Surface water quality across the Beetaloo study area varies widely due to climate conditions, associated with significant rainfall during the wetter months of the year and minimal rainfall during drier periods. There are few historical surface water quality data within the study area, as summarised in the Baseline Report. From the combined river, creek and spring sample locations within the study area, a limited set of field parameters were used to help identify a baseline of water quality. The only field parameters that were available were those of dissolved oxygen, pH, electrical conductivity and turbidity. These data generally show neutral surface water pH, while spring water shows more alkaline pH. Salinity varies from fresh to brackish conditions; however, it is greatly reduced during the wet season due to rainfall.

No communities within the study area officially utilise surface water as a drinking water source. However, there is the potential for surface water to be used for agriculture and cultural uses by local communities. The following locations were identified as priorities for future water quality monitoring of nearby surface water:

- Aboriginal communities of Jingaloo, Marlinja, Lily Hole and Elliott near Newcastle Creek in the south of the Beetaloo Sub-basin.
- Aboriginal communities of Mulggan, Mataranka Town Camp and Jilkminggan near the Roper River, in the north of the Beetaloo sub-Basin.

8.3.6. Future water quality monitoring

Table 8-13 shows a set of analytes that should be considered as candidates for future surface and groundwater monitoring to detect contaminants that may affect human health. Analytes of particular interest for groundwater monitoring include total dissolved solids, chloride and electrical conductivity because drilling fluids, hydraulic fracturing fluids, well suspension fluids and produced formation fluids may have concentrations of chloride that are orders of magnitude higher than background values in potable waters. In addition, strontium and barium are typically elevated in water produced from unconventional shale gas reservoirs and serve, among others, as additional useful tracers.

Recommendations for future monitoring are to:

- include the communities of Jomet (Urpalarwn), Lily Hole and Jingaloo in water monitoring programs
- include the identified private entities in water monitoring programs
- expand the water quality monitoring bores in the basalt and Bukalara Sandstone aquifers
- increase the current analysis suite to include analytes recommended in the Australian Drinking Water Health and Aesthetic guidelines in water quality sampling and testing regimes
- develop formal sampling, analysis and quality plans for site-based investigations.

Table 8-13. Suggested analytes relevant to human health for future groundwater monitoring.

General	Anions	Cations and Metals		Petroleum	Phenols
Dissolved Oxygen	Chloride	Aluminium	Magnesium	Benzene	2-Chlorophenol
Electrical conductivity	Fluoride	Antimony	Manganese	Benzo[a]pyrene	2,4-Dichlorophenol
Gross Alpha	Hydrogen sulfide	Arsenic	Mercury	Dissolved Ethane	2,4,6-Trichlorophenol
Gross Beta	Nitrate	Barium	Molybdenum	Dissolved Methane	
Hardness as $CaCO_3$	Nitrite	Beryllium	Nickel	Dissolved Propane	
pH	Sulfate (as SO4)	Boron	Potassium	Ethylbenzene	
Total Dissolved Solids	Total Alkalinity	Cadmium	Selenium	Toluene	
Total Suspended Solids	Total Cyanide	Calcium	Silica	TRH (NEPM 2013 fractions)	
		Chromium	Silver	Xylenes	
		Cobalt	Sodium		
		Copper	Strontium		
		Iron	Uranium		
		Lanthanum	Vanadium		
		Lead	Zinc		
		Lithium			

8.4. Soil quality

The aim of the Environmental Health Soil Quality study was to provide a regional-scale understanding of the nature of the soil types within the Beetaloo Sub-basin. This would form the basis on which management and monitoring requirements for soil quality can be established to inform future development applications and decision-making in relation to onshore gas activities in the region. The soil study included:

- reviewing existing studies and relevant data within the Beetaloo Sub-basin
- assessing a range of data relevant to soil types and geology in the Beetaloo Sub-basin to develop geospatial datasets, including soil type distribution, dominant characteristics and interpretation of vulnerability to impact or adverse effects from onshore gas activities
- identifying the contaminants of potential concern that are associated with unconventional onshore gas operations and establishing the relative toxicity or potential for adverse human health effects to occur if these contaminants of potential concern were released into the soils of the Beetaloo Sub-basin, and the potential for their migration in the ground as a pathway to sensitive human health receptors.

8.4.1. Literature review

Various sources were reviewed to inform the site information and soil characterisation sections of this study. The main owners/custodians of the sources included:

- Northern Territory Government
- Department of Climate Change, Energy, the Environment and Water
- CSIRO
- Geoscience Australia (Bioregional Assessment Program)
- Australian Soil Resource Information System
- Australian Geological Survey Organisations Network portal.
- Bureau of Meteorology.

8.4.2. Soil types of the Beetaloo study area

There are a variety of soils across the Beetaloo study area and, following the Australian Soil Classification system, these can be broadly grouped into Orders. The soil types identified across the study area are described below, noting this is based on available soil mapping at a coarse scale (Figure 8-3).

- Kandosols are the most dominant soil type in the study area, covering approximately 60% of the area. Kandosols are found in the central-eastern part of the study area. They also occur throughout the northern and southern areas amongst the other minority soil types.
- Tenosols are present within the study area along the southern and northern boundaries, as well as locally on the eastern boundary.
- Vertosols are predominantly found in the floodplain and drainage areas in the study area. These occur most abundantly in the south, north and central parts of the study area.
- Rudosols are most abundant in the central and eastern parts of the study area, as well as minor occurrences on the western and southern boundaries. Rudosols are associated with current and previous watercourses.

- Hydrosols generally occur in lower slope positions where the drainage of the area is poor.
- Chromosols only occur on the north-western boundary of the study area. Yellow and grey chromosols are usually found in poorly drained areas with rainfall between 250 mm and 900 mm. Brown and red chromosols are usually found in well-drained areas with rainfall between 350 mm and 1,400 mm. These soils are generally restricted to small occurrences across colluvial and alluvial plains.
- Dermosols only occur in the middle of the western boundary of the study area, surrounded by chromosols. Yellow and grey dermosols are often typically found in poorly drained areas with rainfall between 550 mm and 1,350 mm and in well-drained areas with rainfall between 450 mm and 1,200 mm.
- Ferrosols are sparsely identified across the study area and only occur in small areas on the north-eastern and north-western borders of the study area.
- Calcarosols have been identified locally in the study area. The few locations are found in proximity to river channels.

Each soil type was characterised in terms of its composition and mineralogy; permeability and porosity; erosion potential; land salinisation potential; pH and acid sulfate soil risk; and physical characteristics. More detailed information on the characterisation of soil types is available in the Baseline Report.

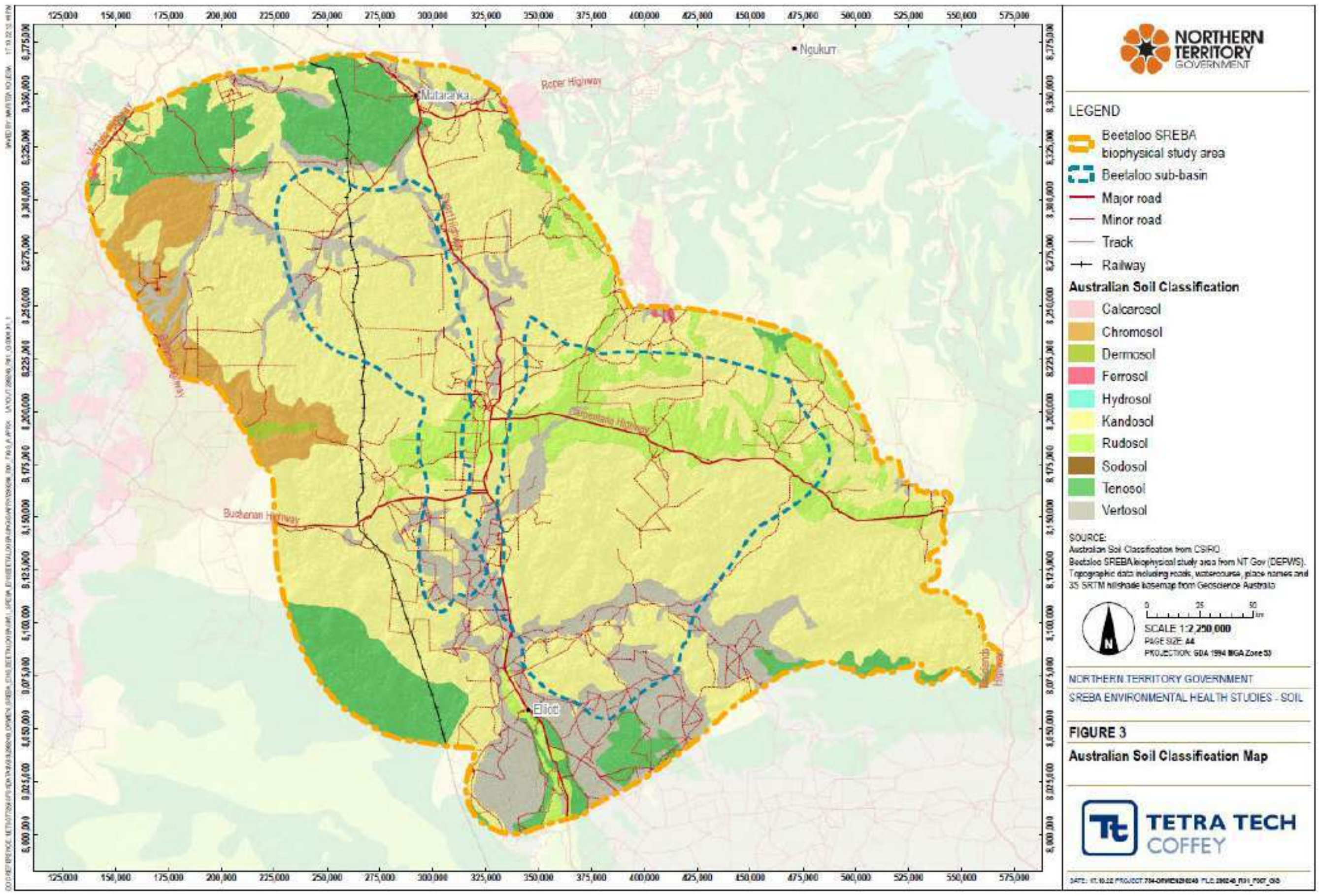

Figure 8-3. Soil types in the Beetaloo study area, following the Australian Soil Classification (Isbell 2021).

8.4.3. Soil type risk from onshore gas operations

Based on the soil characterisation information, risk ratings consisting of three categories of potential risk to soil from unconventional onshore gas operations were developed.

Group 1 – Risk from hydraulic fracturing contamination (permeability and water-holding capacity)

A soil's ability to allow fluids to migrate through it has significant bearing on the risk to the surrounding environment and potential receptors. If a chemical remains in effect at the point of release, its potential to contact receptors is reduced to the immediate vicinity of the release. However, if a soil readily allows chemicals to move, they will spread away from the point of release through varied transport mechanisms, allowing potential exposure over a greater area and to a potentially greater number of receptors. Therefore, if a soil has a high permeability and low water holding capacity, it presents a higher risk for the movement of a released chemical.

Group 2 – Physical risk from installation of infrastructure (erosion potential and clay content)

If a soil can be mechanically mobilised and has retained chemicals from operations, or contains naturally elevated levels of potential contaminants, infrastructure installation or operational use (drainage etc.) can increase the risk of exposure. Therefore, the potential for soils to erode (movement) and the particle sizes influence the risk of contamination and transport.

Group 3 – Retention of contamination risk (total organic carbon and cation exchange capacity)

Soils that retain organic and/or inorganic contaminants are able to reduce the extent of chemical migration and often reduce the potential for exposure at a location. A soil with a high total organic carbon and high cation exchange capacity will retain organic and inorganic chemicals and reduce the potential for exposure and movement.

The risk ratings were determined by applying a score for each soil characteristic in each group, and then combining the total scores of each group for an overall score. The overall scores were then assigned a risk level (Table 8-14). The minor soil type occurrences are omitted from the risk matrix due to their minor prevalence, noting that these soils had an overall risk of 'Medium' and are extremely unlikely to be encountered and affected. More details of the risk assessment are given in the Baseline Report.

These risk ratings can be spatially portrayed as a soil risk map for the study area (Figure 8-4).

Table 8-14. Overall risk rating for each soil type in the Beetaloo study area.

Risk Type	Kandosol	Tenosol	Vertosol	Rudosol	Chromosol
Group 1	High	Very High	Low	Medium	Low
Group 2	Medium	High	Medium	High	Medium
Group 3	Medium	Medium	Medium	Medium	Medium
OVERALL	High	Very High	Medium	High	Medium

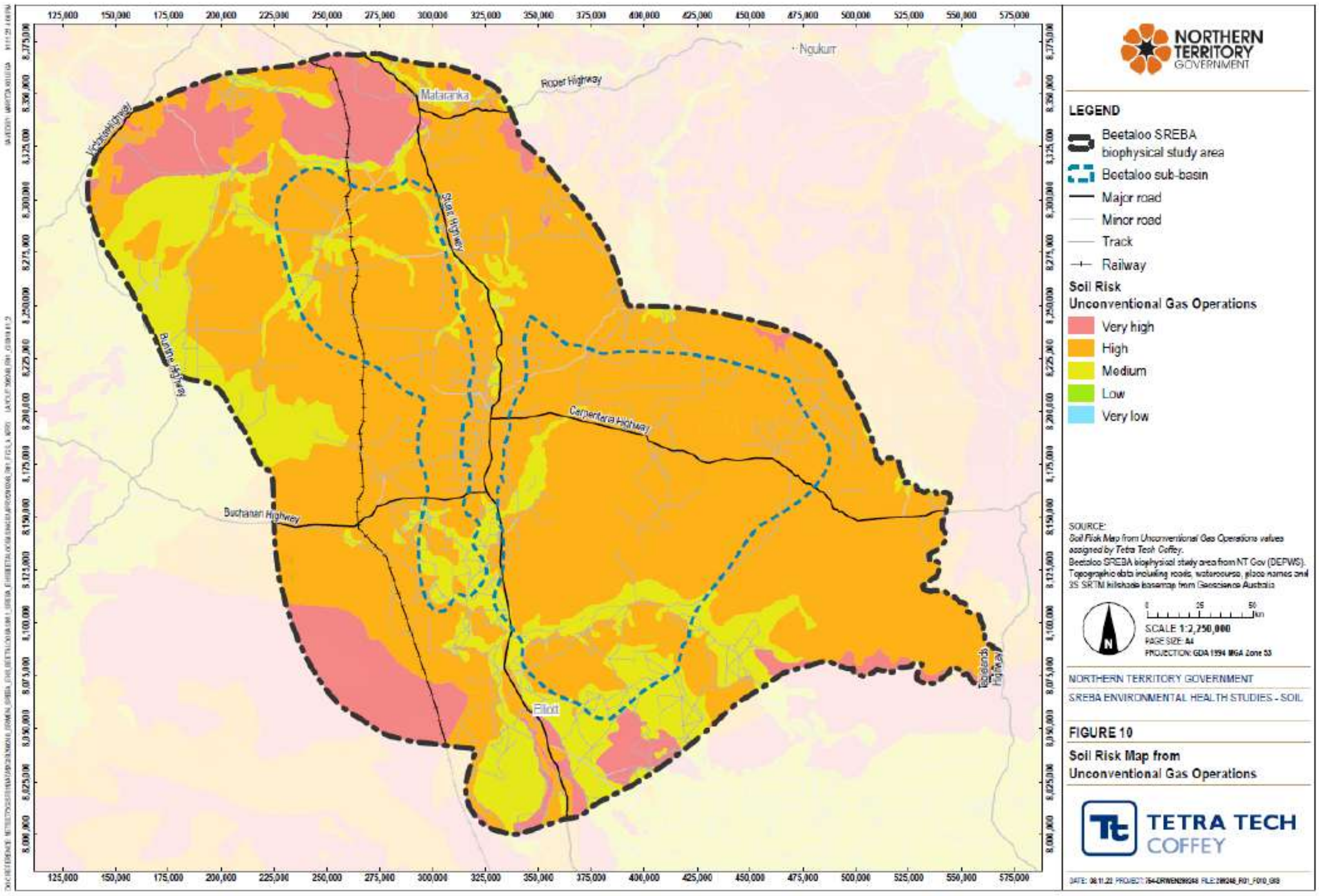

Figure 8-4. Soil risk map for onshore gas operations.

8.4.4. Conclusion

The soil study has established a solid basis to assess potential risks to soils from hydraulic fracturing operations within the Beetaloo Sub-basin. The existing datasets provide a substantial body of data that have been used to develop an outline of risk on a regional scale.

The study has also established five key data gaps within the current body of knowledge for the study area, and addressing these data gaps would enable refinement of the risk map. These are described further in the Baseline Report.

Based on the soil risk assessment process, a monitoring and management plan for soils was developed for each project phase: exploration, construction and commissioning, and production. The plan is designed to provide a guide for the site-specific management and monitoring of soils with the development of unconventional onshore gas operations in the Beetaloo area, and to assist in maintaining consistency across individual approvals and licensing processes. The Northern Territory Government has published various guidance materials to assist proponents in meeting their obligations for Environment Management Plans (EMPs) under the *Petroleum (Environment) Regulations 2016*, with the main publication being the *Code of Practice: Onshore Petroleum Activities in the Northern Territory* (2019). The latter addresses the management of environmental risks and environmental impacts associated with the conduct of regulated activities. The monitoring and management plan provided in the Baseline Report is relative to the soil risk levels that have been established in the report and purely focuses on soils. Therefore, the monitoring and management plan is to be used in conjunction with, and to complement, existing guidance and regulations in the Northern Territory.

8.5. References

8.5.1. Population health

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8.5.4. Soils

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9. Social, cultural and economic baseline studies

The University of Queensland (UQ) conducted the Social, Cultural and Economic (SCE) SREBA studies with a specialist team of experienced UQ researchers and (NT-based) local experts. The studies were undertaken in line with the approach set out in the SREBA Framework and the Scope of Works, and comprise a baseline assessment report identifying the social, cultural and economic characteristics of the region and a regional social assessment report that:

- identifies regional development aspirations and potential outcomes
- identifies and assesses the potential cumulative impacts of multiple projects over time
- describes a monitoring and evaluation program.

9.1. Research objectives

The SCE studies seek to understand the wellbeing of people and communities to provide a point-in-time snapshot, as a baseline of the social, cultural, and economic characteristics of the Beetaloo Sub-basin and as a starting point for ongoing monitoring.

Establishing the SCE baseline around identified themes requires both quantitative and qualitative data. Some SCE characteristics can be measured in numbers (quantitative), such as population and employment, but many others can only be assessed through asking questions and listening to people's stories (qualitative). Furthermore, the ongoing process of listening and understanding is necessary to ensure the validation and currency of the baseline is maintained through a participatory approach. Relevant information is needed to understand what is important to people in the region, their concerns and aspirations for the future, connections with each other and their environment, liveability, culture and wellbeing. The SCE baseline assessment can be an empowering process for communities facing any type of development. It can allow development to be better informed and therefore managed to protect values, build on existing strengths and address areas sensitive to development.

9.2. Background and approach

Northern Territorians have participated in several types of inquiries and public consultations on oil and gas development. A wide range of stakeholders have presented information, including the media and other public forums, as well as there being strong lobbying and advocacy from those both for and against the onshore gas industry. Many of the individuals and communities in the Beetaloo region have already experienced some type of impact from either the activities of the onshore gas industry to date, or the public debate surrounding it.

Many of the social, cultural and economic disruptions associated with COVID-19 are reflected in the data, including acute staff shortages, business income losses, supply chain interruptions, overcrowded housing, temporary cessation of cultural and community activities and events, declined school attendance, and a general feeling of uncertainty.

In consideration of the dynamic nature of communities, the SCE SREBA has drawn on longitudinal data wherever possible; the aim of this is to identify trends, interpret data and distinguish changes due to long-term trends from those associated with onshore gas activities.

The SREBA SCE study has generated five key community profiles for Elliott, Katherine, Borroloola, Tennant Creek and Mataranka, so change can be tracked in selected 'communities of interest'. This focus on communities does not overlook or dilute the perspectives of those who live and work on pastoral stations as these voices have been aggregated and are included in the studies.

9.3. Methods

The SCE studies took a mixed methods approach: using available existing quantitative data, and supplementing this with qualitative and quantitative data from the study region. Research methods included: interviews, surveys, street walks, observations, and conversations in public spaces where people were asked for words they felt described the community. A strong focus on a participatory approach to the studies was taken. This included the development of the Aboriginal Knowledge Protocol to ensure cooperative and trusted relationships could be formed between researchers and Aboriginal participants.

Given the research context, the study team employed locally known anthropologists to facilitate conversations, with a focus on respectful engagement at all times. The research team focused on being 'on country' as much as possible, within the limitations of working during COVID-19, and met with over 200 people and drove more than 7,000 km. Detailed descriptions of the development of the research approach and methods can be found in the SCE Scope of Work document.

9.4. Baseline assessment

9.4.1.1. Indicators

Indicators are measurements that provide information about past and current trends and assist government and community leaders in making decisions about future outcomes. They should reflect the characteristics of a community that are important to people, and their concerns and aspirations for future development.

Determining with representative organisations and groups the most relevant indicators that reflect the concerns of a wide range of interests proved difficult due to high uncertainty about how, and to what extent, onshore gas development may impact communities. UQ selected the preliminary indicators, based on prior knowledge, experience in studying the socioeconomic impacts of resource development elsewhere and data mapping conducted as part of developing the Scope of Works. They presented these indicators to representative organisations that have an interest in the Beetaloo region to ensure those indicators thought to most reflect the concerns of the wide range of interests were selected.

Noting that an agreed set of core indicators could not be resolved through this engagement process, indicators were chosen to gain the best coverage of the SCE themes, as identified in the SCE SREBA Framework. These themes are:

- living environment
- people and communities
- strong voice
- cultural identity
- healthy country
- local economies
- infrastructure and services.

9.4.2. Data – participants, collection and analysis

Desktop data mapping identified readily available data and where qualitative data collection was needed. Quantitative data were collected, noting different statistical boundaries and that, in some cases, only regional or local government area data are available. This highlighted the importance of 'ground-truthing' data. Qualitative data were also collected via a survey that UQ developed with subject matter experts concentrating on questions for social, economic and cultural themes.

Participants were recruited using several pragmatic and flexible approaches, initially through contact with representative organisations such as Land Councils and Aboriginal Corporations, industry organisations and networks, Aboriginal service providers and local government in addition to open consultations in public spaces. Interviews were held in Borroloola and surrounding outstations, Minyerri and surrounding outstations, Jilkminggan, Beswick, Burunga, Katherine and suburbs, Mataranka, Larrimah, Daly Waters, Dunmarra, Elliott, Newcastle Water, Marlinja and Tennant Creek with visits to pastoral stations where these could be arranged. Other pastoralists were contacted by phone and email.

The data collection methods sought to capture a reasonable cross-section of interests and perspectives, as well as to establish a balance in the ages and gender of participants. Nevertheless, the participants tended to be older people, perhaps as they were seen to have the experiential knowledge required to best answer questions about living in the region. The identification of Aboriginal participants was not limited to Native Title interest holders or Traditional Owners.

The boundaries for the data in the community profiles are made clear. Longitudinal data are presented with underlying trends, where possible to differentiate between existing trends and change that may be associated with future development. The qualitative data were captured in comprehensive field notes, which have been transcribed and analysed using thematic coding to identify common themes, as well as anomalies and emphasis.

9.4.3. Community profiles

Community profiles for five key communities — Katherine, Elliott, Borroloola, Tennant Creek and Mataranka — have been developed to show data for each indicator by theme. This includes insights on trends and interrelationships where possible, along with stories and survey results that illustrate the indicator meaning and measures. These have been reported back to participants through feedback workshops in the major centres, and through focus group discussions held in regional communities. The community profiles are presented in the SCE Studies Baseline Report.

9.4.4. Baseline assessment key findings

These findings, drawing on both quantitative and qualitative data, describe the regional context, including a summary of reported values, issues and concerns about development. They also provide an overview of the type of responses for each theme. More detail of the narrative behind each theme can be found in the SCE Studies Baseline Report.

9.4.5. Social study

Each community has different strengths and issues and they will respond to development differently. Pastoral stations operate as small communities in themselves, but each is unique and will also respond differently.

A general theme was the widespread lack of trust that government will be able to manage onshore gas development well given it is a highly influential and powerful industry. Others thought that while there may be good intent, regulating would take strong leadership and commitment to principles. There is a general feeling of not being adequately represented or heard, and the word “forgotten” was commonly used, especially in relation to federal level representation.

Across the region, there is a lack of activities for youth and older people. People wanted to see activities for youth that would engage them in physical challenges and healthy choices, and offer alternatives to drinking and drug use.

Mobility around communities is also inadequate for those with disability or mobility issues. Footpaths are uneven or non-existent, particularly in smaller communities (Borroloola and Marlinja, also Larrimah) impacting community members’ ability to participate fully across community activities.

Road conditions can be dangerous on minor roads but also with wandering stock and wildlife on major roads.

All communities within the study reported critical housing and skills shortages, with increasing costs of living, including the cost of fuel as a growing concern. Fragmented responsibility for services causes confusion and perceived overlap and inefficiencies.

Low connectivity was raised as a challenge, noting internet is by satellite and is slow and expensive. Phone coverage is poor outside of towns and some communities only have 3G phone coverage (Marlinja).

Disengaged youth is seen as an increasing social problem that was considered to be linked with increasing crime and violence. Alcohol and substance misuse is also thought to be an increasing social issue, mostly among the Aboriginal population.

9.4.6. Economic study

The economic theme describes the local economies, jobs and employment, incomes, business and investment.

Participation in the workforce is lower across the region (ranging from 27% in Elliott and Borroloola to 63% in Katherine, which is the same as the participation rate for the whole of the Northern Territory) than the Australian participation rate (67%).

Across the communities generally, men and women are equally likely to be employed or not in the labour force. Aboriginal people are much more likely not to be in the workforce than non-Aboriginal people.

