Tree water sourcing at the Mataranka Springs Complex

A technical report from the CSIRO Roper River Water Resource Assessment for the National Water Grid

Clément Duvert[1], Lindsay B. Hutley[1], Sébastien Lamontagne[2], Adam J. Bourke[1], Diego Alvarez Cortes[1], Dylan J. Irvine[1], Andrew R. Taylor[2]

[1] Research Institute for the Environment and Livelihoods, Charles Darwin University

[2] CSIRO

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Important disclaimer

CSIRO Roper River Water Resource Assessment acknowledgements

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Aspects of the Assessment have been undertaken in conjunction with the Northern Territory Government.

The Assessment was guided by two committees:

i. The Assessment's Governance Committee: CRC for Northern Australia/James Cook University; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Qld Department of Agriculture and Fisheries; Qld Department of Regional Development, Manufacturing and Water

ii. The Assessment's joint Roper and Victoria River catchments Steering Committee: Amateur Fishermen's Association of the NT; Austrade; Centrefarm; CSIRO, National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Cattlemen's Association; NT Department of Environment, Parks Australia; Parks and Water Security; NT Department of Industry, Tourism and Trade; Regional Development Australia; NT Farmers; NT Seafood Council; Office of Northern Australia; Roper Gulf Regional Council Shire

Responsibility for the Assessment's content lies with CSIRO. The Assessment's committees did not have an opportunity to review the Assessment results or outputs prior to its release.

This report was reviewed by Dr Tanya Doody and Dr Jodie Pritchard of CSIRO.

The authors acknowledge the Traditional Owners as the custodians of the land in and around Elsey National Park. We thank the Mangarrayi rangers, Elsey National Park rangers and Coodardie cattle station owners for access to sites. We thank Adam Bourke, Diego Alvarez, Bart Edmeades and Jace Emberg (fieldwork); Greg Skrzypek and Douglas Ford (analyses).

Acknowledgement of Country

CSIRO acknowledges the Traditional Owners of the lands, seas and waters, of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture and pay our respects to their Elders past and present.

Photo

An image of the diversity of vegetation communities in Elsey National Park. Source: Clement Duvert – Charles Darwin University

Director’s foreword

Sustainable regional development is a priority for the Australian and Northern Territory governments. Across northern Australia, however, there is a scarcity of scientific information on land and water resources to complement local information held by Indigenous owners and landholders.

Sustainable regional development requires knowledge of the scale, nature, location and distribution of the likely environmental, social and economic opportunities and the risks of any proposed development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpins the resource security required to unlock investment.

In 2019 the Australian Government commissioned CSIRO to complete the Roper River Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to provide data and insight to support consideration of the use of land and water resources for development in the Roper catchment. While the Assessment focuses mainly on the potential for agriculture, the detailed information provided on land and water resources, their potential uses and the impacts of those uses are relevant to a wider range of regional-scale planning considerations by Indigenous owners, landholders, citizens, investors, local government, the Northern Territory and federal governments.

Importantly the Assessment will not recommend one development over another, nor assume any particular development pathway. It provides a range of possibilities and the information required to interpret them - including risks that may attend any opportunities - consistent with regional values and aspirations.

All data and reports produced by the Assessment will be publicly available.

C. Chilcott

Chris Chilcott

Project Director

The Roper River Water Resource Assessment Team

Project Director	Chris Chilcott
Project Leaders	Cuan Petheram, Ian Watson
Project Support	Caroline Bruce
Communications	Chanel Koeleman/Kate Cranney, Siobhan Duffy, Amy Edwards