The largest employing sectors in the region are governments (public administration and safety), health care and social assistance, and education and training.

In the interviews, people said they would like to see more local job opportunities, particularly for young people, but that they would like meaningful jobs. It was explained how the processes of finding and contracting employment, managing payments and taxes, and timetabling working hours and transport to work can be onerous for Aboriginal people in remote communities, often exacerbated by a lack of access to a computer or internet. Therefore, there is little motivation to go through this processes for work that is “meaningless”, or through which little satisfaction is derived.

Given the complexities and obstacles that hinder the opportunities to study and work in meaningful employment across all communities, it was suggested repeatedly that there needs to be better support for people wishing to make the transition into the workforce.

In terms of the types of roles of interest, responses from interviews included roles that involve caring for people and country such as ranger positions, child care, aged care, and health care. Also mentioned were jobs in preserving Aboriginal culture, such as documenting languages, stories, songs and dances, and passing cultural knowledge on to younger generations. There were also aspirations for jobs in environmental science, and particularly in environmental and water monitoring.

In terms of income, the data show clear evidence of an increasing economic divide, with increasing numbers of people earning “good money” (mostly non-Aboriginal people) and, at the same time, increasing numbers of people living in poverty (mostly Aboriginal people).

This is likely to be further emphasised with increasing costs of living across the region, with almost everyone feeling that food was expensive to buy and that prices for basic goods in remote communities are higher again. Store operators, both community-owned and private businesses, explained that increasing freight costs are the main driver of higher retail prices.

Economic activity across the region was said to be slowed due to COVID-19 impacts but a “bumper” tourism season was experienced in 2022. Many businesses reported “struggling” to keep up with demand and were not able to capture the full economic benefits of higher visitor numbers due to a lack of staff (could not extend either hours or services), being unable to procure goods and services (waiting on spare parts, empty shelves etc.), and increasing costs of operation.

Housing/accommodation shortages were said to have been a significant limitation on businesses' abilities to attract staff to the region.

9.4.7. Cultural study

The themes in the cultural study looked specifically at Aboriginal culture in the region although in full recognition that there is overlap and some themes that apply also to non-Aboriginal residents, particularly around land and environmental management and sustainability. Many of these themes also overlap with the biophysical SREBA baseline studies. The information presented is mainly based on interviews and meetings as there is lack of quantitative data for many of the indicators.

Aboriginal culture and the environment (including plants, trees, all animals, water, weather, seasons and climate) are inextricably linked. Any effect on one will always mean an effect on the other.

Culture is still strong in some ways but there is a general view that it is weakening, due to the people removed from pastoral stations in the 1960s now having deceased. Not as many ceremonies are taking place as in the past and, as people move away from the area for different reasons, holding ceremonies becomes more difficult. There is a desire for more support to continue cultural practices as these contribute to the health and wellbeing of the community.

9.5. Strategic regional assessment

The strategic regional assessment was developed by comparing and contrasting all the data (both quantitative and qualitative) across the community profiles to identify commonalities and differences, and also trends and issues to inform a ‘big picture’ understanding of the region. The main findings from the baseline assessment were presented back to key representative organisations, and participants' responses regarding concerns and aspirations for development were analysed for main themes.

This study is a collation of SCE data and insights for the purpose of better informing decisions about future development in the region. It is intended to provide a strategic overview of existing issues and concerns but, also importantly, the values of people in the region that need to be protected. It provides a concise summary of the richness and diversity of the conversations held in undertaking this study, noting that there is much more capacity for place-based, community-led innovation to be explored.

This section discusses the most prominent themes from the combined analysis of all data sources. Highlighted are residents' own aspirations for development, including key values and concerns, as well the identification of the potential cumulative impacts on the region.

9.5.1. Social themes

9.5.1.1. Trajectories of change and community-led development

Across the region, there were mixed views about whether people thought their local community was unchanged, or had changed for the better or worse. Positive change was attributed to new housing and community infrastructure, and housing and store upgrades. Negative change was attributed to alcohol, violence, drugs, crime, reputation, a lack of jobs and the cost of living.

While most communities had some form of community discussions about current and preferred trajectories of change, whether outcomes would be achieved was questioned. There was a strong feeling that development of the region should involve the local communities and that planning for development should be a community-led process.

9.5.1.2. Low appetite and limitations for growth

People were mostly happy with the current population and size of communities. They were not against growth opportunities but, with the exception of Daly Waters and Larrimah, thought their community was not prepared for population growth, mainly due to housing availability.

Communities that are not ready for rapid population growth would need to be managed carefully, with significant upfront investment in housing, waste management, water and power infrastructure and communications to cater for population growth in the region.

9.5.1.3. Population mobility and immobility

While there is a proportion of the population that is highly mobile, there is also a core, stable population with a strong sense of place that is highly committed to the region and will choose to stay, even if changes that upset them occur. Immobility can increase vulnerability when people are not able to move to avoid being negatively affected.

Existing seasonal population fluctuations, high workforce turnover in some sectors, and short-term public sector contracts do not necessarily mean the region can support an additional influx of non-resident and temporary workers. The core, stable population is vulnerable to any negative social or environmental impacts, particularly pastoralists and the communities of Elliott and Borroloola, as they feel they carry the burden and responsibility for risk.

9.5.1.4. Low trust environment

Onshore gas development is taking place in a very low trust environment. People felt government and industry objectives were too closely aligned for regulation to be effective and that communities are not 'heard'. To build trust, regulation and ongoing monitoring will need to have built-in mechanisms for independence and accountability, with consideration to independent oversight and strict processes for accountability, Aboriginal ranger groups supporting monitoring, improved communication and engagement that empowers communities.

9.5.1.5. Skills and training

Education levels across the region are comparatively low, providing implications for local job opportunities. Women are more educated than men, and girls are more likely to complete school to year 12 than boys.

Strategically, local opportunities for employment should recognise this and not be limited to unskilled labourer or trades jobs, which are traditionally taken up by men. To capture the economic benefits of a new local industry, additional training is needed to provide "bridging" programs. There should also be consideration of alternative pathways to employment for those without the education requirements.

Critical skills gaps that could be filled by local people were identified, including in aged and child care, Aboriginal health workers, hairdressers, mechanics and other trades. In building skills to meet the needs of onshore gas development, training for a range of enabling occupations needs to be provided, particularly aged and child care.

9.5.2. Economic themes

9.5.2.1. Inequity in opportunities

There are clear differences in education levels, average incomes and labour force participation between Aboriginal and non-Aboriginal residents in the region. This inequity in people's abilities to capture or leverage economic opportunities that might be created by development should be considered in planning. Initiating deliberative mechanisms that enable community-led economic development and that identify new types of economic opportunities for Aboriginal people and culture could boost Aboriginal participation.

People mostly reported having enough money, although the data show an increasing number of people in the region below the Australian poverty line and increasing pressure as a result of rising costs of goods and services. Many cannot afford any further increases or inflated costs of living associated with increased demand for goods and services for a developing industry.

9.5.2.2. Co-existence with other industries

Due to the effects of COVID-19 travel restrictions on the tourism sector and consecutive dry years on the pastoral industry, the baseline figures for these industries may not reflect the true value of their economic contributions to the region. These industries contribute to the social identity of the region. Pastoral stations and roadhouses are considered an integral part of the history, character, lifestyle and experience of the Beetaloo region. It is expected any new industry would not dramatically change the character of the region, and would not detract from or threaten existing industries but would instead complement and add to the character in new and positive ways.

9.5.2.3. Local business resilience

There is a high turnover of businesses in the region. The impacts of losing a business are possibly greater in the smaller communities, and cause greater inconvenience if people have to travel to access the service and potentially remove a former communal gathering point.

There was an expectation that new industry development would create opportunities for new businesses and also sustain or enhance existing businesses. Given high business turnover and fatigue among some existing business owners, a cross-industry Beetaloo regional economic development and regional advocacy group should be considered as a coordinated approach to providing additional support (such as business growth coaching and mentoring).

9.5.3. Cultural themes

Aboriginal culture in the region is still strong and diverse. General cultural awareness training for people coming to the region for work in any type of industry or to conduct studies could help visitors to develop a greater appreciation of Aboriginal culture and cultural landscapes and a heightened sensitivity of how their own actions and behaviours while in region may impact Aboriginal people.

Cultural awareness training was also thought to improve the relationships between contractors, service and care providers and those wishing to do business in Aboriginal communities. Provision of this training could also create business opportunities for local Aboriginal people and contribute to economic self-sufficiency.

A strategic perspective of sustainable development in the region should consider the opportunities that an onshore gas industry can bring to help local Aboriginal people in their efforts to preserve and maintain cultural integrity and connection, and consult with Aboriginal leaders on how it can minimise any further pressures it might place on the transmission of culture.

9.5.4. Regional development aspirations

The main themes regarding residents' aspirations for development and their views on the potential benefits of the proposed development of gas and other sectors of in the region are:

- safe and sustainable development
- coordinated development
- strong communities
- strong connection to land.

9.5.4.1. Safe and sustainable development

People in the Beetaloo know the region is rich in resources and opportunities. They are generally welcoming of well-managed development that can co-exist with existing industries and does not compromise the natural environment or Aboriginal culture. However, respondents were adamant that development cannot compromise life-sustaining water resources.

There was a general consensus that projects should be legitimate and worthy. That is, they should be able to demonstrate there is a need for the project and that projects contribute to the public good. Development should not compromise the ability of future generations to live and prosper in the region or the Northern Territory and Australia more broadly.

9.5.4.2. Coordinated development

Residents of the study region thought that development should consider the full lifecycle of projects and should leave a positive legacy for local communities and businesses on exit. This requires early planning and adaptive management as projects come online. Coordinated management will require the participation of a range of stakeholders and a willingness to collaborate with neighbouring and sometimes competing businesses. At the moment, there is no collective or collaborative forum for potential long-term planning to achieve these goals.

9.5.4.3. Strong communities

A priority for the region is to maximise local opportunities from development by increasing the local skills base, especially in transferable skills that can be employed across industries. People are also hopeful for business development opportunities that serve local communities (e.g. for businesses like cultural training and tourism, contracting/procurement opportunities with industry, support for existing sectors). There is an aspiration among Aboriginal communities for services such as housing, health, supermarket, water supply and waste management to be community-led.

It is hoped that development will help communities transition to become more sustainable economic centres that can offer a diversity of meaningful employment options. People would like:

- information on current projects and what opportunities are on offer
- pathway programs that help young people participate more in community, culture and the economy
- more opportunities for women to participate
- support for language and culture
- community infrastructure.

Coordination among companies and projects is needed in relation to social impact management plans and ensuring these meet community expectations.

9.5.4.4. Strong connection to land

Aboriginal people seek opportunities to preserve and strengthen culture by being on country, learning about country, and protecting and caring for country. New access roads should mean greater accessibility for Traditional Owners and their families to be on country and development should increase opportunities for Aboriginal people to be on country.

Pastoralists also have strong connections to land and will make social and economic sacrifices to remain living and working in the Beetaloo region. For them to remain on the land, to continue managing land and resources, and contributing to the economy, they must remain economically viable.

Hunting and fishing is a strong part of the culture in the Beetaloo region for both Aboriginal and non-Aboriginal people. Development should occur in a way that people are still able to go hunting and fishing safely and successfully, and to consume their catch without fear of contamination. For Aboriginal people, hunting supplements household costs of living, and procuring and consuming traditional foods keeps Aboriginal people physically, mentally and culturally healthy.

9.6. Cumulative impact

Project factors (such as the number of projects, speed of development, timeframes and physical location) and broad exogenous forces (such as changes in commodity prices, exchange and interest rates) will influence the nature and scale of impacts.

Cumulative social impacts are associated with changes in population. For example, immigration is due to work or business opportunities, short-term contract workforces, temporary workers, or project consultants. Communities may be indirectly impacted by projects due to increases in the number of people travelling through the community.

Cumulative impacts of development in the study region have been considered in the context of the common community-level cumulative impacts identified in Blakely and Franks (2021):

- social disruption, displacement
- loss of social capital, cohesion
- cultural erosion, language loss
- heritage loss
- inequality (income, gender, etc.)
- disease and health impacts.

9.6.1. Social

Potential cumulative effects were identified from the combination of what was shared in interviews, trends in the indicator data and the literature on social and cumulative impacts of resource development and are summarised below.

- Consultation fatigue and costs of engaging.
- Migration in and out increasing homelessness and costs of living, people receiving royalties leaving and new people coming impacting culture and community safety.
- Social cohesion changes, such as increased inequality and tension due to recognition and rights and different views on development, new people impacting cultural practices and community-led responses, damaged relationships between pastoralists and local people, and collaborative governance mechanisms and multi-stakeholder cooperation fostering shared understanding, effective relationships and social networks.
- Increased traffic and new roads causing disturbance to plants and animals, increased access deteriorating culturally important places, more accidents and road trauma, road deterioration and costs, and longer travel times.
- Increased population, noise and traffic, cultural diversity in the region impacting Aboriginal culture and practices and song lines or repercussions from ancestor spirit disturbances.
- Increased health and mental health issues, and social stress, improved safety awareness and culture in industries across the region, improved road safety outcomes if roads are upgraded.
- Loss of access to areas.
- The pace of development putting pressure on services and infrastructure and an increased lack of trust if social and environmental impacts are not managed well.
- Increased public investment in the region, and increased pressure on existing infrastructure and services.

9.6.2. Economic

- Already high staff and skills shortages increased due to ‘poaching’ of staff, and pushing up wages for local business.
- Increased costs for local businesses and residents, due to competition for goods and services and cost of living increases.
- Greater investment in the region leading to better health, education, housing and roads, due to increased income for the Northern Territory from exports, taxes and royalties.
- Potential for ‘boom and bust’ in property values and development uncertainty affecting property values.
- The rollout of gas infrastructure resulting in incremental loss of land for pastoral activities.
- Increased tourism/visitors putting strain on community infrastructure and services and disturbing Aboriginal cultural places.

9.6.3. (Socio-)Environmental

- Water concerns including bore users impacted by ‘draw down’ on aquifers, quality of domestic water supply deteriorating, and loss of water in the landscape for stock, wildlife, and social and cultural activities.

- Loss of the 'natural' identity of the landscapes and the sense of autonomy, freedom and peace due to increased traffic and onshore gas activities.
- Habitat disturbance and destruction.
- Long-term effects on stygofauna.
- Introduction of new pests and weeds and the spread of existing weeds.
- Communities need time and coordinated efforts to build local capacity and skills, services and infrastructure to cope with any additional pressures due to increased visitation.

9.6.4. Thresholds of acceptance

Water and scared sites protection, biosecurity, and human rights are 'non-negotiables' to the residents of the Beetaloo Sub-basin. Negative impacts on these are considered unacceptable costs that cannot be outweighed by the potential benefits of the proposed projects.

9.6.4.1. Water

Water is a consistent and major concern for all stakeholder groups of the Beetaloo region, and intersects with a wide range of issues, including: domestic supply and quality; industrial use; contamination; water allocations; water and food sources; fishing; flora and fauna needs; and sacred sites protection.

9.6.4.2. Sacred sites

Any disruption to sacred sites, whether intentional or not, would not be acceptable. The incident at the Juukan Gorge caves in Western Australia has highlighted for many that sacred and significant sites can be destroyed where there are not clear lines of communication and accountability.

9.6.4.3. Biosecurity

Biosecurity concerns are in regards to the introduction of pests and weeds to the region impacting on economic activity (pastoralism and tourism) and culture (hunting, foraging).

9.6.4.4. Human rights

Interpretations of human rights are being constantly expanded. In October 2021, the United Nations Human Rights Council formally recognised the human right to a clean, healthy and sustainable environment. The UN Commissioner said the recognition was deserved as "environmental degradation and climate change are interconnected human rights crises". She went on to say that: "Bold action is now required to ensure this resolution…serves as a springboard to push for transformative economic, social and environmental policies that will protect people and nature".

The people in the region would welcome these types of transformative policies, as recognition and protection of the interconnectedness of people and nature was a significant theme.

9.6.5. Social, cultural and economic studies recommendations

This section outlines recommendations for future consideration based on the most prominent themes in relation to the future development of the region. These recommendations are directly linked to findings that describe residents' aspirations for development, including key values and concerns, and the potential cumulative impacts on the region.

1. The process of engagement for the SCE study has been highly participatory and represents just the starting point for important and ongoing conversations. It is critical to continue engagement between planners, service providers, policy makers and communities so that these types of conversations can be continued and stakeholders can voice their aspirations and concerns and ask questions about future development scenarios.
2. A coordinated information program that is independent of industry and government and that provides "factual, neutral" information about the onshore gas industry to stakeholders is needed. One such program is already in place and being delivered by CSIRO. Further recommendations specifically related to this or other information programs include:
   - It is important not only to seek to provide information, but to "listen" to people and understand the type of information that they need in order to be adequately informed and empowered to be able to participate in future development opportunities.
   - Information should not focus only on onshore gas development but include other proposed types of developments to provide local residents with an overview or "big picture" understanding of what development scenarios might look. This could include, for example, which projects are proposed, what stage of approval they are at, how firm they are, etc.
3. Mechanisms for building regional collaborations for community and economic development are explored so that the distribution of benefits from development can be more equitably shared across the communities and the region and so that capacity is built regardless of development type.
4. Further research be conducted into understanding the drivers of trust so they can be enhanced and adequately incorporated into future policy and regulation as well as into ongoing monitoring. This will likely require specific social science capabilities.
5. Further investigations and conversations be held with the relevant organisations including the Northern and Central Land Councils, Aboriginal organisations and pastoralist groups to explore options for how such a program could be established, funded, managed and sustained.
6. Consideration be given to exploringe whether there is a widespread appetite for an Independent Regulator and, if so, whether a new role needs to be established or whether the role fits into existing structures (keeping in mind proposed changes to the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*).
7. Data be collated to calculate the estimated and projected number of non-resident workers in communities, and reported at community and district scales, similar to the Queensland Government's Surat Basin population reports (Queensland Government 2022). Community-level data should also be collected for key indicators proposed in the ongoing monitoring plan.
8. Mechanisms for establishing a pooled trust or foundation to which multiple projects contribute should be explored.Consideration should include where and under what institution the funds would be held, and the administration of, and processes for, determining the allocation of those funds. One example of this is the Gladstone Foundation, although there are lessons from this experience that should not be repeated.
9. Local communities are supported to develop cultural awareness training and 'welcome' packages for those wishing to do business with local Aboriginal businesses or spend time in Aboriginal communities. These would be available to all kinds of workers including tradespeople, health and service providers so they understand and respect the ways of the community.

10. Capacity development needs are explored further so that communities and the region are better prepared for the onshore gas industry. This to avoid some of the 'timing' effects known in cumulative socio-economic impacts, where the pace of development is faster than communities are able to keep up.
11. Review and assess the current programs to transition to the workforce and create a readily accessible referral portal or a 'one stop shop' for services and, if needed, to explore options for establishing pathway programs, perhaps similar to the 'MyPathway' model (https://mypathway.com.au/).

9.7. Regional monitoring framework

Understanding community concerns about onshore gas development is fundamental to the design of an ongoing monitoring framework. Community concerns identified in the baseline study are likely to change over time as projects become surer and information regarding them more specific. Therefore, the monitoring framework is an ongoing learning journey, rather than a destination.

To generate trust and acceptance in the findings of future monitoring of the baselines, developing the monitoring framework should include the following:

- an independent committee for oversight
- demonstrable value of independence and trusted persons
- testing industry data against independent measures for reliability or peer-reviewing by a stakeholder-nominated reviewer, until trust with industry is built
- transparent and publicly accessible data
- consideration of context when evaluating data
- a long-term perspective, especially where the science and risks are uncertain
- the use of existing knowledge, especially local knowledge
- being clearly communicated
- empowering stakeholders through clear processes to raise concerns, and move towards targets
- involving the local community
- recognition of system dynamics, including that the baseline is not from an unaffected community.

Important questions to be considered in the design of a monitoring framework are listed below.

- Who determines thresholds of acceptance?
- Will there be 'trigger points" that trigger action or at least caution to proceed?
- What will be the process if risks or concerns are found? How will this be communicated?
- How will the effects from onshore gas development be separated out from other drivers of change?
- How can other industries, government agencies/NGOs be involved?
- Who will fund monitoring programs? If industry, will that lead to compromises or conflicts? How will independence be demonstrated and safeguarded?

9.7.1. Governance

The monitoring program should not only deliver reliable and valid findings but should be considered independent and trusted by the community.

An oversight or steering committee, made up of trusted senior figures from government, industries, research and interest groups, could be established to safeguard the integrity of the processes used and ensure a neutral and balanced approach to monitoring, evaluation and communication of data.

Consultative committees — including a representative community advisory panel, Aboriginal leaders advisory committee (both male and female), and subject matter or technical focus groups — could be established as responsive points of advice should issues arise.

A multi-stakeholder organisation for collective approaches to regional monitoring has successful precedents in Canada. There, such organisations are funded through cross-industry membership of companies operating in the region and government agencies and draw on local knowledge and participation.

9.7.2. Participatory monitoring for social learning and community resilience

In the SREBA context, full environmental and social monitoring must suit the needs of multiple stakeholders, including government for regulation, approvals and policy; industry for performance evaluation and compliance; interest groups for accountability and transparency; as well as communities for their own planning and strategies.

While the baselines and strategic assessment have identified what is important to people, there needs to be further engagement, potentially through the proposed consultative committees. These would focus on what is important to monitor and how to set the objectives for communities in how they see themselves building resilience and responding to the opportunities and impacts of onshore gas development into the future.

9.7.3. What to monitor

Monitoring should focus on what is important. The baseline and strategic assessments identified the four main themes that reflect widely held aspirations for the future and community values:

- safe and sustainable (and coordinated) development
- strong communities
- maintaining and enhancing connection to land and culture
- informed and fair local participation.

These themes could form the pillars of an ongoing monitoring framework with a set of indicators for each. Indicators must:

- measure factors that are valued
- be designed and understood by those who will use them
- stand up to expert critique
- have trusted measures
- capture manageable properties that link to potential actions
- act as ‘boundary objects’ that are the starting point for actions and strategies.

The set of indicators for an ongoing monitoring program needs to be refined from the baseline assessment. It is recommended that this takes places in the form of workshops and meetings with key informants and the proposed multi-stakeholder representative organisations.

A full list of indicators for which data were collected in the baseline assessment is included in the SCE Baseline Report.

9.7.4. How to monitor

Monitoring will use updated publicly available data, government- and industry-supplied data, and surveys and interview data. Monitoring needs to be time- and cost-efficient and not create an unreasonable burden on local residents, noting already widely expressed 'consultation fatigue'. The following steps are recommended.

Step 1: Annual update of all publicly available baseline data in community profiles.

Step 2: Search for comparable data where annual updates are not available. In some cases, new data will need to be generated. The estimated number of non-resident workers in the region and future projections can be calculated using workforce and accommodation data collected from industry sources.

Step 3: Convene annual meetings of the advisory committees and/or hold interviews with committee members to 'ground-truth' the quantitative data, discuss trends in the community profiles, and conduct a survey for indicators where data are not available. The survey instruments for culture and socio-economic themes that were used in the Baseline Report are a good starting point for qualitative data collection, but will need refining.

Step 4: A shortened online survey can be developed for general circulation at periodic intervals. Local, trained and retained 'data stewards' could facilitate this in communities and outstations. Data stewards could also be responsible for uploading information about communities relevant to the indicators. Community sentiment and key indicators could be collected every two years, and every 6-12 months in selected communities and amongst pastoralists. Data stewards could be part of an Aboriginal ranger program for broader environmental monitoring.

9.7.5. Aboriginal rangers and citizen science

It is recommended that a regional ranger group be established to assist with and undertake social, cultural and environmental monitoring for the Beetaloo region. This group would represent several language groups with interests in the region. Funding arrangements must ensure independence.

Pastoralists may also choose to support environmental monitoring on their properties, particularly if this could be an additional source of income or if the training and skills provided helps them attract and retain quality staff.

9.7.6. Evaluation

There is more work to be done on identifying targets, or at least desired trajectories of change for the social, cultural and economic components. This could be remit for the oversight and advisory committees. There is also more work to be done on defining thresholds of acceptance, what changes in monitoring data would trigger a response, and what the processes for collaborative responses to cumulative effects could be.

The monitoring and evaluation system in its entirety should be subject to review every 5 years. This would ensure that methods are up-to-date and indicators are relevant as the industry matures, and that community resilience and engagement grows as other projects come into play.

9.8. References

Blakely JAE and Franks DM (eds) (2021). *Handbook of cumulative impact assessment*. Edward Elgar Publishing. Cheltenham, UK.

Queensland Government (2022). Surat Basin population report, 2022. Queensland Government Statistician's Office, Queensland Treasury, Brisbane. Available at https://www.qgso.qld.gov.au/statistics/theme/population/non-resident-population-queensland-resource-regions/surat-basin [accessed 14 November 2022].

10. Synthesis – key findings and important values

Sections 4 to 9 of this report describe the results and findings of the baseline studies in the six domains of the SREBA. This section highlights the key findings from those studies and considers where there are common emergent themes from multiple domains. This leads to a synthesis of important values of the Beetaloo region and identification of areas with particularly high values. These are discussed in the context of potential risks from onshore gas development and mechanisms to mitigate risks and protect these values.

10.1. Key findings

10.1.1. Water

There is now a very large body of data and research findings relating to water resources in the Beetaloo Region and in particular to the groundwater resources in the Cambrian Limestone Aquifer (CLA). Scientific understanding has increased greatly in the past decade and since the Inquiry, partly due to the SREBA but also through the GBA program, GISERA and other research projects. While deeper aquifers are less well known, this is not a barrier to sustainable water allocation as they are likely to be used only by the gas industry, and to a limited extent.

A sound conceptual understanding of the geology and hydrostratigraphy of the sub-Basin has been developed, and this is very important for minimising any risks from hydraulic fracturing. The CLA is generally isolated from deeper aquifers by extensive aquitards (basalts and the Cox Formation), but there are restricted areas where it is potentially in contact with deeper aquifers. There are few areas where there is potential for active connection between deep (gas-bearing) and shallow formations, but one area (Hot Springs Valley, which is not part of the CLA) has been identified where faulting may provide a connection between the Beetaloo Sub-basin to the surface.

The CLA is also generally overlain by a thick (50+ m) layer of Cretaceous sediment, but outcrops or comes close to the surface around the Roper and Flora River discharge zones.

While there is vertical structuring within the CLA, a precautionary approach is to assume a high degree of connectivity throughout the CLA and its sub-units. However, two primary regional groundwater flow systems within the CLA overlying the Beetaloo Sub-basin have been identified; these are separated by the Birdum Fault and discharge into the Roper and Flora River discharge zones. This understanding, in addition to variations in climate and recharge rates, form the basis for delineating boundaries of water allocation plans relating to the groundwater resources.

Groundwater levels have been measured in bores across the water study area and the groundwater height, and depth to groundwater, mapped. The regional groundwater level is deep below the surface over most of the Beetaloo Sub-basin (up to >100 m below ground level), but becomes shallow close to the northern discharge areas (Roper and Flora rivers), on the margins of the Cambrian basins where there is outcropping CLA, and beneath some of the large ephemeral surface water bodies to the south of the Beetaloo region such as Lake Woods and the Barkly lakes.

Groundwater velocities have been modelled and are low (<0.1 m/year) across most of the CLA and all of the Beetaloo Sub-basin. Even considering limitations in this modelling is unlikely that groundwater flow velocities exceed 1 m/year over the Beetaloo Sub-basin because the hydraulic gradients are not sufficient to drive greater velocities. Higher groundwater velocities (>10 m/year) occur very close to groundwater discharge areas.

Groundwater monitoring bores in the region show three common groundwater level fluctuation patterns. A seasonal recharge response occurs in the northern part of the study area (Daly Basin), mostly beyond the northern extent of the Beetaloo Sub-basin. Episodic trends, with limited groundwater level variation across multiple years until there is a wet season with sufficiently intense rainfall to induce recharge, occur in areas of relatively thin Cretaceous sediments and where point sources of recharge (e.g. sinkholes) are abundant, and at the northern margin of the Arid Zone climate zone. Gradual storage change trends are characterised by slow groundwater level fluctuations that occur over years to decades, and this is the most common trend across the Beetaloo Sub-basin where there is limited seasonal recharge or point sources of recharge. The longest groundwater level records in the region — spanning approximately 20 years — show a prolonged period of increasing groundwater levels, indicating some degree of slow diffuse recharge.

Recharge into the CLA in the northern part of the region occurs primarily through direct recharge where Cretaceous sediments are thin (less than 30 m) and where the Lower CLA outcrops near the surface, and is likely aided by numerous karstic sinkholes. The dominant form of recharge in the southern area of the CLA occurs where surface water channels into pseudo-karst, ephemeral drainage lines (such as Western Creek, Newcastle Creek) and lakes (such as Lake Woods and Barkly lakes), particularly where surface water persists in drainage terminus features. Mountain-front recharge also occurs along the flanks of the Ashburton Ranges.

Estimates of recharge for the region have been obtained from four methods, the most quantitatively accurate (and most conservative) using the Daly Roper (DR2 2020) model. This model is constructed specifically for the region, supported by the most current conceptualisation of the entire connected water resource, and calibrated to observed groundwater levels and river discharges. This provides estimates of annual average and median wet season recharge for the four water allocation planning management areas relevant to the SREBA area. The northern (Tindall Limestone) areas receive substantial and regular seasonal recharge.

The CLA overlying the Beetaloo Sub-basin has two main discharge areas at the Flora River and Roper River, near the communities of Djarrung and Mataranka. At these locations, the Lower CLA outcrops at or close to the surface and discharge occurs through springs (e.g. Bitter Springs, Rainbow Spring and Fig Tree Spring), in diffuse discharge along riverbeds (e.g. Elsey Creek, Roper River) and by evapotranspiration, including through groundwater-dependent vegetation.

Environmental tracer studies support the assumption that groundwater discharge at the Roper River discharge area is overwhelmingly derived from the CLA. Multiple lines of evidence indicate that groundwater discharge at the Roper River is mostly sourced from groundwater originating relatively close to the river. Groundwater originating from deeper formations or from areas of the CLA flowpath further to the south (overlying the Beetaloo Sub-basin) are likely only a very minor portion of the total discharge at the Roper River. Mechanisms at the Flora River discharge area are mostly the same as at the Roper River.

There are some other springs around the margin of the study area at which groundwater discharge occurs, but not all of these springs are sourced from the CLA. Notably, the series of springs in Hot Springs Valley on Tanumbirini Station are likely sourced from deeper Mesoproterozoic formations. Springs and groundwater discharge areas also occur around the locality of Top Springs to the west of the Beetaloo Sub-basin; these appear to be sourced from a localised flow system that captures recharge within the nearby catchment area or from shallow perched aquifers that are separate from the regional CLA.

A large dataset of groundwater quality data has been compiled from across the SREBA (and extended water study) region. This provides a broad-scale overview of water quality trends across the CLA, and is an important baseline for ongoing monitoring of water quality associated with onshore gas development.

There are no perennially flowing waterways overlying the Beetaloo Sub-basin because there are no groundwater discharge areas, due to the depth of the regional water table. However, some long-lasting waterbodies may be maintained by localised perched groundwater systems that exist above, and are separate from, the regional water table. Numerous waterholes, some permanent, are documented throughout the SREBA study area, while some terminus features including lakes and swamps may persist well into the dry season, or even over multiple years after wet seasons with significant rainfall.

The Daly-Roper model (DR) is a coupled numerical surface water-groundwater flow model that covers the portion of the CLA that is connected to the major drainage systems of the Daly and Roper River, and was mostly recently updated in 2020 ('DR2'). A peer review of DR2 2020 found the model classification to be Class 2-3 and also noted that DR2 2020 was a "leading example of best practice". Based on the data and improved knowledge arising from the SREBA, the water model will be updated to DR3 for use in future water planning and licencing in this region.

The scope and quality of the data and understanding of the water resources in the Beetaloo region documented for the SREBA provide a robust scientific base for the development of water allocation plans.

10.1.2. Aquatic ecosystems

Systematic biodiversity surveys and regional mapping have greatly increased knowledge of the aquatic ecosystems in the Beetaloo region.

10.1.2.1. Surface aquatic ecosystems

Surface aquatic ecosystem in the SREBA area have been mapped using satellite imagery and a range of other data sources. These cover 12% of the study area, the majority of which (90%) are floodplain systems, and the remainder palustrine (9%), riverine (1%) and lacustrine (0.01%) systems. Mapped streams have a total length of 13,787 km within the study area, of which almost 15% are classified as major streams. Twenty-two spring locations have been identified within the study area, primarily around its margins.

Mapping and field surveys identified aquatic refugia at 89 point locations across the study area, of which 37 have permanent or near-permanent surface water.

Systematic surveys at 44 sites across the study area identified 291 species of aquatic fauna, including 36 fish species; 11 species of aquatic and semi-aquatic reptile species including seven turtle species; 28 mollusc species; seven decapod species; 49 species of aquatic and semi-aquatic water bugs; 15 mayfly species; 69 species of non-biting midges (Chironomidae); and 76 species of aquatic beetles. When data from all sources are combined (including plants and frogs) a total of 400 species associated with surface water habitats were identified in the study area.

Most sites with high fish species richness occurred along the northern margin of the study area, and fish diversity in the study area centres on the perennial reaches of the upper Roper River. Parts of Western Creek hold a diverse fish fauna but are probably dependent on upstream migration from the Roper through Western Creek. Waterbodies throughout most of the study area feature a sub-set of common, widespread fish species, and species richness decreases as connectivity decreases in upstream waterholes. The spatial pattern for all aquatic species mirrors the pattern for fish, with highest diversity along the northern margin of the study area, and low total richness throughout the majority of the region. Waterbodies within the Sub-basin generally have low fish species diversity and a widespread, disturbance tolerant invertebrate community.

Four threatened aquatic fauna species occur in the study area, the most notable being the Gulf Snapping Turtle and Largetooth Sawfish in the upper Roper River.

Multiple lines of evidence indicate that the highest conservation values for aquatic biodiversity occur in the northern margin of the study area, and largely align with the Mataranka Thermal Pools Site of Conservation Significance. Nevertheless, refugia throughout the region are important for the maintenance of aquatic biodiversity, which also requires maintaining connectivity between refugia. Waterbodies on intermittent systems in the region also have high conservation value as waterbird habitat.

10.1.2.2. Stygofauna

Stygofauna comprise aquatic taxa occurring in groundwater aquifers and subterranean water bodies. The SREBA completed the most detailed study of subterranean biodiversity in the NT to date, and significantly increased knowledge of stygofauna assemblages in the CLA south of Katherine.

Stygofauna were detected in 23 of the 66 groundwater bores that were sampled, and at least 28 species-level taxa were detected. The fauna is strongly dominated by crustaceans, particularly copepods and decapods. The known stygofauna of the study area now conservatively stands at 38 species-level taxa, 34 of which occur in the Tindall Limestone formation. Species accumulation curves suggest approximately 60 species occur in the study area. Only a single stygofauna species (*Parasia unguis*) was recorded in the Wiso basin, while five species were recorded from the Georgina Basin, with four of these recorded only within that Basin.

Using eDNA sampling, the shrimp *Parisia unguis* was detected in half the bores sampled and this species has a broad distribution in the CLA, including in the Georgina and Wiso Basins.

The highest diversity of stygofauna came from the Tindall Limestone in the northeast of the study area, where 26 of the 28 taxa detected during the survey were recorded. This formation also had the highest proportion of sample sites with stygofauna (73%), and all of the eight sites that had more than a single species detected.

The data suggest stygofauna are most abundant in aquifers with a relatively shallow depth to groundwater, well-developed superficial karst features, and transmissive and interconnected saturated habitat space. Annual recharge into the aquifer may be important to stygal ecosystems to maintain suitable groundwater quality and provide primary trophic level inputs to subterranean food webs.

10.1.3. Terrestrial ecosystems

Regional vegetation mapping and systematic flora and fauna surveys have greatly increased knowledge of the terrestrial ecosystems in the Beetaloo region.

10.1.3.1. Flora and vegetation

Flora surveys contributed 15,419 new plant records for the study area. The number of plant taxa (described at least to species level) known from the study area is 1,818, with 1,093 plant taxa recorded in the Sub-basin.

Based on analysis of floristic data, plus interpretation by botanical experts, 51 vegetation communities have been described in the study region. These have been aggregated into 21 broad vegetation groups that have been mapped across the study area from remote imagery, other spatial data and data from nearly 13,000 on-ground sites.

Despite the size of the study area and the relatively high total richness of plant species occurring within it, no plants are endemic to the region, and only two threatened plant species were recorded in the study area. Four other plant species were considered significant as they have restricted ranges within their total distribution. The wetland habitat of most of these significant species reinforces the high conservation value of these restricted parts of the landscape. No geographic areas of high conservation value were identified in the region on the basis of plant biodiversity.

Disturbance was prevalent across all broad vegetation groups, despite site selection being biased towards 'best on offer' condition, and was variously associated with fire, cattle, pigs and weeds.

Environmental relationships with plant species composition in the study are complex. Overall, the latitudinal-rainfall gradient is significantly related to variation in vegetation structure, floristic composition, and with a range of species groups and habitat attributes. However, other environmental drivers such as soil type can override the influence of rainfall, and there are complex interactions between rainfall, soil type, fire and grazing regimes.

Five broad vegetation groups (comprising 25 vegetation communities) were identified as having high ecological value. Seven of the vegetation communities were identified as potential groundwater-dependent ecosystems, at varying levels of certainty. In areas mapped as potential groundwater-dependent ecosystems where depth to regional aquifers is relatively deep, vegetation may be accessing a shallower perched groundwater system.

Three broad vegetation groups predominantly occurring in the north of the study area were classified as significant vegetation and groundwater-dependent ecosystems: *Monsoon forest and thicket*, *Melaleuca forests (springs, river channels)* and *Riparian woodland (ephemeral streams)*. Groundwater-dependent ecosystems (*Riparian woodland a*nd *Melaleuca forest)* are also associated with sandstones ranges and escarpments on the eastern margin of the study area, where the Sturt Plateau and Gulf Fall & Uplands bioregions converge.

The *Ephemeral wetland* and *Lignum shrubland* broad vegetation groups were also identified as having high ecological value.

10.1.3.2. Fauna

A total of 354 vertebrate species were recorded from all surveys and incidental observations during the SREBA and GBA Program, including 14 amphibian species, 202 bird species, 39 mammal species and 99 reptile species. Including other sources, a total of 512 vertebrate species have been recorded in the study area. The ant fauna in the region is extraordinarily diverse, with 748 ant species recorded, a high proportion of which have not been previously collected.

Nine birds, one invertebrate, six mammals and four reptile species that occur in the study region are listed as threatened, and twenty species are listed as migratory under the EPBC Act. At a regional scale, the study area has relatively high total vertebrate species richness. However, no terrestrial vertebrate species are endemic to the study area.

Patterns of fauna diversity and composition relating to the latitudinal climatic gradient and landscape and habitat attributes were apparent across all fauna groups sampled. Disturbance (notably fire and grazing pressure) modifies the quality and suitability of habitat for fauna species across the landscape.

Riparian and swamp habitats have high value for bird diversity, facilitating the occurrence of more tropical bird assemblages into lower rainfall areas and the maintenance of bird diversity in the study area during dry periods. No other broad vegetation groups were identified has having notably high value for terrestrial faunal biodiversity.

Targeted surveys were undertaken for the threatened Crested Shrike-tit, Gouldian Finch, Greater Bilby, Ghost Bat and Plains Death Adder; and Northern Brushtail Possum, Mertens' Water Monitor, Mitchell's Water Monitor and Yellow-spotted Monitor were also sampled during regional surveys. Sufficient data were collated to develop spatial distribution models for the Gouldian Finch, Crested Shrike-tit, Greater Bilby and Yellow-spotted Monitor, and potential Ghost Bat roosting habitat was also mapped. There is extensive habitat for Gouldian Finch, Crested Shrike-tit and Yellow-spotted Monitor in the Sub-basin, although likely nesting habitat for the Gouldian Finch is far more spatially restricted.

Over 7,000 records of 81 waterbird species from the study area were collated, and a total of 55 wetland sites was surveyed for waterbirds. All large-scale waterbird breeding events recorded from the study area, and the largest congregation of waterbirds, were from Lake Woods and nearby waterholes on Newcastle Creek. This area also has the highest concentrations of records of migratory shorebirds. Smaller persistent wetlands in the Newcastle Creek drainage system and on the Sturt Plateau support small-scale waterbird breeding events and are likely to be refuges for waterbird persistence during dry periods.

10.1.3.3. Terrestrial biodiversity values and risks

The main terrestrial biodiversity values within the study area are summarised as follows.

- Sites of Conservation significance (SoCS)
    - Mataranka Thermal Pools
    - Lake Woods and Longreach Waterhole
- High value vegetation
    - Monsoon forest and thicket
    - Melaleuca forest (springs, river channels)
    - Riparian woodland (ephemeral streams)
    - Ephemeral wetland
    - Lignum shrubland
- Habitat for waterbirds and threatened species.

Habitats for waterbirds and other significant plant and animal species associated with aquatic environments are spatially restricted. Habitat for the threatened Crested Shrike-tit, Gouldian Finch and Common Brush-tail Possum occurs in extensive woodland communities across much of the study area, including inside the Sub-basin. In contrast, habitat for Greater Bilby and Ghost Bat occurs outside of the Sub-basin, to the south-west and north respectively.

Many of the identified threats to these biodiversity values are already present in the landscape (habitat degradation, fragmentation and loss; competition and predation; invasive plants) but could potentially be exacerbated by onshore gas development. Others key potential threats from onshore gas development are changes in surface water hydrology, reduction in groundwater availability, and contamination of surface or ground water. Additionally, predicted changes under climate change scenarios — particularly increasing number of very hot days and increasing evapotranspiration rates — may reduce the resilience of terrestrial biodiversity in the study area, particularly species with a requirement for persistent water or climate-buffering habitats.

10.1.4. Greenhouse gases

A series of mobile surveys across varying seasons and years using optical gas analysers has established a “pre-development” baseline for ambient methane concentrations in the Beetaloo Basin. Overall, the background methane concentrations measured within the study area were closely aligned with the Australian national reference values and trends.

The main sources of elevated methane concentrations detected during the surveys were cattle, fires and towns/fuel stations. An inventory of the estimated emission rates for each identified source and sink for the study area has been compiled.

There was no evidence from survey data of elevated methane levels associated with potential geological seep targets other than at Clints Gorge on Tanumbirini Station, where methane and ethane were recorded bubbling from hot springs. This area warrants further monitoring and investigation.

Currently the most practical and effective method of monitoring regional methane concentrations for the Beetaloo region is through periodic mobile surveys, possibly supported by targeted deployment of long-term autonomous emission monitoring stations.

10.1.5. Environmental health

Population health

A review of literature was undertaken to build understanding in relation to health issues potentially associated with onshore gas activity. The findings of the literature review were then used to identify relevant health indicators that may be applicable in the context of the demographics of the Beetaloo region, which has a higher proportion of Aboriginal people and lower median age compared to the Northern Territory and Australia. The available baseline information on relevant health indicators for the region was then reviewed.

The Mataranka SAL (Suburb and Locality; geographical boundaries used in the Australian Bureau of Statistics' census data) and the Elliott SAL both have a mixed picture in terms of health conditions when compared to the Northern Territory and Australia as a whole. These SALs have a lower proportion of one or more long-term health conditions within the population, and lower levels of asthma. However, conditions commonly associated with lifestyle and behavioural factors, such as diabetes and heart disease, which can be caused by smoking, poor diet, lack of exercise and high blood pressure, are more prevalent.

While the health data for the Beetaloo Sub-basin population and SA2 region provided by NT Health has substantial limitations, it does generally suggest that national trends in health inequalities between Aboriginal and non-Aboriginal populations are also reflected in the local community health profile. This appears to be the case for respiratory condition hospitalisations and deaths, cardiovascular condition hospitalisations and deaths, blood and immune disorder hospitalisations and deaths, neurological condition hospitalisations and STI notifications. Cases for cancers, foetal defects and adverse birth outcomes were too low to draw conclusions.

An outline monitoring plan was developed for the relevant health indicators. It was recommended that stakeholders be further engaged to refine and agree on the indicators prior to finalising an implementable monitoring plan.

Air quality

Five air quality monitoring stations were installed in the region as part of the Beetaloo SREBA. Monitoring will be undertaken for a period of at least 12 months, which is considered the minimum to characterise the baseline environment throughout all seasons. The following parameters are being monitored:

- deposited dust – using dust deposition gauges (DDG)
- suspended particulate matter (PM2.5, PM10) – using a real time light scattering device
- gases (NO_2, SO_2, H_2S, VOCs and aldehydes) – using passive sampling methods
- meteorological parameters (wind speed, wind direction, temperature, humidity, and rainfall).

While compliance monitoring for future onshore gas activities is expected and would be the responsibility of the proponent, additional regional baseline monitoring is valuable for ensuring human health and environmental impacts are minimised and so that communities are aware of their air quality environment.

Water quality

Existing groundwater and surface water quality data from the study area were collated, summarised and reviewed in the context of implications for human health. Analysis of groundwater data from the five main aquifer types in the study area showed:

- average pH generally ranged from lower neutral to a slightly acidic pH
- average electrical conductivity generally ranged from fresh to brackish conditions
- sulfate concentration was highest within the Upper Cambrian Limestone Aquifer and lowest in the Jamison Sandstone Aquifer
- average field and laboratory pH generally range from lower neutral to a slightly acidic pH, apart from Antrim Plateau Volcanics aquitard, which had a neutral pH
- metal concentrations were generally low and remain below the health and aesthetic guidelines across the study area
- nutrient concentrations were generally low and below the health and aesthetic guideline values across the study area, except for sulfate and chloride which exceeded health guidelines.

An environmental risk assessment was undertaken during the GBA Program of 116 chemicals associated with drilling and hydraulic fracturing operations in the Beetaloo region, of which 33 were of potentially high concern. Future groundwater monitoring programs aimed at detecting contamination from onshore gas activities should be informed by identified chemicals of potential concern.

Routine groundwater quality monitoring data from water supplies at serviced townships and Aboriginal communities within the study area shows none of these water supplies exceed Australian drinking water health guidelines, except for some aesthetic guidelines that affect palatability.

There are a variety of private entities in the study area including seven service stations and one aerodrome, but there is currently no water quality data or registered contaminated land status for any of these locations.

There are limited surface water quality data from the region, apart from field quality parameters. To improve the baseline of surface water quality analysis, it was recommended that Australian Drinking Water Health and Aesthetic guideline analytes be added to future monitoring programs. Given the potential for surface water to be used for agriculture and cultural uses by local communities, some priority locations for the future monitoring of surface water quality have been identified.

Soil quality

Existing information on soil types in the Beetaloo region was collated and reviewed. The dominant soil types in the region were identified and representative soil types selected for characterisation, in order to identify those soils that may be sensitive to impact or adverse effects from onshore gas activities.

Chemicals approved for use in hydraulic fracturing in the Northern Territory, as listed on the Chemical Register developed by NT Government, were reviewed. An assessment of chemicals of concern and potential hazards to soil, such as the likelihood of transportation through the soil, was then made in order to inform the development of a risk assessment framework. Based on the soil characterisation information, risk ratings were developed for three categories of potential risk to soil from unconventional onshore gas operations; these risk ratings were then combined for an overall risk score for each soil type. These risk ratings can be spatially portrayed as a soil risk map for the study area.

Based on the soil risk assessment process, a monitoring and management plan for soils was developed. The plan is designed to provide a guide for the site-specific management and monitoring of soils with the development of unconventional onshore gas operations in the Beetaloo Sub-basin, and to assist in maintaining consistency across individual approvals and licensing processes.

10.1.6. Social, cultural and economic

The social, cultural and economic (SCE) SREBA studies draw on publicly available data from reputable sources such as the Australian Bureau of Statistics Census data, Northern Territory Government data, Medicare, and Commonwealth government data. Indicators in themselves cannot tell the full story of complex adaptive systems such as communities and so this study relied on high levels of participation by residents of the study communities, pastoralists and stakeholder groups. The SCE SREBA studies should be seen as the starting point for ongoing conversations and community involvement in planning for future development in the Beetaloo region. The findings of the SCE studies are summarised below.

- Onshore gas development is taking place in a very low trust environment. Most people interviewed have very low trust in the gas industry to adhere to best practice and very low trust in the government's ability to regulate the industry effectively. Low trust translates to calls for "careful" development, for "watchdog" mechanisms including independent oversight and inspections, and high levels of transparency and accountability. In the eyes of the people, the industry must "earn the right to self-regulate".
- Just as there is biophysical diversity, the Beetaloo basin is socially, culturally and economically diverse. Diversity is a highly valued characteristic of the region and is associated with resilience and connection. People in the Beetaloo want to preserve social, cultural and economic diversity (which is inextricably linked with ecological diversity). Some suggestions for preserving diversity in the region include through the maintenance of Aboriginal languages and culture, protection of existing and future industries and economic opportunities, and enhanced opportunities for employment and training.
- There is high and widespread concern for aquatic ecosystems (including subterranean) and water sources as underpinning life and livelihoods. Most of the opposition to the industry is based on this concern.
- Many Beetaloo residents are highly committed to and/or invested in 'place'. They will not or cannot simply leave if their lifestyle changes unfavourably or if impacts become unacceptable. They feel they are disproportionately vulnerable and carry a greater burden of risk.
- Almost everyone supported development opportunities that can help facilitate the aspirations of local Aboriginal people to build greater economic self-sufficiency but designing the pathways for doing so should be community-specific and Aboriginal controlled. There was no further detail in the interviews about what processes might best facilitate a transition to Aboriginal-controlled economic development, except the need for government and industry to "come and talk to us". One known example of an Aboriginal–controlled economic development initiative is the Myuma Group of companies, established by the Traditional Owners from the Indjalandji-Dhidhanu people of Camooweal and surrounding area. They have also partnered with The University of Queensland to develop innovative industries based on the farming, harvesting and bioprocessing of spinifex grass.
- Onshore gas and any other (mining) industry development should be "balanced" and able to exist alongside existing industries. It should not detract from existing industries and regional identity, or compromise future economic opportunities. Meanings of 'minimal harm' need to be negotiated and defined.

- Most people would feel more comfortable if there were Aboriginal rangers and custodians "keeping an eye on" the condition of country and actively involved in environmental monitoring and land management. Pastoralists interviewed saw opportunities for mutual benefits and for greater collaboration and expressed a general willingness to cooperate with Aboriginal ranger groups. Some concerns raised about the concept of establishing Aboriginal ranger groups however included who would fund the ranger groups (noting that industry funding could lead to rangers feeling compromised), who would be eligible to become rangers and how would they be recruited, who determines the allocation and prioritisation of tasks (for example some pastoral stations would oppose burning of pastures).
- Many people did not feel they have been consulted adequately. There is not widespread understanding of what onshore gas development will look like or what impacts it may have for the region. It is felt that only those directly impacted have had the industry explained to them. There is a desire for more "neutral", "factual" information.
- Even some of the people who have been highly engaged feel conflicted or confused because they are hearing "two very different sides to the story". It was explained how information that can empower local people to raise their concerns or to make suggestions for how improve practices is needed. The 'Beetaloo basin' does not exist in the social data and there are no matching socio-political boundaries for coordinated management and decision-making.
- There are pockets of strong voices but no collective voice or representation of all the interests in the Beetaloo region. People in the region would like to see governance mechanisms that are "truly representative" of the interests of the region and facilitate meaningful dialogue about development opportunities and concerns.
- The importance of communication with all stakeholders was a strong and common theme — not just consultation with those directly impacted when lodging an EMP or as part of other approvals processes. It was suggested that there need to be regular and openly available updates on project/s progression. There also needs to be more effort in establishing relationships with neighbours and other affected stakeholders.
- Representative organisations such as land councils, the Northern Territory Cattlemen's Association and advocacy groups play an important role disseminating information to their members and putting their interests forward. However, it is not enough to engage through these groups alone, as there can be very different experiences of, and expectations for, the onshore gas industry within the groups. There were suggestions of establishing a multi-stakeholder representative body for the Beetaloo region, and a separate cultural authority body.
- There are differences in community structures and functions, and leadership capacities, which will determine communities' abilities to respond to onshore gas development opportunities and challenges.
- Baseline trends show improvements in some areas, such as education levels and housing quality, but not in others, such as crime and alcohol-related harm. There is variation in the collection and reporting of data over time, which makes it difficult to detect consistent trends. This variation is thought to result in part from data quality issues, such as low response rates to census and low samplenumbers make reporting at community level difficult for privacy reasons (health and crime statistics).