Activities

Agriculture and socio-economics	Chris Stokes, Caroline Bruce, Shokhrukh Jalilov, Diane Jarvis[1], Adam Liedloff, Yvette Oliver, Alex Peachey[2], Allan Peake, Maxine Piggott, Perry Poulton, Di Prestwidge, Thomas Vanderbyl[7], Tony Webster, Steve Yeates
Climate	David McJannet, Lynn Seo
Ecology	Danial Stratford, Laura Blamey, Rik Buckworth, Pascal Castellazzi, Bayley Costin, Roy Aijun Deng, Ruan Gannon, Sophie Gilbey, Rob Kenyon, Darran King, Keller Kopf[3], Stacey Kopf[3], Simon Linke, Heather McGinness, Linda Merrin, Colton Perna[3], Eva Plaganyi, Rocio Ponce Reyes, Jodie Pritchard, Nathan Waltham[9]
Groundwater hydrology	Andrew R. Taylor, Karen Barry, Russell Crosbie, Phil Davies, Alec Deslandes, Katelyn Dooley, Clement Duvert[8], Geoff Hodgson, Lindsay Hutley[8], Anthony Knapton[4], Sebastien Lamontagne, Steven Tickell[5], Sarah Marshall, Axel Suckow, Chris Turnadge
Indigenous water values, rights, interests and development goals	Pethie Lyons, Marcus Barber, Peta Braedon, Kristina Fisher, Petina Pert
Land suitability	Ian Watson, Jenet Austin, Elisabeth Bui, Bart Edmeades[5], John Gallant, Linda Gregory, Jason Hill[5], Seonaid Philip, Ross Searle, Uta Stockmann, Mark Thomas, Francis Wait[5], Peter L. Wilson, Peter R. Wilson
Surface water hydrology	Justin Hughes, Shaun Kim, Steve Marvanek, Catherine Ticehurst, Biao Wang
Surface water storage	Cuan Petheram, Fred Baynes[6], Kevin Devlin[7], Arthur Read, Lee Rogers, Ang Yang,

Note: Assessment team as at June 15, 2023. All contributors are affiliated with CSIRO unless indicated otherwise. Activity Leaders are underlined.

[1]James Cook University; [2]NT Department of Industry, Tourism and Trade; [3] Research Institute for the Environment and Livelihoods. College of Engineering, IT & Environment. Charles Darwin University; [4]CloudGMS; [5]NT Department of Environment, Parks and Water Security; [6]Baynes Geologic; [7]independent consultant; [8]Charles Darwin University; [9]Centre for Tropical Water and Aquatic Ecosystem Research. James Cook University.

Shortened forms

SHORT FORM	FULL FORM
CLA	Cambrian Limestone Aquifer
DEPWS	Department of Environment, Parks and Water Security
DOI	Document Object Identifier
GDE	Groundwater-dependent ecosystems
GWC	gravimetric water content
^{2}H	deuterium
LiDAR	Light Detection and Ranging,
LMWL	local meteoric water line
LWP	leaf water potential
NT	Northern Territory
NTG	Northern Territory Government
^{18}O	oxygen-18
Ψ_{leaf}	leaf water potential (MPa)
Ψ_{soil}	soil matric potential (Mpa)
UTM	Universal Transverse Mercator
WA	Western Australia

Units

UNIT	DESCRIPTION
°C	degrees Celsius
g	gram
km	kilometres
m	metres
mm	millimetres
MPa	megapascals
%	percent
‰	per mille

Preface

Sustainable regional development is a priority for the Australian and Northern Territory governments. For example, in 2023 the Northern Territory Government committed to the implementation of a new Territory Water Plan. One of the priority actions announced by the government was the acceleration of the existing water science program ‘to support best practice water resource management and sustainable development’.

The efficient use of Australia’s natural resources by food producers and processors requires a good understanding of soil, water and energy resources so they can be managed sustainably. Finely tuned strategic planning will be required to ensure that investment and government expenditure on development are soundly targeted and designed. Northern Australia presents a globally unique opportunity (a greenfield development opportunity in a first-world country) to strategically consider and plan development. Northern Australia also contains ecological and cultural assets of high value and decisions about development will need to be made within that context. Good information is critical to these decisions.