Not only have the SREBA SCE studies been useful for generating knowledge and establishing an understanding of community concerns in the baseline, but they have also created partnerships and relationships amongst a range of stakeholders interested in the outcomes. However, the relationships and conversation started in the SCE studies do not end with the completion of the reports. It is the intention that this report and the insights it brings will provide the basis for an ongoing Regional Monitoring Framework that is seen as an ongoing learning journey rather than a destination. This journey will involve multiple stakeholders from public, private and community sectors. The monitoring program should not only deliver reliable and valid findings but should be considered independent and trusted by the community, driven by what is considered important.

The baseline and strategic assessments identified the four main themes that reflect widely held aspirations for the future and community values: safe and sustainable (and coordinated) development; strong communities; maintaining and enhancing connection to land and culture; and informed and fair local participation.

10.2. Emergent regional values

10.2.1. Water-related values

The strongest theme emergent from each of the baseline studies was the importance of water within the landscape. Most of the high ecological values identified during the Beetaloo SREBA baseline studies were associated with sites or ecosystems that depend on either groundwater or surface water, and this is mirrored by the importance of these water resources both culturally and economically. The region is almost entirely underlain by an extensive aquifer system with huge groundwater reserves. The surface expression of this groundwater is responsible for permanent flows in the Roper and Flora River systems, the groundwater-dependent vegetation around these discharge areas, and the large variety of ecological, cultural, recreation and economic values associated with them. The Cambrian Limestone Aquifer itself, while relatively deep underground in most of the Beetaloo region, provides most of the water to support economic activity in the region, most notably water for stock, as well as water for domestic use. Compared to many regions of the Northern Territory, surface water is relatively sparse in the Beetaloo landscape; this is particularly the case in the Sub-basin, where all water courses are non-permanent and mostly ephemeral. Nevertheless, permanent and near-permanent waterholes, ephemeral wetlands and drainage lines support a diverse aquatic biota, riparian and floodplain vegetation, and are essential to the maintenance of elements of terrestrial biodiversity. The most significant expression of these ecological values is in the Lake Woods/Longreach Waterhole system at the terminus of the Newcastle Creek drainage. Waterholes and wetlands provide important food resources and are generally of cultural and spiritual value for Aboriginal people. Use of surface water is also important regionally to the pastoral industry, although this has often led to substantial modification of their condition and ecological function.

The SCE studies found that water is a consistent and major concern for all stakeholder groups of the Beetaloo region, and intersects with a wide range of issues, including domestic supply and quality; industrial use; contamination; water allocations; water and food sources; fishing; flora and fauna needs; and sacred sites protection. Residents of the Beetaloo Sub-basin considered any negative impacts on water to be an unacceptable cost that cannot be outweighed by the potential benefits of the proposed projects.

This emergent theme from the SREBA studies is not new or surprising, but rather the SREBA provides additional data and knowledge to more fully enunciate water-related values. The potential risk to water and water-related values from onshore gas development has consistently been at the forefront of community concern, both during the Inquiry and subsequently. A significant number of the Inquiry recommendations were directed toward addressing these concerns and minimising risks to water.

Based on the outcomes from the biophysical SREBA studies, the water-related places of the highest environmental value are described and spatially delineated below. The primary purpose of this is to guide the management of potential risks to these places and their associated values (as discussed further in

Sections 11 and 12 below). This assessment does not explicitly draw on cultural information, although it is noted that water-related places of high ecological value are likely to also be culturally important, and that many of the Aboriginal sacred sites in the region documented by the Aboriginal Areas Protection Authority are associated with waterholes, wetlands and springs.

Water-related places and values generally fall into one of three categories:

- surface water ecosystems that are not dependent on groundwater from the regional aquifer
- ecosystems dependent on the surface expression of groundwater (including groundwater-dependent vegetation and springs and riverine systems fed by groundwater)
- sub-surface aquifer systems, notably the CLA.

It is noted that there are connections between these categories but, for this descriptive purpose, their environmental values are relatively independent.

Two nominal categories - outstanding and high - are used to rate the relative value of important water-related places, primarily to inform the approach to risk management.

Approaches to risk management are recommended for each of the priority places described below, based on information arising from the SREBA studies, previous risk assessments described in Section 11, and requirements for regional monitoring described in Section 12.2.

10.2.1.1. Roper Discharge Zone

This is the area where groundwater in the Roper flow path discharges to the surface in the vicinity of Mataranka, and is considered of 'outstanding value'.

Values

- Estimated annual discharge of 63,2000–252,000 ML from the Roper Flowpath of the Cambrian Limestone Aquifer through creek beds, springs and shallow diffuse discharge — which sustains permanent water flow in the upper Roper River.
- The highest aquatic biodiversity value in the study area, including high species richness of fish and of all aquatic taxa, the highest number of unique aquatic species and the presence of threatened species, including a significant population of the Gulf Snapping Turtle, and distinct genetic lineages of some aquatic taxa.
- Most of the groundwater-dependent vegetation communities in the study area (particularly those with high or moderate confidence), including *Melaleuca forests (springs, river channels)*, *Monsoon forest and thicket* and *Corymbia bella woodland on alluvial plains*.
- A breeding locality for the threatened Red Goshawk.
- High social and economic value associated with the Mataranka Thermal Pools.

Boundary

The values of this area have been previously delineated by the boundaries of Elsey National Park, and the Mataranka Thermal Pools Site of Conservation Significance. On the basis of the SREBA studies, the area of outstanding environmental value could be more completely represented by boundaries that include:

- the mapped extent of groundwater-dependent vegetation communities
- aquatic survey sites identified as being of high value

- permanent water holes and mapped permanent streams on Roper Creek, Waterhouse River, Elsey Creek and Rope River.

A suitable boundary, including an appropriate buffer, is shown in Figure 10-1.

Risk management

The impact assessment undertaken by GBA (see Section 11.2) did not identify any pathways of potentially high concern from onshore gas activities that may affect the values of this area, and pathways of potential concern associated with surface activities are mostly geographically separated from this area. Nevertheless, in recognition of the outstanding environmental values of this area and the high level of community concern, risks could be further minimised through the following measures.

- Declaration of the entire area shown in Figure 10-1, with an appropriate buffer, as a reserved block under s9 of the *Petroleum Act 1984* (NT), in line with recommendation 14.4 of the Final Report and the subsequent *Northern Territory Petroleum Reserved Block Policy 2019*. It is noted that this area is not believed to be prospective for shale gas or other petroleum resources but such a measure would provide comfort to the community that the values of the area are recognised and protected. Alternatively, a similar level of protection could be afforded through declaration as a protected environmental area under s36 of the *Environment Protection Act 2019*.
- Completion of the Mataranka Tindall Limestone Aquifer Water Allocation Plan, with the explicit objective of maintaining groundwater quality and groundwater flows to the Roper Discharge Area at a level that will sustain the environmental values described above (and other values as determined in the planning process). The water studies documented in the SREBA reports show that most of the groundwater discharge from the Roper flow path of the CLA depends on recharge relatively close to the discharge area (i.e. within the Mataranka Tindall Limestone Aquifer WAP area, rather than within the Georgina Wiso WAP area). Most groundwater extraction for onshore gas development will take place outside the Tindall Limestone portion of the CLA, and the GBA impact assessment (Section 11.2) did not find pathways of potential concern between groundwater extraction and values associated with the Mataranka Thermal Pools area. These values are more likely to be affected by groundwater extraction for other purposes from the Tindall Limestone Aquifer, and sustainable groundwater extraction is best managed through an appropriate WAP.
- Inclusion of sites and indicators from this area in the proposed Beetaloo regional monitoring program (Section 12.2), including:
  - surface water quality
  - aquatic ecosystem health
  - extent of groundwater-dependent vegetation
  - agreed cultural indicators.

  Noting that related or additional indicators may also be developed through the Mataranka Tindall Limestone Aquifer Water Allocation Plan.

Although it is not described in detail here (as it was outside the SREBA study area and SREBA-related studies in this zone were limited to groundwater investigations), a similar approach would be appropriate for the **Flora Discharge Zone**. Notably, this would include completion of the Flora Tindall Limestone Aquifer Water Allocation Plan, to ensure sustainable management of groundwater in the Flora flow path portion of the Tindall Limestone Aquifer.

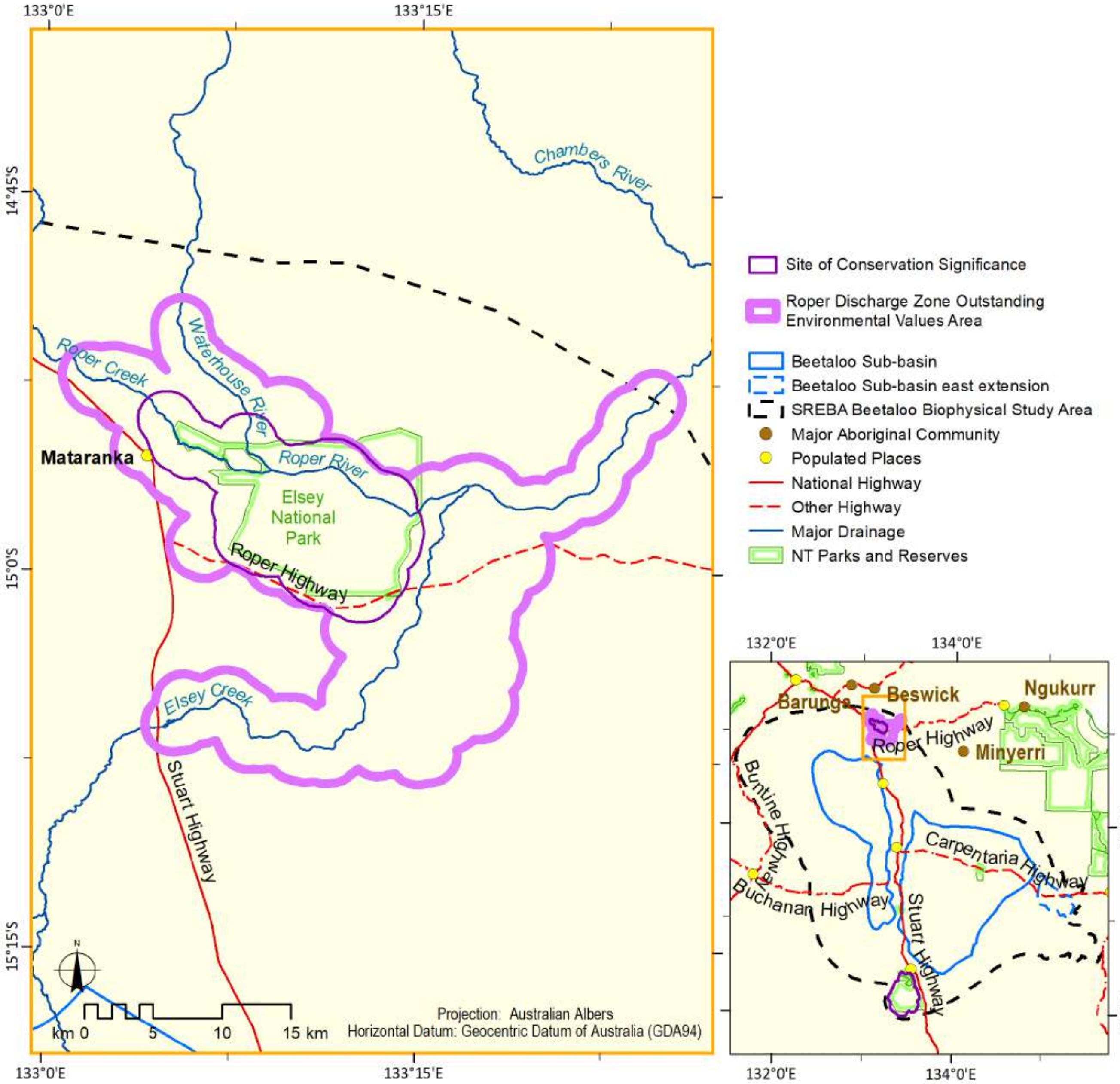

Figure 10-1. Recommended boundary containing the outstanding values of the Roper Discharge Zone.

10.2.1.2. Lake Woods / Longreach Waterhole

This area includes Lake Woods and permanent waterholes near the terminus of Newcastle Creek, with linking riverine sections, and is considered of 'outstanding value'.

Values

- When full, one of the largest temporary freshwater lakes in tropical Australia.
- The largest permanent waterholes in the Newcastle Creek catchment, in the southern half of the study area.
- All of the large-scale waterbird breeding events recorded from the study area. Lake Woods is also the most important site in the study area for large congregations of waterbirds, has the highest concentrations of migratory shorebird records, the only record of the Critically Endangered Curlew Sandpiper in the study area, and a record of the Endangered Australian

Painted Snipe. Lake Woods, together with Longreach and South Newcastle Waterholes, are listed as a 'Key Biodiversity Area' (BirdLife International 2022b).

- An aquatic biota that, while not species-rich, is distinctive to the internally draining catchments of the study area. The highest fish diversity in this catchment occurs in the permanent waterholes on the lower Newcastle Creek.
- An inferred source of recharge into the CLA, particularly when Lake Woods is inundated.

Boundary

The values of this area have been previously delineated by the boundaries of the Lake Woods Site of Conservation Significance (SOCS), and the Lake Woods Conservation Covenant and Longreach Waterhole Protected Area (which are conservation management agreements established over these parts of the Powell Creek and Newcastle Waters pastoral leases under s74 of the TPWC Act). On the basis of the SREBA studies, the area of outstanding environmental value could be more completely represented by extending the SOCS boundary northward along Newcastle Creek to incorporate the near-permanent Homestead Waterhole and the extent of the mapped perennial stream between this and Longreach Waterhole, with an appropriate buffer, and as shown in Figure 10-2.

Risk management

This area is outside the Beetaloo Sub-basin, and the most feasible pathway for any impact from onshore gas development is via contamination of surface waters upstream in the catchment. However, the impact assessment undertaken in the GBA (see Section 11.2) did not identify any pathways of potentially high concern, and pathways of potential concern associated with surface activities are geographically distant. In recognition of the outstanding environmental values of this area and some community concern, risks could be further minimised through the following measures.

- Declaration of the entire area shown in Figure 10-2, with an appropriate buffer, as a reserved block under Section 9 of the *Petroleum Act 1984* (NT), in line with Recommendation 14.4 of the Final Report and the subsequent *Northern Territory Petroleum Reserved Block Policy 2019*. It is noted that this area is not believed to be prospective for shale gas or other petroleum resources but such a measure would provide comfort to the community that the values of the area were recognised and protected. Alternatively, a similar level of protection could be afforded through declaration as a protected environmental area under Section 36 of the *Environment Protection Act 2019*.
- Inclusion of sites and indicators from this area in the proposed Beetaloo regional monitoring program (Section 12.2), including:
    - surface water quality
    - aquatic ecosystem health
    - agreed cultural indicators.

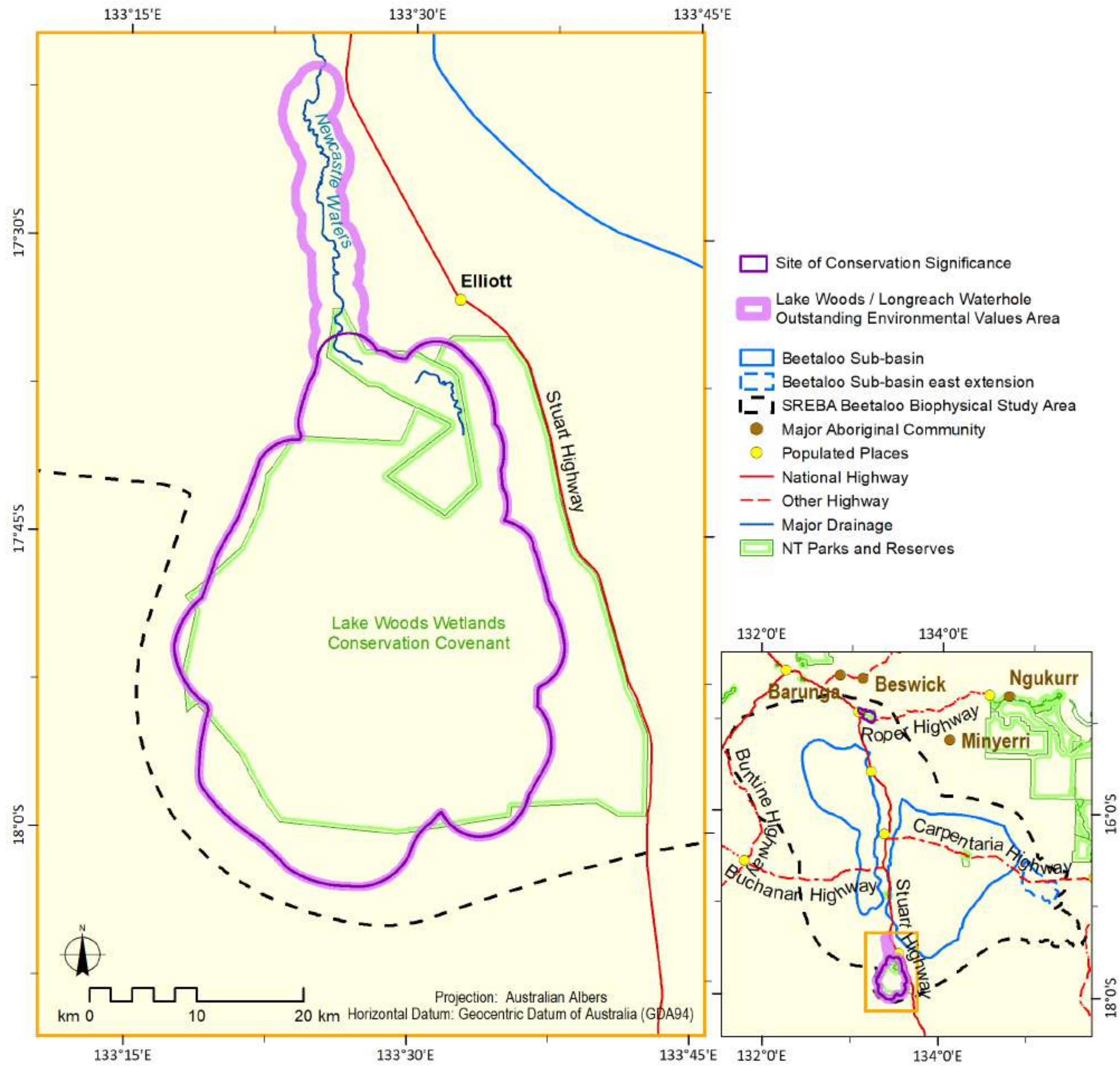

Figure 10-2. Recommended boundary containing the outstanding values of the Lake Woods/Longreach Waterhole area.

10.2.1.3. High-value surface aquatic ecosystems / sites

A variety of water-related places or ecosystems are considered to be of 'high' value on the basis of information collected during the SREBA ecological studies. These include surface water ecosystems and those dependent on the surface expression of groundwater, and are grouped together here because there is a common recommended approach to risk management.

- Groundwater-water dependent vegetation (high or moderate confidence), as mapped in Figure 6-6, that is not included in the Roper Discharge Zone described above, and where modelled depth to groundwater is less than 20 m.
- Other vegetation communities that are mapped in Figure 6-5 as being of high ecological value.
- Localities at which significant plant species associated with wetland environments have been recorded.

- Locations identified as refugia for aquatic biodiversity (based on the mapping the frequency of inundation from satellite imagery), as shown in Figure 5-4.
- Locations identified as likely to be important for waterbirds, as shown in Figure 6-19, that are not in the Lake Woods / Longreach Waterhole area described above.
- Springs, as mapped in Figure 4-21, that are not included in the Roper Discharge Zone described above.
- Perennial mapped streams, as mapped in Figure 5-4, that are not included in the outstanding environmental value areas described above.

All locations meeting the criteria described above are shown in Figure 10-3 and their total extent is provided in Table 10-1. The majority of the high-value ecosystems and sites are outside the boundary of the Sub-basin, although a significant proportion are within 20 km of the Sub-basin boundary. The most common high value features within the Sub-basin are ephemeral wetlands and aquatic refugia.

Risk management

These values are potentially subject to a variety of stressors (either directly or indirectly) arising from onshore gas development, but the most likely risks are associated with changes in water quantity (either through changes to surface flows or groundwater extraction), or changes in water quality (due to contamination of surface water or groundwater). The impact assessment undertaken in the GBA Program (see Section 11.2) did not identify any pathways of potentially high concern and found that pathways of potential concern were primarily related to activities that create a disturbance at the surface (transport of materials and equipment, civil construction), and that risks could be adequately mitigated through existing regulatory controls, such as application of the *Code of Practice: Onshore Petroleum Activities in the Northern Territory* (Code of Practice).

Given that the sites shown in Figure 10-3 have been identified as having high environmental value, it is recommended that risks to these areas could be further minimised by the following measures.

- Refreshing the GBA impact assessment, incorporating the additional data available from the SREBA studies and with these values and locations as explicit endpoints (see Section 11.2.5). If this indicates any pathways with higher levels of concern, consideration should be given to having revised or additional regulatory controls to adequately minimise the specific risk(s).
- Not permitting specified onshore gas activities that have the potential for direct impacts, including wells pads, water extraction bores and storage of wastewater, within a prescribed distance from these areas. The appropriate prescribed distance may be refined through review of the GBA impact assessment pathways, but a buffer of 1 km from the boundary of each high environmental value area is recommended here as a default. Noting that there was inevitably some misattribution of individual objects during the development of the baseline vegetation map, the presence or absence of high-value ecosystems should be confirmed on a project area-specific basis through ground-truthing. This proposed restriction on the location of relevant onshore gas activities may be implemented through incorporation as a mandatory requirement in the Code of Practice.
- Through the Code of Practice, requiring that Environmental Management Plans for onshore gas activities specifically address the potential for downstream impacts on high environmental value areas, where the activities are located where such impacts are feasible.
- Similarly, development of linear infrastructure (roads, pipelines) should be planned to avoid these high environmental value areas including an appropriate buffer (in line with recommendations 7.18 and 8.10 of the Final Report).

- Inclusion of a representative set of area of high environmental value in the proposed Beetaloo regional monitoring program (Section 12.2), including:
    - aquatic ecosystem health indicators
    - extent of groundwater-dependent vegetation
    - agreed cultural indicators.

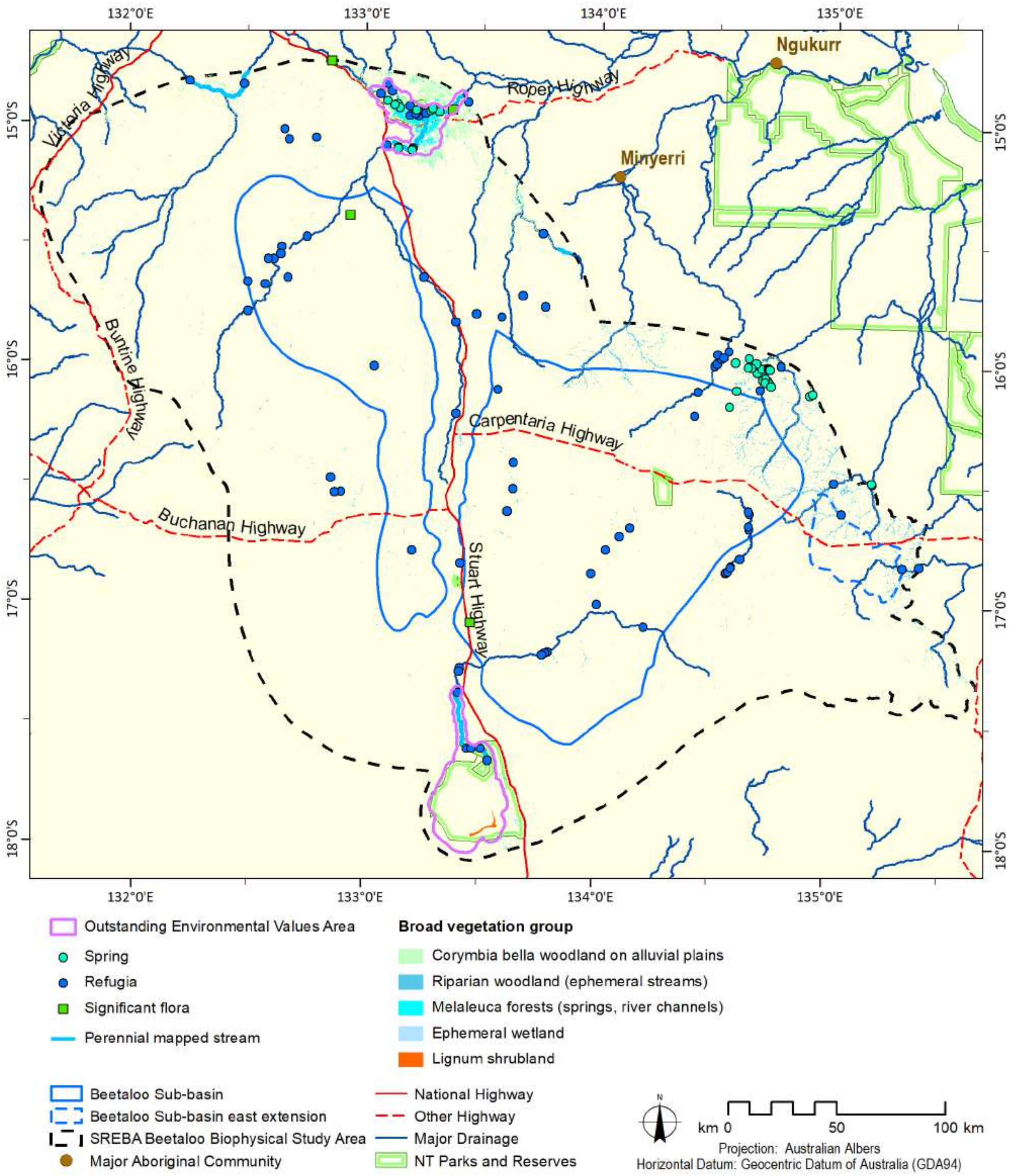

Figure 10-3. Location of high-value surface aquatic ecosystems and sites.

Table 10-1. Extent of surface aquatic ecosystems and sites, including component broad vegetation types and site types, in the study area and Sub-basin.

	Study area	Sub basin	Sub basin + 20 km buffer
Vegetation communities (ha)	152,813	20,548	55,704
Corymbia bella woodland on alluvial plains	72,656	95	9,491
Riparian woodland (ephemeral streams)	50,441	19,278	41,582
Melaleuca forests (springs, river channels)	25,366	783	3,567
Ephemeral wetland	2,676	392	1,065
Lignum shrubland	1,674	-	-
Permanent streams (km)	214.4	0	28.4
Sites (n)	150	32	97
Refugia	90	29	61
Spring	56	1	34
Significant flora	4	2	2

10.2.1.4. Cambrian Limestone Aquifer

This aquifer system is recognised as having 'high' environmental value because it ultimately underpins the values associated with the surface expression of groundwater in the areas of high value described above, and it is also the primary source of water for stock, domestic, agricultural and industrial use within the Beetaloo region. Additionally, stygofauna present in the CLA, and particularly in the Tindall Limestone formation, represent a subterranean groundwater-dependent ecosystem.

Risk management

A large number of recommendations of the Scientific Inquiry were directed toward minimising risks to the groundwater quantity and quality, particularly of the CLA (see section 11.1). The GBA impact assessment (Section 11.2) did not identify any pathways of potential concern in relation to groundwater drawdown or impacts on groundwater quality through contamination, as these risks were adequately mitigated by existing regulatory controls. The GBA assessment did not include stygofauna as a specific endpoint, although the 'aquifer condition' endpoints likely act as a surrogate for the health of the stygofauna community, and stressors and processes relevant to stygofauna were included in the assessment.

It is recommended that risks to the areas could be further minimised by the following measures.

- Ensuring water extraction is within sustainable limits through implementation of Water Allocation Plans (Georgina-Wiso, Mataranka Tindall Limestone and Flora).
- Not permitting specified onshore gas activities that entail potential risk of surface spills of contaminants, including hydraulic fracturing fluids or wastewater, at locations where depth to the CLA or any unconfined aquifer is less than 20 m. This restriction may be implemented through incorporation as a mandatory requirement in the *Code of Practice: Onshore Petroleum Activities in the Northern Territory*.
- Refreshing the GBA impact assessment, incorporating the additional data available from the SREBA studies and with stygofauna as an explicit endpoint (see Section 11.2.5). If this indicates

any pathways with significant levels of concern, consideration should be given to revised or additional regulatory controls to adequately minimise the associated risk(s).

- Reviewing the *Preliminary Guideline: Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-basin* in light of the improved understanding of hydrostratigraphy and baseline groundwater quality in the Beetaloo Basin to ensure that is best fit for purpose, particularly for production-level well development.
- Development proponents in the Beetaloo region area should undertake a thorough assessment of the location of sinkholes and depression features in and near the project area, as these are potential recharge points to the underlying aquifer. Measures to minimise interruption or contamination of surface flows into these features should be described in the Environmental Management Plan (or equivalent documentation for environmental impact assessment).
- Inclusion of these values in the proposed Beetaloo regional monitoring program (Section 12.2), including:
    - groundwater levels and groundwater quality
    - stygofauna community composition, dependent on further GISERA research (see Section 12.2.3).

  It is noted that much of these data may be provided through monitoring undertaken by proponents as a requirement of the Code of Practice and environmental approvals.

10.2.2. Other values

There are a broad variety of values in the Beetaloo region that are not directly water-related, including ecological, cultural, social and economic values. These include, for example, a moderately rich terrestrial vertebrate biodiversity and a very rich ant fauna; a number of threatened vertebrate species in terrestrial (non-aquatic) habitats; the spiritual and cultural connection to land of Aboriginal people, as well as a variety of food and other resources associated with terrestrial ecosystems; the economic value of pastoral land use over most of the region and associated social values; and the 'natural' identity of the landscapes, and the sense of autonomy, freedom and peace described in the social and cultural baseline assessment.

Many of these values are at least partly captured in the concept of 'healthy' ecosystems, which are largely structurally intact, where biodiversity and ecosystem functions are maintained, and where there is access to land by traditional custodians for cultural practices. Threats or stressors that reduce ecosystem health include the broad-scale impacts of inappropriate fire regimes, spread of environmentally or economically damaging weeds and pest animals, excessive grazing pressure, and clearing and fragmentation of native vegetation. Most of these threats are already present in the region to varying degrees and are not specific to the development of an onshore gas industry, although the latter may potentially exacerbate many of them. Risks from many of these stressors were identified by the Scientific Inquiry (for example in Chapter 8 of the Final Report), which made a number of recommendations to reduce the potential impacts of weed incursion and spread (Recommendations 8.2 to 8.4), manage the impacts of fire (Rec. 8.5) and minimise the impacts of clearing and fragmentation (Recs. 8.6 to 8.11). Impacts of shale gas development on landscape amenity was also considered (Rec. 8.15).

The Beetaloo GBA impact assessment also found that pathways of potential concern were primarily related to activities that create a disturbance at the surface (transport of materials and equipment, civil construction, decommissioning and rehabilitation, and seismic data acquisition) and pathways connected these activities with protected fauna and terrestrial vegetation (see Section 12.2).

The SREBA Terrestrial Ecology baseline study did not identify areas of high environmental value for which specific risk management actions are recommended, in contrast to those for water-related values. However, some potential applications of the SREBA outputs are noted here.

- Spatial distribution models for some threatened terrestrial fauna species have been developed, and these should be applied in evaluating the risks of project-specific activities (for example, in Environment Management Plans). In particular, measures should be considered to minimise impacts on hollow-bearing trees within vegetation communities identified as suitable for nesting of Gouldian Finch, and on larger trees within the preferred habitat for Crested Shrike-tit.
- The uniform vegetation map developed for the study area allows the cumulative effect of vegetation clearing to be precisely calculated, along with metrics of fragmentation. This also potentially allows thresholds for acceptable change to be considered and implemented.
- Regional monitoring relevant to terrestrial ecosystems (Section 12.4.4) could include:
  - bird fauna of riparian and swamp habitats
  - landscape fire regimes
  - vegetation clearing and fragmentation.

As noted in the Final Report and the SCE Baseline Report, many environmental land management activities, as well as environmental monitoring, could be undertaken or assisted by regional Aboriginal ranger groups. Where environmental offsets are required, funding the management of landscape-scale threats such as fire, weeds and feral animals as an offset is consistent with the *Northern Territory Biodiversity Offset Policy*. Through the SCE study, it was also clear that most people would feel more comfortable if there were Aboriginal rangers and custodians 'keeping an eye on' the condition of country and actively involved in environmental monitoring and land management. Some concerns raised about the concept of establishing the Aboriginal ranger groups included who would fund the groups, who would be eligible to become rangers, how would they be recruited and who would determine the allocation and prioritisation of tasks.

The SREBA SCE studies identified other thresholds of acceptance that represent issues that are non-negotiable to the residents of the Beetaloo Sub-basin. These were negative impacts on water (covered in Section 10.2.1), sacred sites, biosecurity and human rights in recognition and protection of the interconnectedness of people and nature. Any negative impacts on these issues are considered unacceptable costs that cannot be outweighed by the potential benefits of proposed projects.

10.3. References

BirdLife International (2022b). The World Database of Key Biodiversity Areas. Available at: https://www.keybiodiversityareas.org/

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Northern Territory Government (2019) Petroleum Reserved Block Policy, Department of Industry, Tourism and Trade Darwin, Northern Territory Government. https://nt.gov.au/__data/assets/pdf_file/0005/715631/petroleum-reserved-block-policy.pdf.

Northern Territory Government (2021) Code of practice: Onshore petroleum activities in the Northern Territory, Department of Environment, Parks and Water Security, Palmerston, Northern Territory.

Northern Territory Government (2021). Land Clearing Guidelines. Northern Territory Planning Scheme. Department of Environment, Parks and Water Security, Palmerston, Northern Territory.

11. Risks from onshore gas development

As described in the Final Report, the purpose of the SREBA is to provide the information necessary for appropriate decisions to be made about the development of any onshore shale gas industry in the NT, including assessment of water and biodiversity resources, to inform land-use planning, and the collection of baseline data to provide a reference point for ongoing monitoring. The SREBA is not in itself a risk assessment, but provides appropriate information to allow government, regulators and industry to apply robust risk assessment.

There have been two very substantial risk assessments undertaken relating to potential impacts from onshore gas resource development in the Northern Territory and, more specifically, the Beetaloo Sub-basin: as a key component of the Scientific Inquiry (published in 2018), and as the final, integrative stage of the Beetaloo GBA Program (published in 2021). The SREBA does not remake those risk assessments, but rather provides additional data and understanding to address knowledge gaps or uncertainties identified during those assessments.

The sections below discuss the key outputs of the SREBA in relation to the risk assessments undertaken for the Scientific Inquiry and the Beetaloo GBA Program.

11.1. Scientific Inquiry

The task of the Scientific Inquiry was to identify the environmental, cultural, economic and social risks and impacts associated with hydraulic fracturing and onshore shale gas development, and to identify how those risks and impacts may be managed to a level that is 'acceptable' and consistent with the principles of ecologically sustainable development. The Panel used the principles of ESD to formulate environmental objectives as an initial part of its risk assessment process and to identify mechanisms that would ensure that those objectives are achieved. The Panel determined that the biophysical (water, land and air) and public health issues were best assessed by applying a standardised multi-step risk assessment process, which was described in Section 4.5 of the Final Report. Different approaches were used for assessment of risks associated with Aboriginal people and their culture (Chapter 11 of the Final Report), social impacts (Chapter 12), and economic impacts (Chapter 13).

For the biophysical and public health risks, the Panel adopted a qualitative risk assessment framework that combined the estimated likelihood of an impact occurring, and the consequence(s) of that impact, to assess the resultant risk level. Definition and understanding of consequence and likelihood for each theme were developed by the Panel based on data, literature, submissions to the Inquiry and the Panel's professional judgement. Where the resultant risk was initially assessed as unacceptable (either medium or high), the panel identified measures that could reduce the residual risk to an acceptable level (low). Each of the biophysical and human health chapters in the Final Report developed their own definition of what is considered 'acceptable' based on the best-available scientific information (Table 4.5 in the Final Report). The Panel also identified some measures that would further reduce some risks that were already identified as low. Such mitigation measures are the basis for many of the Inquiry's recommendations, noting that the assessment was based on the regulatory regime in place in the Northern Territory at the time the Inquiry was undertaken.

In some cases, there was insufficient scientific knowledge and baseline information available to the Panel to complete the final residual risk assessment. This led to the recommendation to undertake a strategic regional environmental and baseline assessment (SREBA) to provide these data and understanding.

Appendix 3 of the Final Report details the risk assessment matrices developed by the Panel for assessing the biophysical and public health risks. These are reproduced in Table 11-1 for those risks where conducting a SREBA was explicitly identified as a required mitigation measure, and for other risks where the baseline data from the SREBA are clearly relevant to informing mitigation measures and the residual risk assessment.

The data and information collected through the SREBA that are relevant to these biophysical and public health risks are summarised in Table 11-2. These data and information will allow for the implementation or refinement of appropriate mitigation measures, and for the assessment of residual risks to be completed.

Chapters 11 and 12 from the Final Report of the Inquiry outlined a range of risks relating to community concerns regarding readiness for any onshore gas activity, government's capacity to regulate the gas industry and the impact on the people living in and around the Beetaloo region, specifically Aboriginal people in the region.

The Inquiry recommended that a strategic Social Impact Assessment (SIA) be conducted to generate and disseminate the information needed to allow for informed decisions about development that is consistent with the public interest.

The Inquiry also found that, in order to provide the community with confidence in government's ability to regulate any onshore shale gas industry, the regulatory and policy frameworks needed to be strengthened, gaps in knowledge needed to be addressed and greater transparency was required to build trust in the community.

The Social, Cultural and Economic (SCE) studies are a critical component of the Beetaloo Sub-basin SREBA and aim to address the recommendations from the Inquiry aimed at mitigating the risks identified from a social, cultural and economic perspective (refer Table 11-3).

The SCE studies relied on high levels of participation by Beetaloo region residents and representatives to obtain information about people, culture, communities and livelihoods. The SCE studies provide a point-in-time snapshot, as a baseline of the social, cultural and economic characteristics of the Beetaloo Sub-basin. Respecting Aboriginal people's rights and ensuring their inclusion in the decision-making and planning processes for development is a key aim of the SCE SREBA. The activities undertaken for the studies have played an important role in supporting participatory decision-making about the future of the Beetaloo Basin, and therefore upholding the rights of the region's Aboriginal people. As outlined in the studies, public participation is a standard element of contemporary development planning and governance. Community contribution to the discussions, including recognition of rights, concerns, aspirations and values, influences the decisions and plans about implementation of the project and is supported through the studies.

Government has existing mechanisms to monitor community sentiment as part of Environment Management Plan approvals under the *Petroleum (Environment) Regulations 2016*, and for proposals assessed by the NT Environmental Protection Authority (EPA).

While it is the responsibility of industry to negotiate local and regional support for their activities, the SCE study provides the baseline information to inform consultations and to ensure that people have access to information regarding the impact of industry development on their communities, opportunities to participate in ongoing monitoring, and appropriate arrangements to raise concerns and maximise opportunities to improve community outcomes.

In addition to addressing the lack of information, the SCE studies were designed to capture a baseline understanding of life and livelihoods in the Beetaloo region as a reference point for ongoing monitoring. This includes considerations regarding the impact of development and the flow-on effects this may have on access and the use of Country.

The combined regulatory, policy and assessment activities in place, in addition to the baseline information, the Strategic Regional Assessment and the Regional Monitoring Framework, will help ensure that the community, gas industry, businesses and other key stakeholders are involved and can contribute to the development of the onshore gas industry in the Northern Territory and, through doing so, increase trust and confidence in the Government's capacity to regulate such development.

Table 11-3. Summary of Scientific Inquiry recommendations specific to addressing certain risks of social, cultural and economic impacts

A comprehensive assessment of the cultural impacts, conducted in accordance with world-leading practice including engagement with Land Councils, AAPA, traditional Aboriginal owners, native title holders and the affected Aboriginal communities. **(Recommendation 11.8)**
A strategic SIA be conducted to obtain essential baseline data and to mitigate potential negative impacts. **(Recommendations 12.1, 12.3, 12.6 and 12.20)**
Early engagement and communication of the findings of the strategic SIA to provide for a shared understanding of roles and responsibilities and time for stakeholders and affected community members to respond to development opportunities and impacts. **(Recommendation 12.4)**
Ongoing monitoring and measurement of social and cumulative impacts, with a mechanism for community advice and results being made publicly available online including the establishment of a long-term participatory regional monitoring framework, including periodic and standardised reporting to communities on the social, cultural, economic and environmental performance of the industry through either the regulator or a specialised research institution. **(Recommendations 12.5 and 12.7, 12.17)**
Gas companies establish a relationship with communities to determine how to best facilitate community cohesion on an individual and collective level. This should be done in consultation with all landholders, Land Councils and local government, and include the use of the baseline information established through the SREBA SCE studies to ensure that the needs of all stakeholders are accommodated. **(Recommendation 12.16)**

Table 11-1. Risk assessment matrix developed by the Scientific Inquiry for biophysical and public health risks, adapted from Appendix 3 of the Final Report. Only risks relevant to the requirement for a SREBA are shown: non-highlighted rows are those where the SREBA is explicitly mentioned as a mitigation measure; rows highlighted gold are risks where the SREBA was mentioned in the text associated with a mitigating Recommendation, or where the data and understanding from the SREBA are clearly relevant to managing the risk; cells highlighted green are Recommendations that mention the SREBA but were not included in the original risk assessment table in the Final Report. Appendix 3 of the Final Report used summary descriptions of the Recommendations, and these have been expanded here where that provides greater clarity. In two instances apparent errors in the numbering of Recommendations in the original table have been corrected. GHG = greenhouse gases.

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Chapter 7 Water			
Environmental value 1: water quantity			
Environmental objective 1: to ensure all surface and groundwater resources are used sustainably			
Excessive extraction from surface water	*Likelihood* - low, lack of permanent surface water in Beetaloo Sub-basin and other semi-arid and arid regions *Consequence* - medium *Risk* - low	• That before any further production approvals are granted, a regional water assessment be conducted as part of a SREBA for any prospective shale gas basin, commencing with the Beetaloo Sub-basin. The regional assessment should focus on surface and groundwater quality and quantity (recharge and flow), characterisation of surface and groundwater-dependent ecosystems, and the development of a regional groundwater model to assess the effects of proposed water extraction of the onshore shale gas industry on the dynamics and yield of the regional aquifer system (***Recommendation 7.5***) • That the use of surface water be prohibited (***Recommendation 7.6***) • That WAPs be developed for the northern and southern regions of the Beetaloo Sub-basin (***Recommendation 7.7***)	Low
Excessive extraction from groundwater – regional impacts	**Northern Beetaloo Sub-basin:** *Likelihood* - low *Consequence* - medium *Risk* - low **Southern Beetaloo Sub-basin:** *Risk* - cannot be assessed, lack of detailed knowledge on recharge rates in the region	• That before any further production approvals are granted, a regional water assessment be conducted as part of a SREBA for any prospective shale gas basin, commencing with the Beetaloo Sub-basin. The regional assessment should focus on surface and groundwater quality and quantity (recharge and flow), characterisation of surface and groundwater-dependent ecosystems, and the development of a regional groundwater model to assess the effects of proposed water extraction of the onshore shale gas industry on the dynamics and yield of the regional aquifer system (***Recommendation 7.5***) • That the use of surface water be prohibited (***Recommendation 7.6***)	Low for northern Beetaloo Sub-basin. Not able to be determined for southern Beetaloo Sub-basin.

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
		• That the Daly-Roper Water Control District (WCD) be extended south to include all of the Beetaloo Sub-basin and that Water Allocation Plans (WAP) be developed for the northern and southern regions of the Beetaloo Sub-basin (***Recommendation 7.7***) • That use of water by the shale gas industry be restricted to less than that which can be sustainably extracted (***Recommendation 7.7***) • That groundwater extraction be prohibited in semiarid regions until there is sufficient information to demonstrate that there are no adverse impacts (***Recommendation 7.7***)	
Excessive extraction from groundwater - local impacts	*Likelihood* - low of an unacceptable aquifer drawdown further than 1 km from the gas company bore fields *Consequence* – medium; if aquifers are drawn down excessively this could reduce the effectiveness of bores used by pastoralists and communities *Risk* – low	• That before any further production approvals are granted, a regional water assessment be conducted as part of a SREBA for any prospective shale gas basin, commencing with the Beetaloo Sub-basin. The regional assessment should focus on surface and groundwater quality and quantity (recharge and flow), characterisation of surface and groundwater-dependent ecosystems, and the development of a regional groundwater model to assess the effects of proposed water extraction of the onshore shale gas industry on the dynamics and yield of the regional aquifer system (***Recommendation 7.5***) • That the extraction of groundwater for hydraulic fracturing be prohibited within at least 1 km of existing or proposed domestic or stock bores (***Recommendation 7.8***) • That WAPs include provisions to control the rate and volume of water extraction by the gas companies (***Recommendation 7.8***) • That gas companies monitor drawdown in local water supply bores (***Recommendation 7.8***) • That gas companies 'make good' and rectify any problems if the drawdown is found to be excessive (***Recommendation 7.8***) • That appropriate modelling of the local and regional groundwater system must be undertaken before any production approvals are granted to ensure that there are no unacceptable impacts on groundwater quality and quantity. This modelling should be undertaken as part of a SREBA (***Recommendation 7.16***)	Low

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Environmental value 2: surface and groundwater quality			
Environmental objective 2: to maintain acceptable quality of surface and groundwater			
Unacceptable groundwater contamination from leaky production wells	**Wastewater (salts and chemicals)** *Likelihood* - very low, little evidence of faulty contemporary wells *Consequence* - medium, will depend upon the behaviour of contaminants in the groundwater (dispersion, transport, degradation) *Risk* - medium **Methane** *Likelihood* - low to medium, methane leakage more likely than leakage from bores of contaminated flowback or produced water *Consequence* - low, little evidence that methane contamination of groundwater is harmful. Methane in water is considered non-toxic, but a possible explosion risk in drinking water bores or storage tanks if dissolved concentration exceeds 28 mg/L *Risk* - low.	• That guidelines be developed for human and environmental risk assessments for all onshore shale gas developments (***Recommendation 7.4***) • That information about hydraulic fracturing fluids, flowback and produced water be publicly disclosed (***Recommendation 7.10***) • That all wells to be hydraulically fractured are constructed to at least Category 9 or equivalent and be tested to ensure well integrity before and after hydraulic fracturing, with the results certified by the regulator (***Recommendation 7.11***) • That there is an offset of 1 km between well pads and water supply bores (***Recommendation 7.11***) • That there is real-time groundwater quality monitoring around each well pad (***Recommendation 7.11*** and ***7.13***) • That well pads are equipped with multilevel observations bores (***Recommendation 7.11***) • That electrical conductivity and other water quality indicators are measured (***Recommendation 7.11***)	Low (wastewater) Low (methane)
Unacceptable groundwater contamination due to spills of hydraulic fracturing chemicals and wastewater: on-site spills	*Likelihood* - medium, spills are typically small volume; the likelihood of the contaminants penetrating to the aquifer is low for most of the Beetaloo Sub-basin *Consequence* - medium, contamination could result in health issues for humans and stock using the aquifer for drinking *Risk* - medium	• That wastewater management plans and spill management plans be mandated (***Recommendation 7.12***) • That enclosed tanks be used for wastewater (***Recommendation 7.12***) • That well pads be bunded to prevent run off and be treated by a geomembrane to prevent infiltration into the soil (***Recommendations 7.12***) • That groundwater be monitored* (***Recommendation 7.13***)	Low
Unacceptable groundwater contamination due to changed groundwater pressures	*Likelihood* - low due to very large distance between shale formation and aquifers. *Consequence* - medium *Risk* - low, provided that the fracturing operations avoid the proximity of existing faults	• That modelling of the groundwater system be undertaken as part of a SREBA (***Recommendation 7.16***)	Low

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Adverse effects of linear infrastructure (roads, pipelines) on the quality and distribution of surface water across the landscape			Low
Environmental value 3: aquatic ecosystems and biodiversity			
Environmental objective 3: to adequately protect ecosystems and biodiversity that are dependent on surface water or groundwater			
Excessive extraction from surface waters	*Likelihood* - low, given the lack of permanent surface water in Beetaloo Sub-basin and other semi-arid and arid regions *Consequence* - medium, if volumes and flow regimes are altered *Risk* - medium	• That before any further production approvals are granted, a regional water assessment be conducted as part of a SREBA for any prospective shale gas basin, commencing with the Beetaloo Sub-basin. The regional assessment should focus on surface and groundwater quality and quantity (recharge and flow), characterisation of surface and groundwater-dependent ecosystems, and the development of a regional groundwater model to assess the effects of proposed water extraction of the onshore shale gas industry on the dynamics and yield of the regional aquifer system (***Recommendation 7.5***) • That the use of surface water be prohibited (***Recommendation 7.6***) • That WAPs be developed for the northern and southern regions of the Beetaloo Sub-basin (***Recommendation 7.7***)	Low
Excessive extraction from groundwaters	*Likelihood* - low, for surface GDEs since none known in Beetaloo Sub-basin, undetermined for subterranean ecosystems (stygofauna) *Consequence* - undetermined for subterranean ecosystems *Risk* - undetermined, lack of detailed knowledge of impact of subterranean fauna (stygofauna)	• That before any further production approvals are granted, a regional water assessment be conducted as part of a SREBA for any prospective shale gas basin, commencing with the Beetaloo Sub-basin. The regional assessment should focus on surface and groundwater quality and quantity (recharge and flow), characterisation of surface and groundwater-dependent ecosystems, and the development of a regional groundwater model to assess the effects of proposed water extraction of the onshore shale gas industry on the dynamics and yield of the regional aquifer system (***Recommendation 7.5***) • That the use of surface water be prohibited ***(Recommendation 7.6)*** • That the Daly-Roper Water Control District (WCD) be extended south to include all of the Beetaloo Sub-basin and that Water	Low for surface GDEs but undetermined for subterranean ecosystems

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
		Allocation Plans (WAP) be developed for the northern and southern regions of the Beetaloo Sub-basin (***Recommendation 7.7***) • That use of water by the shale gas industry be restricted to less than that which can be sustainably extracted (***Recommendation 7.7***) • That groundwater extraction be prohibited in semi-arid regions until there is sufficient information to demonstrate that there are no adverse impacts (***Recommendation 7.7***)	
		• That the SREBA undertaken for the Beetaloo Sub-basin must take into account groundwater-dependent ecosystems in the Roper River region, including identification and characterisation of aquatic ecosystems, and provide measures to ensure the protection of these ecosystems ***(Recommendation 7.19)***	
		• That the Beetaloo Sub-basin SREBA must identify and characterise all subterranean aquatic ecosystems, with particular emphasis on the Roper River region ***(Recommendation 7.20)***	
Unacceptable contamination of surface waters (aquatic ecosystems)	*Likelihood* - low *Consequence* - medium *Risk* - low	• That the discharge of wastewaters (treated or untreated) to any surface water body be prohibited (***Recommendation 7.17***) • That wastewater management plans and spill management plans be mandated (***Recommendation 7.12***) • That enclosed tanks for wastewater be used (***Recommendation 7.12***) • That well pads be bunded to prevent run off and be treated by a geomembrane to prevent infiltration into the soil (***Recommendations 7.12***) • That groundwater be monitored adjacent to each well pad (***Recommendation 7.13***)	Low
Unacceptable contamination of groundwaters (groundwater dependent ecosystems)	*Likelihood* (leaky wells) - low, little evidence of faulty contemporary wells leaking solutes *Likelihood* (spills) - medium *Consequence* -undetermined, impact of contaminants on surface GDEs and subterranean fauna unknown *Risk* - undetermined	• That before any further production approvals are granted, a regional water assessment be conducted as part of a SREBA for any prospective shale gas basin, commencing with the Beetaloo Sub-basin. The regional assessment should focus on surface and groundwater quality and quantity (recharge and flow), characterisation of surface and groundwater-dependent ecosystems, and the development of a regional groundwater model to assess the effects of proposed water extraction of the onshore shale gas industry on the dynamics and yield of the regional aquifer system (***Recommendations 7.5***	Undetermined

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
		• That the SREBA undertaken for the Beetaloo Sub-basin must take into account groundwater-dependent ecosystems in the Roper River region, including identification and characterisation of aquatic ecosystems, and provide measures to ensure the protection of these ecosystems ***(Recommendation 7.19***).	
Chapter 8 Land			
Environmental value 1: terrestrial biodiversity and ecosystem health			
Environmental objective 1: to ensure there is a low risk of impact on the terrestrial biodiversity values of affected bioregions and to ensure that the overall terrestrial ecosystem health, including the provision of ecosystem services, is maintained			
Unacceptable location of shale gas developments within a region	*Likelihood* - high, due to lack of region-wide biodiversity knowledge *Consequence* - high, significant threat to species that might occupy highly restricted ranges in development area *Risk* - high	• That a SREBA for all affected bioregions prior to any onshore shale gas production be conducted (***Recommendation 8.1***) • That areas with high conservation value be excluded from shale gas development (***Recommendations 8.1*** and ***14.4***)	Low
Unacceptable increase in the spread or impact of weeds	*Likelihood* - high, given experience with onshore gas developments elsewhere. *Consequence* - high, given severe potential impact on conservation and production values. *Risk* - high.	• That a baseline assessment of all weeds is undertaken (***Recommendation 8.2***) • That gas companies employ a dedicated weed management officer (***Recommendation 8.3***). • That gas companies have a weed management plan in place (***Recommendation 8.4)***	Low
Unacceptable increase in the spread or impact of exotic invasive ants	*Likelihood* - medium, given that such species are established elsewhere in northern Australia and are readily spread by vehicles and machinery. *Consequence* - high, major impacts on native species if introduced. *Risk* - high.	• That hygiene measures for vehicles and machinery are implemented (see discussion at Section 8.4.2.2 and ***Recommendation 8.4***)	Low
Unacceptable changes to fire regimes	*Likelihood* - medium, increased human activity and hence sources of ignition. *Consequence* - high, given the ecological importance of fire and its role in GHG gas emissions. *Risk* - high.	• That gas companies comply with regional fire management plans, which include requirements for baseline data, monitoring for any increase in fire frequency, and implementation of management actions as appropriate (***Recommendation 8.5***).	Low

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Unacceptable loss of native vegetation	*Likelihood* - high, given that substantial areas will be cleared of vegetation *Consequence* - low, because only small proportion of the landscape will be cleared, and fragmentation and edge effects are likely to be limited *Risk* - medium	• That as part of a SREBA, a study be undertaken to determine if any threatened species are likely to be affected by the cumulative effects of vegetation and habitat loss, and if so, that there be ongoing monitoring of the populations of these species. If monitoring reveals a decline in populations (compared with pre-development baselines), management plans aimed at mitigating these declines must be developed and implemented (***Recommendation 8.6***) • That vegetation clearing is minimised (***Recommendation 8.7***) • Progressively rehabilitate cleared areas (***Recommendation 8.8***) • Design and implement offsets to compensate for local vegetation and habitat losses (***Recommendation 8.9***)	Low
Roads and pipelines as ecological barrier or corridors	*Likelihood* - medium, given impacts of past construction of roads and pipelines *Consequence* - medium, given ecological importance of run-on/run-off dynamics in flat, semi-arid landscapes *Risk* - medium	• That gas companies be required to identify critical habitats during corridor construction and select an appropriate mechanism to avoid any impact on them ***(Recommendation 8.10)*** • That clearing for corridors, well pads and other operational areas be kept to a minimum, that pipelines and other linear infrastructure be buried (except for necessary inspection points), and that all disturbed ground be revegetated (***Recommendation 8.11***). • That directional drilling under stream crossings be used in preference to trenching (***Recommendation 8.12***) • That roads and pipeline surface water flow paths minimise erosion of all exposed surfaces and drains (***Recommendation 8.13***). • That all corridors be constructed to minimise the interference with wet season stream crossings and comply with relevant guidelines (***Recommendation 8.14***)	Low
Chapter 9 Greenhouse gases			
Environmental value 3: climate change			
Environmental objective: to limit the emissions of methane and greenhouse gases to the atmosphere			
Excessive upstream fugitive emissions of methane during upstream extraction, processing, transport and distribution	*Likelihood* - high, given that methane emissions occur mostly on a continuous basis but with some episodic releases	• That the US EPA New Source Performance Standards of 2012 and 2016 be introduced (***Recommendation 9.1***) • That a code of practice or other guideline for the ongoing monitoring, detection and reporting of emissions from wells be undertaken ***(Recommendation 9.2***)	Methane levels reduced to a level consistent with the acceptability criterion for methane

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
	Consequence - low, given that upstream methane emissions (from any new shale gas field) will contribute a very low proportion of net global methane emissions *Risk* - medium	• That baseline monitoring of methane concentrations be undertaken for at least six months prior to the grant of any exploration approvals (***Recommendation 9.3***) • That baseline and ongoing monitoring be undertaken ***(Recommendation 9.4)*** • Monitoring results should be published on a continuous real-time basis ***(Recommendation 9.5***) • That once emission concentration limits are exceeded the problem is rectified (***Recommendations 9.6***)	emissions (**Table 9.9**), but the risk remains medium (see GHG mitigation).
Chapter 10 Public health			
Environmental value 1: to prevent adverse impacts on public health by exposure to chemicals in contaminated water and air			
Environmental objective 1: to assess and manage health risks associated with contaminated surface and groundwater			
The risk estimates and risk mitigation measures for this objective are identical to those associated with water quality in Chapter 7.			
Environmental objective 3: to ensure human health risks associated with airborne emissions from gas wells and associated infrastructure are acceptable			
Unacceptable impacts on the health of nearby communities from volatile or gaseous chemicals emitted from well heads, storage ponds, processing facilities or pipelines	*Likelihood* - medium for methane. Low for VOCs but highly dependent on the distance between source and potentially exposed humans. *Consequence* - low for methane (relatively non-toxic gas). Medium for toxic gases and VOCs (such as NOx, BTEX), especially where associated with gas combustion events (flaring). *Risk* - low to medium.	• That wells are constructed and maintained to a high standard to ensure well head assemblies and pipelines are not leaking, coupled with regular monitoring to detect point source leaks (***Recommendations 5.4* and *9.4***) • That appropriate setback distances are set to minimise risks identified in HHRA reports, including potential pathways for waterborne and airborne contaminants. In the absence of local information, a default minimum setback distance of 2 km (based on US data) should be used (***Recommendation 10.2***).	Low
Unacceptable impacts on the health of nearby communities from dusts and/or diesel exhaust fumes from shale gas site preparation activities	*Likelihood* - medium, but likely to be of relatively short-term impact during the pre-production phase of well head and facility development. *Consequence* - low to medium, depending on controls over equipment movements and/or dust suppression measures. *Risk* - low to medium.	• That appropriate setback distances (based on scientific evidence) are set to protect landowners and local communities. In the absence of local information, a default minimum setback distance of 2 km (based on US data) should be used (***Recommendation 10.2***)	Low to medium

Risk	Preliminary risk assessment	Mitigation measure	Residual risk
Environmental objective 4: to ensure the human health risks associated with potential impacts on wellbeing are acceptable			
Public Health Impacts	The assessment of this objective is primarily covered in Chapter 9, together with the assessments contained in Chapters 11 and 12.	Chapter 9 does not have specific recommendations relevant to the SREBA, but notes that (p263): The Panel's analysis and recommendations in this and other Chapters, acknowledges some of the knowledge gaps that will need to be addressed through the SREBA to better inform the HHRAs and predictions of potential impacts on public health. Among these are the need for better baseline information on regional public health prior to any gasfield development (discussed further in Chapter 15).	n/a

Table 11-2. Summary of the contribution of data and understanding derived through the Beetaloo SREBA (and other studies identified in the SREBA reports, including the Beetaloo GBA program and relevant GISERA projects) to the relevant risks identified by the Scientific Inquiry, which are described in Table 11-1.

Risk	SREBA
Chapter 7 Water	
Environmental value 1: water quantity	
Environmental objective 1: to ensure all surface and groundwater resources are used sustainably	
Excessive extraction from surface water	The Beetaloo SREBA has comprehensively addressed the relevant knowledge gaps identified in Rec. 7.5, including: • Identified aquatic refugia and high-value aquatic ecosystems • Increased understanding of recharge processes, with improved and more conservative estimates of recharge • Collated available data on surface water flows and water quality • Improved data and understanding to enhance the existing high-quality coupled surface-groundwater model This risk is essentially avoided through regulatory prohibition on use of surface water by the onshore gas industry.
Excessive extraction from groundwater – regional impacts	The Beetaloo SREBA has comprehensively addressed the relevant knowledge gaps identified in Rec. 7.5, including: • Improved conceptualisation of the hydrostratigraphy of the Beetaloo Sub-basin and surrounding area • Improved understanding of the characteristics of the Cambrian Limestone Aquifer, including groundwater levels and inter- and intra-aquifer connectivity • Increased understanding of recharge processes, with improved and more conservative estimates of recharge • Characterised and mapped groundwater-dependent ecosystems • Improved data and understanding to enhance the existing high-quality coupled surface-groundwater model The SREBA has established a sound information base for the development of water allocation plans for the Georgina and Wiso Basins, which will ensure groundwater use by the onshore gas industry is within sustainable limits (Rec. 7.7).
Excessive extraction from groundwater - local impacts	The Beetaloo SREBA has comprehensively addressed the relevant knowledge gaps identified in Rec. 7.5, including: • Improved conceptualisation of the hydrostratigraphy of the Beetaloo Sub-basin and surrounding area • Improved understanding of the characteristics of the Cambrian Limestone Aquifer, including groundwater levels and inter- and intra-aquifer connectivity • Increased understanding of recharge processes, with improved and more conservative estimates of recharge • Characterised and mapped groundwater-dependent ecosystems • Improved data and understanding to enhance the existing high-quality coupled surface-groundwater model The enhanced surface-groundwater model, combined with mapping of aquatic ecosystems and GDEs, can be used to set limits to the rate and volume of water extraction if this is required to protect water-related assets at a local scale (Rec. 7.8). This may be done through WAPs informed by the SREBA data (Rec 7.7), or other regulatory processes. The conceptual understanding and data relating to aquifer connectivity and groundwater models allow assessment of whether changes in pressure due to water extraction may result in inflow from underlying or overlying aquifers (Rec. 7.16), which would usually be done at a project-specific scale and is a low risk for most of the Sub-basin due to aquifer separation.

Risk	SREBA
Environmental value 2: surface and groundwater quality	
Environmental objective 2: to maintain acceptable quality of surface and groundwater	
Unacceptable groundwater contamination from leaky production wells	The SREBA is not a specific mitigation measure for this risk. However, the SREBA has: • Reviewed all existing groundwater quality data to establish a pre-development baseline for the Beetaloo region • Provided information about the pre-development occurrence of methane and ethane in groundwater, which provides context to any future detection • Established that volatile petroleum hydrocarbons are below detection limits in groundwater samples collected across the CLA and Beetaloo Sub-basin, and so any detection of VOCs should immediately trigger the need for follow-up assessment • Documented the spatial and temporal variability in many general water quality parameters, reinforcing the need for groundwater monitoring to include targeted sampling around a given project (i.e. well-pad impact and control monitoring bore arrays, as well as nearby third-party bores), rather than using regional water quality triggers.
Unacceptable groundwater contamination due to spills of hydraulic fracturing chemicals and wastewater: on-site spills	The SREBA is not a specific mitigation measure for this risk, which is primarily managed through controls established in the Code of Practice and regulated through EMPs. However, the SREBA has: • Modelled depth to groundwater (regional aquifers) throughout the Beetaloo region, which will assist in refining risk assessment at a project scale • Established a regional baseline for groundwater quality, which provides context for groundwater monitoring (as above)
Unacceptable groundwater contamination due to changed groundwater pressures	The conceptual understanding and data relating to aquifer connectivity and groundwater models allow assessment of whether changes in pressure due to water extraction may result in inflow from underlying or overlying aquifers (Rec. 7.16). This would usually be done at a project-specific scale, but is a low risk for most of the Sub-basin due to aquifer separation.
Adverse effects of linear infrastructure (roads, pipelines) on the quality and distribution of surface water across the landscape	The information provided by the SREBA allows landscape and regional impacts to be considered in the planning phase of any infrastructure development (Rec. 7.18). This information includes: • mapping and characterisation of aquatic ecosystems, including identification of high-value systems and sites • use of a time-series of satellite imagery to map maximum extent of surface water and other inundation metrics Uniform mapping of environmental features at relatively high resolution across the region allows cumulative effects of multiple development proposals to be quantified for assessment.
Environmental value 3: aquatic ecosystems and biodiversity	
Environmental objective 3: to adequately protect ecosystems and biodiversity that are dependent on surface water or groundwater	
Excessive extraction from surface waters	The Beetaloo SREBA has comprehensively addressed the relevant knowledge gaps identified in Rec. 7.5, including: • Mapped and characterised aquatic ecosystems throughout the region • Identified aquatic refugia, high-value aquatic ecosystems and important sites for waterbirds • Increased understanding of recharge processes, with improved and more conservative estimates of recharge • Collated available data on surface water flows and water quality

<table>
<tr><th>Risk</th><th>SREBA</th></tr>
<tr><td></td><td>Improved data and understanding to enhance the existing high-quality coupled surface-groundwater model
This risk is essentially avoided through regulatory prohibition on use of surface water by the onshore gas industry.</td></tr>
<tr><td>Excessive extraction from groundwaters</td><td>The Beetaloo SREBA has comprehensively addressed the relevant knowledge gaps identified in Rec. 7.5, including:
Improved conceptualisation of the hydrostratigraphy of the Beetaloo Sub-basin and surrounding area
Improved understanding of the characteristics of the Cambrian Limestone Aquifer, including groundwater levels and inter- and intra-aquifer connectivity
Increased understanding of recharge processes, with improved and more conservative estimates of recharge
Characterised and mapped groundwater-dependent ecosystems
Documented stygofauna occurring in the Cambrian Limestone Aquifer
Improved data and understanding to enhance the existing high-quality coupled surface-groundwater model
The SREBA has established a sound information base for the development of water allocation plans for the Georgina and Wiso Basins, which will ensure groundwater use by the onshore gas industry is within sustainable limits (Rec. 7.7) and that groundwater dependent ecosystems are maintained.
The SREBA mapped groundwater-dependent vegetation associated with groundwater discharge in the vicinity of Mataranka; characterised aquatic ecosystems in the upper Roper catchment, including identifying high-value ecosystems; and documented the stygofauna occurring in the Cambrian Limestone Aquifer with a focus on the Mataranka Tindall Limestone (Rec. 7.20). With the improved conceptual understanding of the CLA and enhanced groundwater-surface water model, this can inform the protection of these ecosystems, through WAPs and other measures (Rec. 7.19).</td></tr>
<tr><td>Unacceptable contamination of surface waters (aquatic ecosystems)</td><td>The SREBA is not a specific mitigation measure for this risk, which is primarily managed through controls established in the Code of Practice and regulated through EMPs. However, the SREBA has:
Mapped and characterised aquatic ecosystems throughout the region
Identified aquatic refugia, high-value aquatic ecosystems and important sites for waterbirds
This can assist in refining risk assessment at a project scale, or developing additional regulatory measures if necessary to further reduce risks to high-value sites.</td></tr>
<tr><td>Unacceptable contamination of groundwaters (groundwater dependent ecosystems)</td><td>The Beetaloo SREBA has comprehensively addressed the relevant knowledge gaps identified in Rec. 7.5, including:
Improved conceptualisation of the hydrostratigraphy of the Beetaloo Sub-basin and surrounding area
Improved understanding of the characteristics of the Cambrian Limestone Aquifer, including groundwater levels and inter- and intra-aquifer connectivity
Increased understanding of recharge processes and groundwater flow rates, with improved and more conservative estimates of recharge
Characterised and mapped groundwater-dependent ecosystems
Documented stygofauna occurring in the Cambrian Limestone Aquifer
Improved data and understanding to enhance the existing high-quality coupled surface-groundwater model
This improved understanding will allow assessment of risks from contaminants to surface and subterranean groundwater-dependent ecosystems to be assessed, noting that the higher value groundwater-dependent ecosystems occur outside the Sub-basin.</td></tr>
</table>

Risk	SREBA
	The SREBA mapped groundwater-dependent vegetation associated with groundwater discharge in the vicinity of Mataranka; characterised aquatic ecosystems in the upper Roper catchment, including identifying high-value ecosystems; and documented the stygofauna occurring in the Cambrian Limestone Aquifer with a focus on the Mataranka Tindall Limestone. With the improved conceptual understanding of the CLA and enhanced groundwater-surface water model, this can inform the protection of these ecosystems through WAPs and other measures (Rec. 7.19).
Land	
Environmental value 1: terrestrial biodiversity and ecosystem health	
ecosystem services, is maintained	
Unacceptable location of shale gas developments within a region	The SREBA has undertaken strategic regional terrestrial biodiversity assessments in line with Rec 8.1, including: • Systematic regional surveys of plants, vertebrate fauna and ants • Describing vegetation communities and developing a uniform vegetation map for the Beetaloo region • Targeted surveys of waterbirds and priority threatened vertebrate species, and development of spatial distribution models for some species This assessment (in combination with equivalent assessment of aquatic ecosystems) allows areas of high conservation value to be identified (Rec 8.1). This can be done on a tiered scale, so that exclusion of development can be considered for the highest value areas, and other regulatory approaches to minimise risks in relatively lower value areas.
Unacceptable increase in the spread or impact of weeds	The text of the Final Report recommended that a baseline assessment of weeds must occur as part of a SREBA, but also that this should occur prior to onshore gas exploration activities. In accordance with Recs. 8.2, 8.3 and 8.4, regulatory requirements for having baseline weed assessments on exploration permits, employing a weed management officer and writing weed management plans were implemented prior to the SREBA commencing. Nevertheless, the SREBA has documented the occurrence of weed species at flora survey sites throughout the Beetaloo region.
Unacceptable increase in the spread or impact of exotic invasive ants	The SREBA undertook a systematic regional survey of the ant fauna across the Beetaloo region, which provides a pre-development baseline of the occurrence and distribution of exotic ant species.
Unacceptable changes to fire regimes	The SREBA: • Documented pre-development fire regimes in the Beetaloo region • Assessed the role of fire regimes as a factor influencing flora and fauna assemblage composition and richness, and the occurrence of and habitat suitability for priority threatened species • Identified vegetation communities and threatened species for which inappropriate fire regimes are likely to be a significant threat • Recommended regional monitoring of fire regimes to assess potential medium- to long-term impacts from onshore gas development
Unacceptable loss of native vegetation	The SREBA: • Described vegetation communities and developed a uniform vegetation map for the Beetaloo region • Undertook targeted surveys of priority threatened vertebrate species and developed spatial distribution models for some species • Evaluated known threats to priority threatened species

Risk	SREBA
	• Recommended regional monitoring of vegetation clearing using remote-sensing techniques to evaluate the cumulative impacts of land clearing, both in terms of the total extent of clearing for each vegetation community and metrics of fragmentation at various scales. The SREBA did not identify any terrestrial threatened species occurring in the Beetaloo that was likely to be affected by cumulative effects of habitat loss, given existing regulatory tools to mitigate that risk. The SREBA found that effective monitoring of threatened species was unlikely to be feasible and this was not recommended.
Roads and pipelines as ecological barrier or corridors	
Greenhouse gases	
Environmental value 3: climate change	
Environmental objective: to limit the emissions of methane and greenhouse gases to the atmosphere	
Excessive upstream fugitive emissions of methane during upstream extraction, processing, transport and distribution	
Public health	
Environmental value 1: to prevent adverse impacts on public health by exposure to chemicals in contaminated water and air	
Environmental objective 1: to assess and manage health risks associated with contaminated surface and groundwater	
Contamination of soil and groundwater	In addition to the measures described above for the Water theme, the SREBA has: • Characterised and mapped dominant soil types of the Beetaloo region, and assessed the risk of transportation or retention of chemicals in these soils, and provided a soils monitoring and management plan • Identified where current water monitoring regimes may need to be extended, with monitoring indicators specifically for human health, upon commencement of onshore gas activities.
Unacceptable impacts on the health of nearby communities from volatile or gaseous chemicals emitted from well heads, storage ponds,	

Risk	SREBA
processing facilities or pipelines	
Unacceptable impacts on the health of nearby communities from dusts and/or diesel exhaust fumes from shale gas site preparation activities	
Environmental objective 4: to ensure the human health risks associated with potential impacts on wellbeing are acceptable	
Public Health Impacts	The SREBA has: • Reviewed relevant literature to identify potentially useful indicators in relation to health issues that may be of relevance in the context of the Beetaloo region • Investigated the availability and utility of relevant health indicators for communities within the Beetaloo region • Developed a monitoring plan with recommended indicators and proposed collection methods, noting the requirement for further stakeholder engagement to refine and agree on indicators • Identified significant limitations to robust epidemiological analysis based on the public health data that are likely to be available through a monitoring program.

11.2. Impact assessment for the Beetaloo GBA region

11.2.1. Background

The GBA Program developed a novel approach using causal networks to assess the regional-scale risks of unconventional gas development in the Beetaloo region (Huddlestone-Holmes *et al.* 2021), as well as for the Cooper Basin. This approach is potentially superior to the conventional likelihood/consequence risk assessment commonly applied in environmental impact assessment because it systematically and transparently quantifies residual risk (i.e. risk remaining after applying all feasible mitigation measures) from impacts on one or more valued assets for multiple causal pathways addressed collectively. It can also represent spatial variation in risk across the potential impact area (Peeters *et al.* 2022).

Causal networks are graphical models that describe the cause-and-effect relationships linking development activities with endpoints (values that we wish to protect). The network consists of nodes that represent the different components of the system (drivers, activities, stressors, processes and endpoints; Table 11-4), connected by links, which show the hypothesised relationship between nodes based on the current understanding of the system.

A causal network provides a consistent way to understand and evaluate impacts on these values due to development activities. Priorities for management, mitigation and monitoring can be identified where the pathway of cause-and-effect relationships from development activities to endpoints could have a material impact — which is a change that exceeds defined thresholds in terms of magnitude, extent, duration, timing or frequency. To assess environmental impacts at a regional scale, a complex causal network consisting of many nodes and links is needed to represent all the cause-and-effect relationships. The causal network approach is explained in detail in Peeters *et al.* (2022).

Table 11-4. Node types, examples and number of each node type in the causal network for the Beetaloo GBA region (Table 1 from Huddlestone-Holmes *et al.* (2021).

Node type	Description	Examples	Number of nodes
Driver	Major external driving forces (human or natural) that have large-scale influences on natural systems	Resource development	1
Activity	A planned event associated with unconventional gas resource development	Civil construction Transport of materials and equipment	9
Stressor	Physical, chemical or biological agent, environmental condition or external stimulus caused by activities	Dust generation Vehicle movement	23
Process	A naturally occurring mechanism that could change a characteristic of an endpoint	Confined aquifer drawdown Habitat degradation, fragmentation and loss	14
Endpoint	A value pertaining to water and the environment that may be impacted by development of unconventional gas resources	Surface water condition Persistence of Gouldian finch	15

The causal network developed for the Beetaloo Basin captures the relationships between unconventional gas resource development activities and the complex and interconnected nature of the natural environment in the assessment region.

The approach allows for a consistent and systematic evaluation of the cause-and-effect relationships that link nodes in the network (Table 115), along with an appraisal of the confidence in this evaluation (Table 11-6). Mitigation strategies mandated through regulatory controls or operational practices are also considered. The link evaluations are then combined to assess the pathways of potential impact between development activities and the environmental values in the region. The assessment is conducted spatially, which allows identification of areas where impacts are unlikely, as well as areas where potential impacts cannot be ruled out.

Overall results of the impact assessment are reported as levels of concern for pathways, ranging from pathways of 'very low concern', where impacts are not physically possible or are extremely unlikely; 'low concern', where impacts can be avoided by current legislation or because the impact does not represent a change that exceeds a defined threshold (material change); 'potential concern', where a pathway could have an impact but the impacts can be minimised or mitigated by existing management controls; to 'potentially high concern' for pathways for which impacts cannot be avoided or mitigated (Table 115).

Table 11-5. Evaluation language used to describe links in the causal network and the corresponding level of concern used to describe the impact pathway through to endpoints (Table 2 from Huddlestone-Holmes *et al.* (2021).

Evaluation			
Not possible	Possible but not material Possible and material but can be avoided	Possible, material and unavoidable but can be mitigated	Possible, material, unavoidable and cannot be mitigated
Level of concern			
Very low concern	Low concern	Potential concern	Potentially high concern
Impacts are not physically possible or are extremely unlikely (having a probability of less than 1 in 1,000)	Impacts can be avoided by current legislation or because the impact does not represent a material change	Impacts can be minimised or mitigated by existing management controls	Impacts cannot be avoided or mitigated at the scale of the GBA region

Table 11-6. Confidence assessment of links in the causal network (Table 3 from Huddlestone-Holmes *et al.* (2021).

Are we confident that the link is possible? [a]	Are we confident that the link is or is not material? [b]	Are we confident the link can or cannot be mitigated? [c]	Confidence
Yes	Yes / Not applicable	Yes / Not applicable	High
Yes	Yes	No	Medium
Yes	No	Yes	Medium
No	Yes	Yes	Medium
Yes	No	No / Not applicable	Low
No	Yes	No / Not applicable	Low
No	No	Yes	Low
No	No / Not applicable	No / Not applicable	Low

[a] based on publication(s) with local system relevance or self-evident
[b] based on publication(s) with local system relevance
[c] based on publication(s) with local system relevance or publicly documented in approval conditions or proponent protocols

11.2.2. Results

The causal network constructed for the Beetaloo GBA region had 62 nodes, 197 links and 2,078 pathways. Activities arising from the single driver (resource development) included transport, civil construction, wastewater management and processing of hydrocarbons, in addition to drilling and hydraulic fracturing. A large number of potential stressors arise from these activities (including, for example, groundwater extraction), which may lead to processes (for example, unconfined aquifer drawdown) that can impact endpoints. The endpoints in the GBA risk assessment were related to water (e.g. aquifer condition, spring condition, surface water condition), other environmental features (e.g. terrestrial vegetation extent and condition, agricultural productivity) and six "protected matters" under the EPBC Act (e.g. persistence of Gouldian Finch, persistence of Gulf Snapping Turtle). The full causal network is illustrated in Figure 11-1, but can also be explored through an interactive web portal GBA Explorer (https://www.bioregionalassessments.gov.au/).

It should be noted that the GBA risk assessment outcomes may differ significantly from those of the Scientific Inquiry, because the former had access to additional information about the Beetaloo region, and considered mitigation measures based on regulatory requirements that have been introduced or strengthened subsequent to the Inquiry, and in line with its recommendations.

The GBA assessment identified no pathways of **potentially high concern** between unconventional gas resource development and water and the environment in the Beetaloo GBA region. All potential impacts could be mitigated through compliance with existing regulatory and management controls, with a high degree of confidence.

Pathways of **potential concern** identified in the assessment were primarily related to activities that create a disturbance at the surface (transport of materials and equipment, civil construction, decommissioning and rehabilitation, and seismic data acquisition). The pathways of **potential concern** connect these activities with protected matters, protected fauna and terrestrial vegetation. There was high confidence that these potential impacts could be mitigated successfully, primarily through the implementation of activity-specific environmental management plans required under Northern Territory regulations. The GBA report noted that the knowledge base was limited for some cause-and-effect relationships and confidence in the assessment would be improved as knowledge of these relationships and material change thresholds are established.

The assessment found that pathways associated with sub-surface activities (drilling, hydraulic fracturing, production of hydrocarbons) were of **low concern** or **very low concern**. Stressors of high community concern, such as those involving well integrity or chemical spills, were unlikely to cause material changes to endpoints when existing regulatory and management controls are implemented.

There was high confidence that potential impacts due to unconventional gas resource development can be mitigated for all pathways of **potential concern**. However, confidence in the cause-and-effect relationship and thresholds of material change was generally low, reflecting that the knowledge base on hydrological and ecological functioning at the local scale was limited (at the time the assessments were done). However, where there was insufficient knowledge to support a robust threshold of material change, links were generally evaluated as 'material' by applying the precautionary principle. The GBA report noted that confidence in the assessment would be improved as knowledge of these relationships and thresholds is developed, although improved understanding of thresholds is likely to reduce the number of pathways of **potential concern**.

The impact assessment outcomes are described further below, summarised from Huddlestone-Holmes *et al.* (2021).

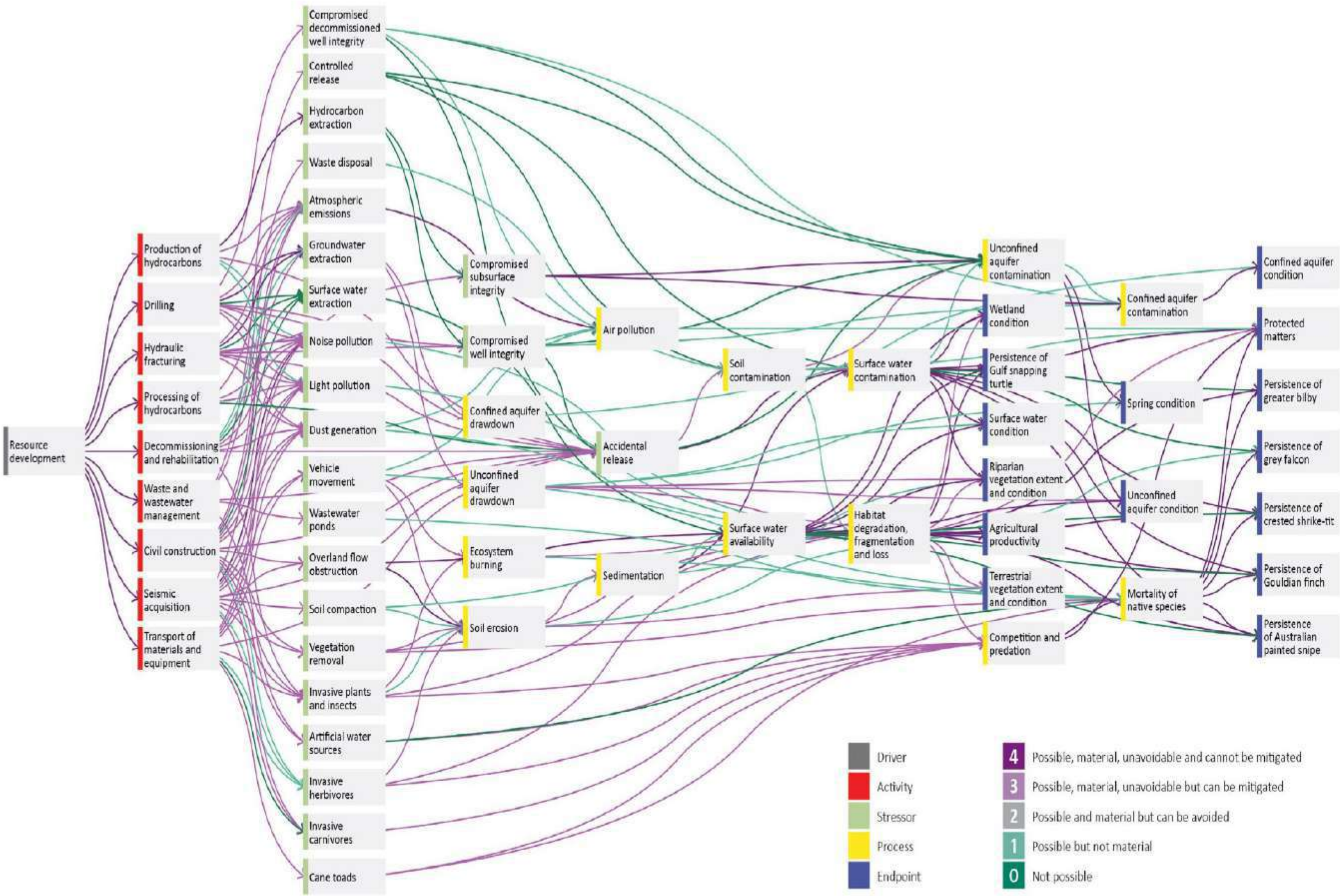

Figure 11-1. Causal network for the Beetaloo GBA region with links colour-coded according to their evaluation of likelihood, consequence and mitigation (Figure 6 from Huddlestone-Holmes *et al.* (2021).

11.2.2.1. Impacts on water

The potential pathways for impacts on water related to water extraction, changes to surface water availability and those resulting in contamination of surface water or aquifers.

Numerical modelling of groundwater drawdown for the volumes likely to be used for onshore gas development found that drawdown at the local scale was of **low concern**, particularly if regulation prevented extraction within 1 km of existing bores. Similarly, assessment using available water volumes, current allocations and estimated recharge showed potential impacts of drawdown at a regional scale were of **low concern**, and impacts on spring flow, base flow to rivers and groundwater-dependent ecosystems were of **very low concern**.

Surface water extraction for petroleum activities is prohibited in the Northern Territory. Impact pathways of **potential concern** were identified for activities that affect surface water flow by diverting or modifying flow paths where these occur in the vicinity of waterways, but these can be mitigated through operational requirements in environmental management plans.

Accidental release of contaminants from leaks and spills is of **potential concern** for surface water and groundwater-dependent ecosystems, but these risks can be mitigated through controls to prevent spills and buffers to waterways. Impacts on groundwater quality from spills and leaks are also of **potential concern** where groundwater is shallow (< 14 m) but groundwater is significantly deeper than this in most of the Beetaloo Sub-basin.

Potential pathways for groundwater contamination through sub-surface activities were assessed as of **low concern** to **very low concern** due to existing engineering controls on wells and hydraulic fracturing operations and the vertical separation distances between unconventional gas resources and overlying aquifers. There was a small area (about 4% of the region) of **potential concern** where the Hayfield sandstone member, a potential target for gas resource development, and the overlying Bukalara Sandstone aquifer are relatively close. This pathway is mitigated by existing engineering controls and the Bukalara Sandstone is unlikely to be used as a groundwater resource by other users.

Contamination due to waste disposal was assessed as of **low concern** due to stringent approval and management requirements. Disposal of hydraulic fracturing waste, including wastewater, to surface water or groundwater is prohibited in the Northern Territory.

11.2.2.2. Impacts on the environment

For this assessment, the environment of the Beetaloo region (excluding aquatic environments considered during assessment of impacts on water) were considered in terms of three ecosystems: (i) terrestrial vegetation that is dominated by rainfall-dependent open woodlands; (ii) riparian ecosystems that include flora and fauna dependent on the presence of rivers and streams; and (iii) ephemeral wetlands.

The pathways of **potential concern** for impacts on the environment resulting from development activities were from the introduction of invasive plants, vegetation removal and vehicle movement. These impacts were generally localised and can be minimised or mitigated, as required by existing regulations, by locating infrastructure away from sensitive habitats, applying buffers to waterways, minimising vegetation removal, controlling invasive species and minimising vehicle access to undisturbed areas.

11.2.2.3. Impacts on protected matters

Six protected matters (species listed as threatened under the EPBC Act) were assessed – Australian Painted Snipe, Crested Shrike-tit (Northern), Gouldian Finch, Grey Falcon, Greater Bilby and Gulf Snapping Turtle.

Pathways of **potential concern** for these fauna species were primarily related to activities that create a disturbance at the surface (civil construction, decommissioning and rehabilitation, transport of materials and equipment, and seismic acquisition), and associated threats including increases in invasive plants and animals and vegetation removal. The aquatic Gulf Snapping Turtle is potentially affected by surface water contamination and the Gouldian Finch, Crested Shrike-tit, Greater Bilby and Grey Falcon by increase in predation by invasive carnivores that may be favoured by access to artificial water sources. Potential impacts can be mitigated by avoiding sensitive habitat; minimising the extent and location of new facilities, roads and pipelines; managing invasive species; and by ensuring rapid and effective remediation of disturbed sites, as well as monitoring.

11.2.3. Assumptions and limitations

As for any such assessment, a number of assumptions were made in using the causal network to evaluate the potential impacts of unconventional gas development in the Beetaloo region. These are described in detail in Huddlestone-Holmes *et al.* (2021), but the key assumptions are summarised below.

- Development activities associated with the five life-cycle stages of unconventional gas resource development were correctly represented in the causal network. This was necessarily based on current and immediately foreseeable technologies and practices.
- The resource development scenario used was a realistic estimate of the likely magnitude of future development. The GBA assessment used a development scenario based on the GALE scenario used in the Scientific Inquiry, with peak production of 365 petajoules per year over a 25-year time period, requiring up to 1,150 wells. The development would directly disturb between 8 km^2 and 35 km^2 for infrastructure such as access roads and well pads within a total project area of between 430 km^2 and 7,700 km^2. This scenario would require a total of up to 46 gigalitres of water over the 25-year development period (1.84 Gl annually), based on an estimate of 40 megalitres per well for drilling and hydraulic fracturing.
- The causal network adequately represents the activities and stressors associated with unconventional gas resource development, their interaction with complex ecological and hydrological systems, and their endpoints at a regional scale. Other drivers (such as climate change and other industries) were not assessed, and there is an implicit assumption that those drivers are not changing processes and predicted responses to such a degree that impacts on endpoints would be materially altered.
- The existing regulatory controls in place to mitigate potential impacts are complied with by industry and enforced by regulators. The mitigation and management practices are most effective at the activity-to-stressor step of a causal pathway, whereas links from stressors to natural processes and from natural processes to endpoints are often difficult, if not impossible, to mitigate. In the Northern Territory, in addition to regulations that prohibit certain activities (such as extraction of surface water or disposal of wastewater to surface water or groundwater), the primary means of mitigation are environmental management practices. These are set out in Environment Management Plans for petroleum activities, as required by the *Petroleum (Environment) Regulations 2016* (NT) and reinforced by mandatory requirements contained in supporting codes of practice and guidelines.

There are some key limitations to the risk assessment arising from the scope of the GBA program and the use of the causal network approach.

- The GBA scope encompassed environmental values, particularly those associated with water and protected matters under the EPBC Act. Social, cultural and economic values were not considered in this assessment.
- Ecological endpoints at the most detailed level (species or ecological communities) were limited to six selected priority species, so risks to other components of biodiversity are potentially unrecognised (for example, stygofauna). However, the assessment did have other endpoints that represent important habitats or integrate major elements of biodiversity (the condition of aquifers, springs, surface water, wetlands, riparian vegetation and terrestrial vegetation). Similarly, the stressors and processes represented in the causal network would be relevant to much of the biota in addition to those specifically represented in the endpoints.
- The causal network encompasses multiple stressors from a single driver (onshore gas development), but does not assess the potential cumulative impacts of multiple stressors from multiple industries. It is theoretically possible to elaborate the network to do this, especially as many of the relevant processes affecting the endpoints are already captured in the network. This would be more easily done when future development scenarios are more certain, and there are projections of the magnitude and likelihood for all stressors (Peeters *et al.* 2021).
- Inevitably, the causal network involves simplification of very complex ecological interactions. For example, it cannot readily incorporate feedback loops in ecological systems; and it only considers potential adverse impacts of activities, whereas they may also provide potential benefits. These considerations reinforce the need for ongoing monitoring and evaluation to test the risk assessment outcomes.

11.2.4. Refinement and monitoring

The GBA Stage 3 report noted that the causal network for the Beetaloo region can be updated as more knowledge becomes available, including through the SREBA program. This would allow refinement of the assessment of the causal pathways identified as being of potential concern, and the addition of new nodes, links and endpoints if needed. There is potential to use the causal network to inform environmental impact assessment at a project scale, through ensuing that pathways of concern are addressed and identifying priorities for mitigation and monitoring.

The causal network can be used to identify particular points along the pathway between activities, stressors, processes and endpoints where monitoring would be most useful. Specific monitoring objectives can be ‘measurement endpoints’ associated with particular endpoints (e.g. abundance of a threatened species). Alternatively, they can be ‘environmental condition indicators’ associated with stressors or processes and that may link to many endpoints (e.g. regional fire metrics). Four broad monitoring objectives were identified.

- Estimating baseline and trend: The baseline comprises measurement endpoints and environmental condition indicators prior to resource development; for example, groundwater chemistry, extent of vegetation communities. These have been established through the GBA and SREBA program for a broad range of endpoints. Future onshore gas developments may require additional monitoring to provide local-scale baseline and trend data for selected indicators.
- Comparing impact and control sites: this is required to measure the true impact of onshore gas development. At a regional scale, ‘control’ sites would be established at locations where no or few processes lead to pathways of ‘potential concern’ and impact sites would be in areas potentially affected by multiple stressors of ‘potential concern’.

- Monitoring compliance with, and effectiveness of, mitigation strategies: Monitoring and reporting of operator compliance to legal requirements is required under NT and Australian Government regulations, including the *Petroleum (Environment) Regulations 2016*. Compliance monitoring is advised for mitigation strategies associated with links between activities and stressors. Meanwhile, the environmental condition indicators associated with links from stressors to processes are good candidates to monitor effectiveness of mitigation strategies associated with a stressor.
- Monitoring to validate and refine the causal network: Monitoring can improve understanding and confidence in the assessment and evaluation of individual links, particularly between stressors and processes along pathways of concern, and provide more information on material thresholds.

11.2.5. Implications of SREBA for the GBA impact assessment

The Beetaloo GBA impact assessment was completed in early 2021, while SREBA studies were underway but before SREBA data collection had been completed. Many of the subject matter experts involved in the SREBA water and ecology baseline studies contributed to the assessment of pathways during the development of the causal network. Conversely, much of the information collected for the Beetaloo GBA program, particularly in relation to hydrogeology, has informed the findings of the SREBA biophysical studies. Nevertheless, the SREBA (along with other very recent studies) has developed significant additional data and understanding relating to the natural environment in the Beetaloo study area to that available during development of the GBA impact assessment, as summarised below.

Water

- Additional pump test data to improve understanding of aquifer properties and connectivity.
- Additional investigation of connectivity between pre- and post-Cambrian formations.
- Improved conceptualisation of the CLA, drawing on updated assessment of downhole geophysical logs and lithological descriptions, water chemistry information and pump tests.
- Additional data on groundwater levels and seasonal, multi-year and long-term groundwater level fluctuations to improve understanding of groundwater flow paths and velocities, and recharge patterns.
- Mapping of potential recharge areas across the wider CLA.
- More accurate quantitative estimates of groundwater recharge rates across the Beetaloo study area.
- Environmental tracer studies of CLA groundwater flow systems to the Flora River.
- Investigation of groundwater and methane discharges in Hot Springs Valley.
- Investigation of AET fluxes for the CLA Flora River and Roper River discharge areas.
- Review of all available groundwater quality data from the Beetaloo study area.
- Review of existing surface water quality data.

Aquatic ecosystems

- Mapping and characterisation of aquatic ecosystems.
- Systematic surveys for of aquatic biota and analysis of environmental drivers of species richness and composition.
- Identification of high-value aquatic ecosystems and refuges for aquatic biota and waterbirds.
- Documentation of stygofauna assemblages and their distribution in the CLA.

Terrestrial ecosystems

- Systematic terrestrial flora and fauna surveys and analysis of environmental drivers of species richness and composition.
- Completion of a uniform vegetation map and characterisation of vegetation communities.
- Identification and mapping of all potential groundwater-dependent vegetation.
- Further targeted survey of priority threatened species, including spatial distribution models for four species.
- Assessment of sites and vegetation communities of high ecological value.

An initial review suggests that it is likely that incorporation of this additional SREBA data and information will not significantly change the results from the GBA impact assessment, because:

- no additional stressors or processes are identified, so most of the structure of the causal network would remain unchanged
- where additional endpoints of concern have been identified (e.g. waterbird aggregations, aquatic refugia, stygofauna), other endpoints that have been assessed are likely to be subject to similar pathways and levels of risk (e.g. wetland condition, aquifer condition).

Rather, the additional SREBA data are likely to:

- significantly improve the confidence associated with the risk assessments, which is low for cause-and-effect relationships and thresholds of material change for many of the pathways in the causal network (see Table 4 in Huddlestone-Holmes *et al.* (2021))
- signficantly improve the spatial resolution at which many of the risk assessment outcomes can be mapped.

The causal network developed by the GBA Program is a powerful and flexible tool for risk assessment that is already well developed (for risks associated with biophysical values) for the Beetaloo Sub-basin. It is recommended (see section 12.5) that the NT Government engage with the Australian Government and CSIRO to incorporate additional data and knowledge obtained through the SREBA into the Beetaloo causal network and to update the impact assessment, with additional endpoints, nodes and links where required.

Additionally, given the substantial investment into this approach, it is recommended that the GBA Explorer interface be developed further as an operational tool that can be applied during the environmental impact assessment process for future onshore gas development in the Beetaloo Sub-basin. This would involve CSIRO working with NT Government regulators to explore how it can be most effectively used to inform the assessment and approval process, with a goal of handing over this tool to the NT Government for future use, including maintenance and update as additional relevant data become available.

11.3. References

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12. Application of the SREBA

This section discusses the application of the SREBA data and information and, based on the preceding sections, provides some recommendations to ensure the value of the SREBA is maximised in the context of any future onshore gas development in the region.

12.1. Enhanced protection for key values

The Scientific Inquiry made a large number of recommendations that it considered in totality could mitigate the risks associated with any onshore gas industry in the NT to acceptable levels. This included recommendations to entirely exclude onshore gas development from parts of the Northern Territory according to a range of criteria (including national parks, areas of high ecological value and areas of cultural significance), a number of recommendation aimed at improving the regulatory regime for onshore gas activities, and recommendations for controls to minimise the likelihood of significant impacts from onshore gas development on key environmental and socio-cultural values, including surface and groundwater.

The implementation of these recommendations is reported elsewhere (https://hydraulicfracturing.nt.gov.au/action-items) but key changes relevant to the assessment of risks to, and improved protection of, values described by the SREBA studies are summarised below.

- Amendments to the *Petroleum (Environment) Regulations 2016* (PER), creating the power for the relevant Minister to establish a code of practice for petroleum activities. The *Code of Practice: Onshore Petroleum Activities in the Northern Territory* was approved in June 2019. All Environment Management Plans submitted for approval for onshore gas activities must demonstrate compliance with the Code of Practice and other requirements of the PER. Amongst other matters, the PER and Code of Practice includes requirements:
  - related to preventing contamination of surface water and groundwater quality, such as the requirement for use of secondary containment for all chemical and wastewater storage areas
  - for groundwater quality monitoring, including a requirement for proponents to comply with the *Preliminary Guideline for Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-Basin*, finalised in November 2018. The Guideline establishes requirements to monitor for leaks from wells to prevent groundwater contamination.
  - for avoidance of sensitive habitat areas such as riparian zones and their buffers to the greatest extent possible when planning activities
  - for the development of project-specific weed management plans that comply with the *NT Weed Management Planning Guide: Onshore Petroleum Projects*. These obligations include requirements to undertake baseline weed studies to ensure adequate understanding of the weeds at sites, and for informing the development of the site-specific weed management plans
  - for consideration of environmental sensitivities when undertaking planning for the location of onshore petroleum activities
  - for the development and implementation of site-specific fire management plans
  - to monitor and report on a range of environmental indicators as a condition of licences and approvals and requirements in the Code of Practice
  - for ongoing methane leak detection from petroleum wells.

- Declaring the Daly Roper Beetaloo Water Control District in July 2018 to ensure any bore drilling or water extraction was captured under a permit and/or licensing regime. The Water Control District boundaries were extended to include the Georgina Basin and part of the Wiso Basin via a further declaration in October 2022. The declaration of the Water Control District in 2018 was a precursor to the development of relevant WAPs under the *Water Act 1992* (NT) for the allocation of water resources in the Beetaloo Basin.
- Amendments to the *Water Act 1992* (NT) in 2018 to remove a provision that exempted mining and petroleum activities from licencing and permit requirements under the *Act*. This means that licence applications for water to support petroleum activities must be assessed under the *Act* and in accordance with the allocation policies and protections to river flows and groundwater-dependent ecosystems that apply to all licencing decisions in the Northern Territory. These protections are further enhanced where a Water Allocation Plan is in effect through specific rules tailored to the region.
- Major reform of the Northern Territory's environmental impact assessment framework, resulting in the repeal of the *Environmental Assessment Act* and introduction of the *Environment Protection Act 2019*. These reforms continue to ensure that significant impacts on the Territory's landscapes are considered by the independent NT EPA within an improved regulatory framework. The reforms also introduced a new 'environmental approval' containing conditions to manage significant impacts, as granted by the Environment Minister at the completion of the assessment process.
- Approval of the *Petroleum Reserved Block Policy* in July 2019, and ongoing implementation of this policy in four tranches (https://nt.gov.au/industry/mining-and-energy/land-tenure-and-availability/petroleum-reserved-blocks). Areas to be declared as Reserved Blocks because they met the criterion of "high ecological value" were identified as being the 67 Sites of Conservation Significance in the NT (https://nt.gov.au/environment/environment-data-maps/important-biodiversity-conservation-sites/sites-of-conservation-significance).

Synthesis of the data and information collected during the SREBA has identified some emergent themes and areas within the Beetaloo study area of outstanding or high environmental value (Section 10). Consideration of these values and the risk assessments previously undertaken for onshore gas development in this region (Section 11) suggest a number of measures that build on the developments described above, which will strengthen the protection of these high-value areas and increase community confidence that these values will be effectively protected.

These measures are described in detail in Section 10.2 in relation to each specific value. In general terms, they involve:

- extending the boundaries of existing Reserved Blocks to capture the full extent of the two identified areas of outstanding environmental value: Lake Woods / Longreach Waterhole, and the Roper Discharge Zone (Figures 10-1 and 10-2)
- refreshing the GBA impact assessment to incorporate the additional data available from the SREBA studies and with the high environmental value areas and associated values as explicit endpoints
- amendment of the Code of Practice to exclude some activities associated with onshore gas development in the vicinity of identified areas of high environmental value (Figure 10-3), and where there is a shallow depth to groundwater within unconfined aquifers

- ensuring groundwater extraction is within sustainable limits through implementation of Water Allocation Plans (Georgina-Wiso, Mataranka Tindall Limestone and Flora)
- inclusion of a representative set of sites in outstanding and high environmental value areas within the proposed Beetaloo regional monitoring program (Section 12.2)
- explicit consideration of risks to identified high-value areas in Environment Management Plans including potential for offsite, downstream impacts.

12.2. Regional monitoring

As described in the Final Report, one of the purposes of the SREBA is the collection of baseline data to provide a reference point for ongoing monitoring. Monitoring the impact of any major onshore gas development in the Beetaloo region is essential to test whether the previous assessment of risks was accurate, that mitigation measures and regulatory controls are effective, and to trigger and inform appropriate corrective measures if unacceptable impacts occur. Monitoring can occur at two general scales.

- The project scale, usually as result of regulatory requirements (for example, water monitoring bores established at each well pad in accordance with the *Preliminary Guideline: Groundwater Monitoring Bores for Exploration Petroleum Wells in the Beetaloo Sub-basin*) and as arising from approval conditions for activities. Project-scale monitoring is generally designed to detect direct effects from project activities on the environment in the immediate vicinity of the project footprint.
- The regional scale, which is rarely implemented through regulations or approvals associated with individual projects. Monitoring at a regional scale, if carefully designed, can be effective in detecting the cumulative impacts of multiple projects that would not necessarily be apparent through project-scale monitoring. It may also detect indirect impacts of projects that occur distant from their footprint and outside the scope of project scale programs. Regional-scale monitoring may use data collated from a set of project-scale monitoring programs, but it is likely that additional data collection will be required to meet the objectives of a regional program.

The Scientific Inquiry paid particular attention to monitoring for potential impacts of drilling, fracturing and wastewater management on groundwater quality (for example, Recommendations 7.11, 7.13); monitoring methane emissions at well and gasfield scales (Recommendations 9.2 to 9.5); and long-term monitoring of social impacts from future development (Recommendations 12.5 and 12.7). Much of the focus of the Scientific Inquiry was on appropriate monitoring of industry activity to ensure regulatory compliance and, with the specific exception of long-term regional monitoring for social impacts (Section 12.5 of the Final Report), there was less attention on the requirement for a structured regional monitoring program across all potential impact pathways and receptors. Nevertheless, the need for such a program is implicit in many of the recommendation of the Final Report, and was one of the purposes of establishing baseline data across multiple domains through the SREBA.

The SREBA Framework and the Scope of Works for each SREBA domain established a requirement for each baseline study to report on suitable indicators and methods for regional monitoring relevant to that domain. More specifically, the design of a regional monitoring framework was one output from the Strategic Regional Assessment as part of the Social, Cultural and Economic SREBA domain.

The findings from each SREBA domain relating to the development of a regional monitoring framework are collated here. These could be broadly grouped into 'biophysical' and 'social impact' themes, noting that there is some overlap between these two (for example, ecological and cultural values may overlap and be monitored together). It is stressed that the monitoring programs described below are focused at the regional scale and are additional to numerous requirements for project-scale monitoring reflected in Inquiry recommendations and the current regulatory regime for onshore gas activities (such as mandatory requirements for monitoring and reporting in the Code of Practice).

The sub-sections below provide a general description of the different components of the regional motoring framework, although more detail is provided for social impact monitoring. Additional work is required to develop the detailed scope and design of each program, drawing on the data and information from the relevant SREBA baseline studies. It is noted that it is desirable to commence some of these components as early as possible in any transition from onshore gas exploration to production in the Beetaloo Sub-basin, as this will allow natural temporal variability (for example, in aquatic ecosystems) to be further quantified prior to significant development occurring.

12.2.1. Groundwater

The water baseline studies reported on the large quantity of data for groundwater levels and quality from bores in the Beetaloo region (see Sections 4.3.3 and 4.3.7). In addition to monitoring bores established by DEPWS and PWC, this includes water monitoring bores established by the gas industry to meet regulatory requirements. Groundwater monitoring data will be available from a steadily increasing number of bores associated with new well pads if onshore gas development in the Beetaloo region goes ahead.

Nevertheless, it is important that suitable groundwater level and quality data are also collected independently of the gas industry as part of a Beetaloo regional monitoring program. This would include ongoing collection of data from DEPWS monitoring bores in the Georgina, Wiso, Mataranka Tindall and Flora Water Management zones, which would generally be consistent with groundwater monitoring programs established in the relevant water allocation plan. Consideration should also be given to whether the existing monitoring bore network is adequate to detect variation from modelled changes in groundwater levels as a result of projected groundwater extraction, and any identified gaps filled with additional bores. Analytes in groundwater quality monitoring should include those relevant to potential contamination from onshore gas activities.

Power and Water Corporation monitors groundwater quality in potable water at communities that it services in the region, and these data should be incorporated into reporting under the regional monitoring framework.

There are currently no water quality data for potable groundwater used by private entities (pastoral homesteads, petrol stations / roadhouses) in the study area, and consideration should be given as to how these can be incorporated into the regional monitoring network.

12.2.2. Surface water

Regional monitoring of surface water quality should be targeted toward detecting downstream contamination from onshore gas activities and as an indicator of ecosystem health for aquatic biodiversity (Section 12.2.3) and waterbirds (Section 12.2.4). To incorporate a broad geographic spread across the study area, this would include water quality sampling at waterholes adjacent to local communities and the candidate sites for aquatic ecosystems described below. Surface water monitoring sites may also be established in relevant water allocation plans and can be incorporated into the regional monitoring network. Water quality monitoring should include the NT Government standard field and laboratory parameters (Waugh 2016). Additionally, a suite of analytes that may be indicative of contamination from onshore gas activities should be included. Monitoring sites where surface water may be used for agricultural, cultural or recreational use should include analytes to meet Australian Drinking Water Health and Aesthetic Guidelines, as discussed in the Environmental Health Water Quality report.

12.2.3. Aquatic ecosystems

The design of a regional monitoring program needs to consider contaminant transport pathways, the nature and scale of potential development-related impacts, the choice of target indicators for monitoring, the appropriate timing of sampling for monitoring, and to have the capacity to distinguish other confounding effects such as cattle grazing and climate change (Capon *et al.* 2021).

In general terms, monitoring should focus on perennial or near-permanent waterbodies rather than ephemeral waterbodies; target fully aquatic species such as fish, molluscs and decapods, rather than air-breathing aquatic species at low risk from water-borne contaminants; and occur during the same hydrological phase.

Candidate sites for monitoring should be selected from the set of sites identified as potential aquatic refugia during the baseline study. Special attention needs to be directed to sites of high conservation value that are potentially vulnerable to impacts associated with water extraction and contamination of groundwater, such as the spring-fed upper reaches of the Roper River and Clint's Gorge on the Cox River.

The capacity to separate development-related impacts from natural variability requires a carefully stratified design and ongoing sampling to improve the temporal baseline. Sampling based on the analysis and detection of environmental DNA (eDNA) may circumvent some of the practical difficulties of sampling in remote, frequently turbid waterbodies, but requires a reference DNA database for local species and validation studies to compare the probability of detection of eDNA versus conventional methods of sampling.

Further investigation of stygofauna in the Beetaloo Basin and the potential risks to stygofauna from onshore gas development is being undertaken by GISERA, which will incorporate information from the SREBA study (https://gisera.csiro.au/research/surface-and-groundwater/examination-of-stygofauna-ecosystems-of-the-beetaloo-sub-basin/). This will help inform decisions about whether stygofauna should be included as an indicator in a regional monitoring program and/or whether project-specific environmental performance monitoring should be conducted. Nevertheless, comprehensive monitoring of groundwater levels and quality are likely to be indicative of any potential risks to stygofauna.

12.2.4. Terrestrial ecosystems

Effective monitoring programs must have the power to detect change in the value or indictor of interest, be feasible to implement and maintain over time, and be informative about causality. These criteria were used in considering the potential to effectively monitor the potential impacts arising from the development of an onshore gas industry on the terrestrial ecological values in the Beetaloo study area described in the Baseline Report.

Monitoring was assessed as being effective and feasible for:

- spatial extent of high- and moderate-value broad vegetation groups
- waterbird habitat condition
- bird fauna of riparian and swamp habitats
- landscape fire regimes
- vegetation clearing and fragmentation.

There are established methods for monitoring these attributes that would be likely to provide sufficient data for monitoring of change over time in relation to potential impacts from onshore gas development.

Monitoring of the other broad vegetation groups and threatened species was assessed as not feasible. In most cases, key risks attributed to these values are not specific to the potential impacts associated with onshore gas development, and ascribing causality would be very difficult. Additionally, in many cases the amount of data required to distinguish directional change due to development impacts form natural variability at a regional scale is prohibitively large.

Ants are recognised as being valuable indicators of ecosystem function and are recommended for monitoring site rehabilitation. However, regional monitoring of the ant fauna is not recommended.

The spatial extent of significant vegetation can be effectively monitored through remote sensing. Remote sensing techniques can also be used to assess directional change in canopy cover and the effects of fire, which are known to influence vegetation condition.

Monitoring of vegetation clearing using remote-sensing techniques enables evaluation of the cumulative impacts of land clearing, both in terms of the total extent of clearing for each vegetation community, and metrics of fragmentation at various scales. This allows for the assessment of the impact of individual clearing applications, enables the strategic design of clearing footprints to minimise impacts, and facilitates the application of regulatory thresholds if these are required.

Landscape-scale fire is amenable to management, including where land is managed by the gas industry and potentially through offset requirements (that may, for example, support local ranger groups). Time series monitoring of fire scars mapped from satellite imagery is a cost-effective tool for determining if fire regimes have changed over a focal period, relative to a preceding baseline period. Fire-scar mapping is available for the study area, and online tools are available to monitor for changes in fire regime elements at multiple scales. Habitat-specific performance thresholds in relation to fire frequency and severity can be developed to inform and guide fire management.

Due to the spatial and temporal fluctuations of waterbird occurrence in the study area, direct monitoring of waterbirds is not likely to provide sufficient data to detect changes in populations that can be attributed directly to impacts from onshore gas development. Monitoring of surface water quality (Section 12.4.1.2) and a subset of aquatic fauna (Section 12.4.1.3) at a set of regionally important wetlands may provide an indication of the quality of habitat for waterbird species.

Amongst the vertebrate fauna, birds are most amenable to monitoring, although monitoring of the bird fauna across the entire study area or Sub-basin is unlikely to be feasible or informative. However, monitoring of the bird fauna of riparian systems and swamp habitats should be considered. Riparian and swamp habitats were identified as having high value for birds in the study area, are restricted in the landscape and are sensitive to the impacts of onshore gas development.

12.2.5. Greenhouse gases

Currently, the most practical and effective method of characterising and monitoring the regional background methane concentrations for the Beetaloo Sub-basin is the deployment of regional mobile surveys. Monitoring programs/campaigns are recommended to occur every 2 to 3 years. When gas wells are operational, the use of regular (yearly or 6 monthly) local-scale mobile surveys specifically to locate sources at wells may be beneficial. In combination with the local-scale surveys, investigating and updating methods for undertaking leak, detection and repair (LDAR) programs would enhance capacity to detect lower-level sources and potentially quantify the emission rates.

Targeted deployment of long-term autonomous emission monitoring stations would be useful to augment regional mobile surveys by allowing capture of the natural diurnal and temporal variations of methane and other greenhouse gas concentrations. The locations where emission monitoring stations may be useful include:

- at least one reference site away from settlements and where no developments are planned
- where new industrial developments are taking place

- where geological seeps are found.

A GISERA project is currently investigating the use of emission monitoring stations, together with either tracers and/or modelling methods at industrial development sites, to characterise the magnitude of methane emissions during the development of wells (https://gisera.csiro.au/research/greenhouse-gas-and-air-quality/methane-emissions-quantification-of-well-drilling-to-completion-processes-in-beetaloo-sub-basin/).

The SREBA study found elevated and correlated methane and ethane concentrations above the bubbles at the Clints Gorge hot springs. Further research to investigate and characterise the source of the emissions at this site is recommended to assess if the input of gas is local or regional. A strong pre-development baseline is particularly important for the industry to consider if such sites are found close to new developments.

There are now a range of new satellites sensors that specifically measure greenhouse gas and which are either in operation or will be launched in the near future (Neumeier *et al.* 2021). While they hold promise for detecting large sources (super emitters), currently they do not have sufficient sensitivities and adequately low detection limits to monitor relatively small and diffused sources such as found in the SREBA study area. However, the development of these technologies should be monitored as they could potentially be a source of monitoring data in the future.

12.2.6. Environmental health - water quality

Monitoring of groundwater and surface water quality is discussed in Sections 12.2.1 and 12.2.2 above. Water quality monitoring should include analytes relevant to detecting potential contamination from onshore gas activities and to meet Australian Drinking Water Health and Aesthetic Guidelines, particularly in monitoring sites close to local communities and where surface water may be used for agricultural, cultural or recreational use.

12.2.7. Environmental health - soil quality

Inclusion of soil quality indicators in a regional monitoring framework is not recommended. Rather, data should be collated from compliance monitoring required as part of project-level approval and regulation.

12.2.8. Environmental health - air quality

Five air quality monitoring stations were installed in the region as part of the Beetaloo SREBA baseline studies. Monitoring equipment was installed and commissioned during September 2022. Monitoring will be undertaken for a period of at least 12 months, which is considered the minimum to characterise the baseline environment throughout all seasons. The following parameters are being monitored:

- deposited dust – using dust deposition gauges (DDG)
- suspended particulate matter (PM2.5, PM10) – using a real time light scattering device
- gases (NO_2, SO_2, H_2S, VOCs and aldehydes) – using passive sampling methods
- meteorological parameters (wind speed, wind direction, temperature, humidity, and rainfall).

While compliance monitoring for future onshore gas activities is expected and would be the responsibility of the proponent, additional regional baseline monitoring is valuable for ensuring human health and environmental impacts are minimised and so that communities are aware of their air quality environment. Air quality monitoring required as part of an ongoing regional monitoring program should be consistent with the current baseline program, although some refinement may be appropriate based on data from the complete baseline study. Refinement may include installation of a compliance-grade air quality monitoring station at one or more of the monitoring locations and/or a reduction in the total number of satellite sites at which monitoring is conducted.

12.2.9. Population health

The Population Health Baseline Report sets out the recommended monitoring indicators and proposed collection methods (subject to confirmation of feasibility of data format and collection). The recommended indicators comprise the following types.

- Indicators for symptoms that are commonly associated with exposure to irritant substances.
- Indicators for chronic health outcomes associated with hazards presented by onshore gas production.
- Indicators for vector-borne and sexuallytransmitted diseases that are associated with natural and social environmental conditions respectively.
- Indicators for risk factors that are also associated with category b) health outcome indicators.

It is proposed to use two main sources of data for ongoing monitoring:

- information provided by the health services (NT Health and Sunrise Health Service Aboriginal Corporation)
- self-reported symptoms by members of the local communities.

A protocol will need to be adopted to ensure privacy of individuals' health data. Stratification by age, gender and ethnicity may lead to very small numbers of cases, which increases the risk that individuals could be identified. The language and accessibility of reporting should be agreed prior to commencement of monitoring and according to advice from the stakeholders listed in the Population Health Baseline Report.

There are several limitations to the draft monitoring plan that will require consideration. The population size is too small to support robust epidemiological analysis. However, the data will support some trend analysis, health service planning and alert authorities to potentially unexpected changes from the health baseline that require further investigation.

12.2.10. Social impact monitoring

Understanding community concerns about onshore gas development is fundamental to the design of an ongoing monitoring framework. Community concerns identified in the baseline are likely to change over time as projects become surer and information regarding them more specific. Therefore, the monitoring framework is an ongoing learning journey, rather than a destination.

To generate trust and acceptance in the findings of future monitoring of the baselines, developing the monitoring framework should include the following:

- an independent committee for oversight
- demonstrable value of the importance of independence and trusted persons
- testing industry data for reliability against independent measures, or peer-reviewing by a stakeholder-nominated reviewer, until trust with industry is built
- transparent and publicly accessible data
- consideration of context when evaluating data
- a long-term perspective, especially where the science and risks are uncertain

- the use of existing knowledge, especially local knowledge
- being clearly communicated
- empowering stakeholders through clear processes to raise concerns, and move towards targets
- involving the local community
- recognition of system dynamics, including that the baseline is not from an unaffected community.

The monitoring program should not only deliver reliable and valid findings but should be considered independent and trusted by the community.

An oversight or steering committee, made up of trusted senior figures from government, industries, research and interest groups could be established to safeguard the integrity of the processes used and ensure a neutral and balanced approach to monitoring, evaluation and communication of data. Consultative committees including a representative community advisory panel, an Aboriginal leaders advisory committee (both male and female), along with subject matter or technical focus groups, could be established as responsive points of advice should issues arise.

While the base studies and strategic assessment have identified what is important to people, there needs to be further engagement, potentially through the proposed consultative committees, about what is important to monitor and to set the objectives for communities in how they see themselves building resilience and responding to the opportunities and impacts of onshore gas development into the future.

The baseline and strategic assessments identified the four main themes that reflect widely held aspirations for the future and community values:

- safe and sustainable (and coordinated) development
- strong communities
- maintaining and enhancing connection to land and culture
- informed and fair local participation.

These themes could form the pillars of an ongoing monitoring framework with a set of indicators for each.The set of indicators for an ongoing monitoring program needs to be refined from the baseline assessment. It is recommended that this takes places in the form of workshops and meetings with key informants and the proposed multi-stakeholder representative organisations.

A full list of indicators for which data were collected in the baseline assessment is included in the SCE Baseline Report.

Monitoring needs to be time- and cost-efficient and not create an unreasonable burden on local residents, noting already widely expressed ‘consultation fatigue’. The following steps are recommended.

Step 1: Annual update of all publicly available baseline data in community profiles.

Step 2: Search for comparable data where annual updates are not available. In some cases, new data will need to be generated. The estimated number of non-resident workers in the region and future projections can be calculated using workforce and accommodation data collected from industry sources.

Step 3: Convene annual meetings of the advisory committees and/or hold interviews with committee members to ‘ground truth’ the quantitative data, discuss trends in the community profiles, and conduct a survey for indicators where data are not available. The survey instruments for culture and socioeconomic themes used in the baseline studies are a sound starting point for qualitative data collection but will need refining.

Step 4: A shortened online survey can be developed for general circulation at periodic intervals. Local, trained and retained 'data stewards' could facilitate this in communities and outstations. Data stewards could also be responsible for uploading information about communities relevant to the indicators. Community sentiment and key indicators could be collected every two years, and every 6-12 months in selected communities and amongst pastoralists. Data stewards could be part of an Aboriginal ranger program for broader environmental monitoring.

It is recommended that a regional ranger group be established to assist with and undertake social, cultural and environmental monitoring for the Beetaloo region. This group would represent several language groups with interests in the region. Funding arrangements must ensure independence. Pastoralists may also choose to support environmental monitoring on their properties, particularly if this could be an additional source of income, or if training and skills provided could help attract and retain quality staff.

The monitoring and evaluation system in its entirety should be subject to review every 5 years, to ensure that methods are up-to-date and indicators are relevant as the industry matures, community resilience and engagement grows and other projects come into play.

12.3. Cumulative impacts and area-based assessment

The conventional approach to environmental assessment and regulation, for onshore gas activities as for other development proposals, is on a project-by-project basis, where a project is typically at the scale of an individual well or well pad. The Inquiry had a strong interest in the potential for regional or area-based assessment for the development of onshore gas resources in the Northern Territory, primarily because of the anticipated scale of development, use of water, and extent of infrastructure required to extract and produce the gas. Area-based assessments have the capacity to examine the cumulative impacts of development across a region or area, allowing for the assessment of impacts on a broader scale than ordinarily addressed through individual project assessments. The Inquiry considered examples of 'play-based' assessments internationally, the use of cumulative management areas for groundwater management in Queensland, and the potential application of the strategic assessment provisions under Part 10 of the EPBC Act. In Recommendation 14.22, the Inquiry required that:

> 'Prior to the granting of any further production approvals, the Government considers developing and implementing regional- or area-based assessment for the regulation of any onshore shale gas industry in the NT.'

Additionally, Recommendation 14.21 requires that:

> 'As part of the environmental assessment and approval process for all exploration and production approvals, the Minister be required to consider the cumulative impacts of any proposed onshore shale gas activity.'

The Final Report notes that this would require the Minister to take the results of the SREBA into account when deciding whether or not an activity should proceed.

The *Environment Protection Act 2019* (NT) has also come into effect subsequent to the completion of the Inquiry. This act provides for the environmental impact assessment of a 'strategic proposal', which is defined as 'a policy, a program, a plan or a methodology' and is analogous to strategic assessment under the EPBC Act.

In light of Recommendation 14.22, PriceWaterhouseCoopers (PWC) were engaged to identify options for area-based assessment relevant to onshore gas development in the NT and to identify a preferred approach that meets the needs of regulators and interest holders. The PWC report was informed by consultation with NT and Commonwealth government agencies, the NT EPA, interest holders, APPEA, industry associations, land councils and peak environment groups.

The PWC report broadly found theoretical support for area-based assessment due to its potential to better consider cumulative impacts from development, but no consensus on the best type of assessment or who should be the proponent for the assessment. It also identified concerns about timing, cost and governance frameworks for any area-based assessment. The PWC report concluded that there were three options suitable for the NT Government's further consideration.

1. Continue the current regulatory framework, incorporating the SREBA into more detailed assessments of cumulative impacts by regulators on an activity- or project-scale level.
2. The NT Government initiate a Strategic Environmental Assessment to consider cumulative impacts associated with development of the onshore gas industry.
3. The NT Government seek 'strategic advice' in relation to the region, and limiting and managing cumulative impacts and risks under s25 of the *Northern Territory Environment Protection Authority Act 2012*. The NT Environment Protection Authority may provide such advice at the request of the Minister for Environment, Climate Change and Water Security or on its own initiative.

The SREBA provides a strong basis for each of these options. The SREBA satisfies many of the requirements of an area-based assessment, as it:

- provides comprehensive baseline data for the Beetaloo region across a broad scope of environmental values
- identifies areas of high environmental value within the region that can inform regulatory and planning approaches to minimise impacts on these values
- provides rich data to better inform consideration of cumulative impacts associated with development. For example, the cumulative impacts of land clearing for infrastructure can be calculated, or modelled for future scenarios, because there is now uniform vegetation mapping across the Beetaloo region
- informs the development of evidence-based Water Allocation Plans for the Cambrian Limestone Aquifer under the Beetaloo Sub-basin, which set sustainable limits to the cumulative effects of groundwater extraction.

Additionally, as outlined in Sections 11.2.5 and 12.2, the SREBA can:

- inform the refinement of the Beetaloo GBA impact assessment, which is a regional-scale assessment of the potential risks to key environmental values from onshore gas development, and which potentially provides a framework for the uniform assessment of gas-field scale development
- provide the basis for the development of a regional monitoring framework, allowing any cumulative impacts of onshore gas development in the Beetaloo region to be properly assessed over time.

The form of any future area-based assessment in the Beetaloo region is a decision for the NT Government, but is not likely to be feasible or necessary until the timing and scale of development becomes clearer. Before then, data provided by the SREBA can inform the assessment of onshore gas development proposals under the *Petroleum (Environment) Regulations 2016* and/or the *Environment Protection Act 2019*, both of which require consideration of cumulative impacts.

12.4. Ongoing data management

The SREBA collected very large amounts of data, which build on existing data from a wide variety of sources. The value of the SREBA will be maximised if these data are readily available to all potential users, including regulators, industry and the public. A data management system has been developed specifically to encompass the diverse data and information collected through SREBA and this is described in Section 2. All SREBA data and reports are publicly accessible through the SREBA Data Catalogue, except where access is restricted due to cultural sensitivities or privacy requirements in accordance with the *Information Act 2002*. Where relevant, SREBA data have been incorporated into Northern Territory Government corporate databases, which also have portals for public access (such as NR Maps NT).

Data collection in the Beetaloo region will not cease with the completion of the SREBA. Relevant data will continue to be collected through mandated monitoring programs, investigations associated with project-level environmental impact assessment, research projects supported by GISERA, and other activities. While the SREBA studies represent a 'snapshot' baseline at a particular time, it is important that relevant data from the Beetaloo continue to be captured and effectively curated, both to add to baseline understanding of the region and to track changes over time.

The data management system created for SREBA provides one mechanism for the ongoing capture and management of relevant data. There are also other systems currently capturing and reporting data, including corporate databases maintained by DEPWS, and the Petroleum Onshore Information Northern Territory (POINT) portal, which provides access to documents and information about onshore petroleum activities in the NT, including results from compliance monitoring programs.

Maintenance of these large and complex data management systems requires significant ongoing resources. Additional work is also required to better align, or combine, existing data portals; and to enhance existing systems to ensure that data are available in forms that can be most easily used and interpreted by diverse users.

12.5. Recommendations

The SREBA is a set of studies to address knowledge gaps and establish appropriate baselines against which the potential impacts of proposed onshore gas activities may be assessed. The baselines can also assist in the design and planning of future development, particularly at a regional scale, in order to minimise impacts. A SREBA is not in itself a risk assessment process, but provides appropriate information to allow government, regulators and industry to apply robust risk assessment. Nevertheless, synthesis and reporting of the SREBA studies has highlighted a number of potential measures that can further maximise the value obtained from the SREBA (as well as the related work undertaken for the GBA Program). This forms the basis for the following recommendations to be considered by the Northern Territory Government.

1. Engage with the Australian Government and CSIRO to incorporate additional data and knowledge obtained through the SREBA into the existing GBA Beetaloo causal network and to update the impact assessment, with additional endpoints, nodes and links where required.
2. In collaboration with CSIRO, develop the GBA Beetaloo causal network and user interface further as an operational tool that can be applied during the impact assessment and approval process for future onshore gas development in the Beetaloo Sub-basin.

3. Implement the measures outlined in Section 10.2 to further minimise risks to the areas identified as having outstanding and high environmental value, and increase community confidence that these values will be protected.
4. Implement a regional monitoring program, as outlined in Section 12.2, to ensure that longer-term and cumulative impacts of a gas-field scale development in the Beetaloo Sub-basin are adequately monitored and transparently reported. This would include both long-term participatory regional social impact monitoring that satisfies Recommendation 12.7 of the Inquiry, and long-term monitoring of selected biophysical indicators.
5. Maintain a data management platform and associated publicly accessible interface that captures and curates the data and information collected during the SREBA, data collected in the future through regional monitoring programs, and other relevant data (e.g. GISERA research projects, project-scale monitoring and environmental investigations).

12.6. References

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