Most of northern Australia’s land and water resources, however, have not been mapped in sufficient detail to provide for reliable resource allocation, mitigate investment or environmental risks, or build policy settings that can support decisions. Better data are required to inform decisions on private investment and government expenditure, to account for intersections between existing and potential resource users, and to ensure that net development benefits are maximised.

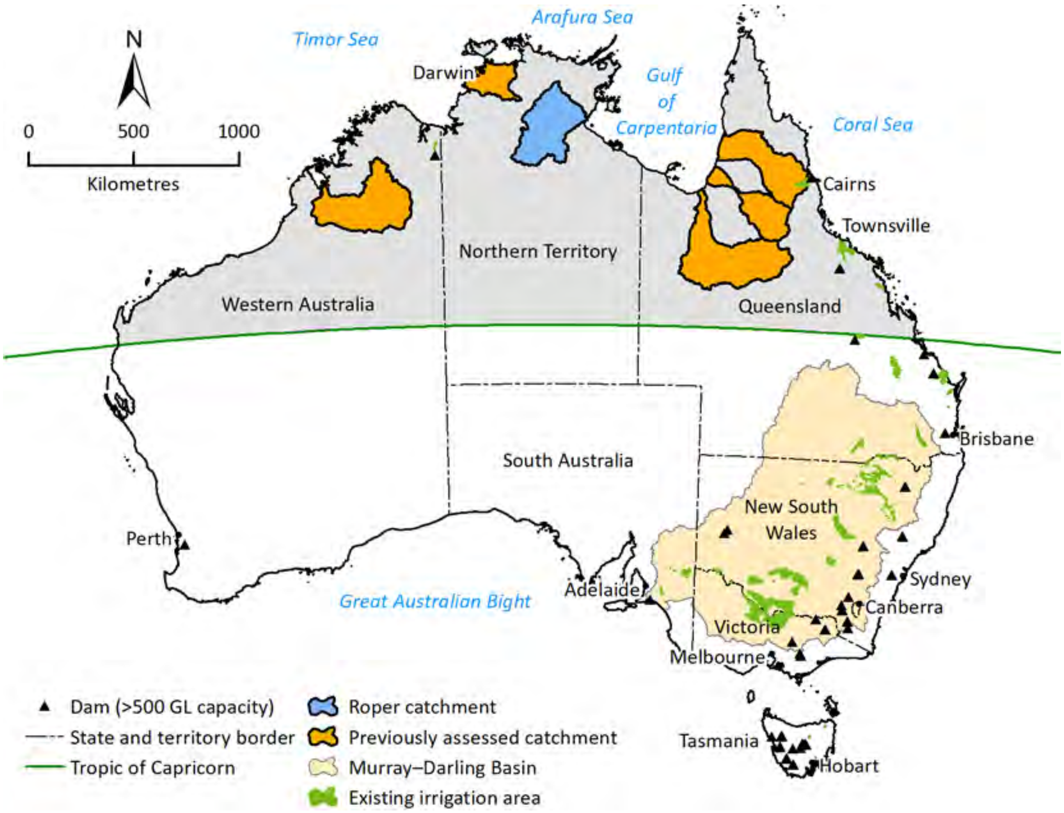
In consultation with the Northern Territory Government, the Australian Government prioritised the catchment of the Roper River for investigation (Preface Figure 1-1) and establishment of baseline information on soil, water and the environment.

Northern Australia is defined as the part of Australia north of the Tropic of Capricorn. The Murray–Darling Basin and major irrigation areas and major dams (greater than 500 GL capacity) in Australia are shown for context.

The Roper River Water Resource Assessment (the Assessment) provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water and agricultural development.

While agricultural developments are the primary focus of the Assessment, it also considers opportunities for and intersections between other types of water-dependent development. For example, the Assessment explores the nature, scale, location and impacts of developments relating to industrial and urban development and aquaculture, in relevant locations.

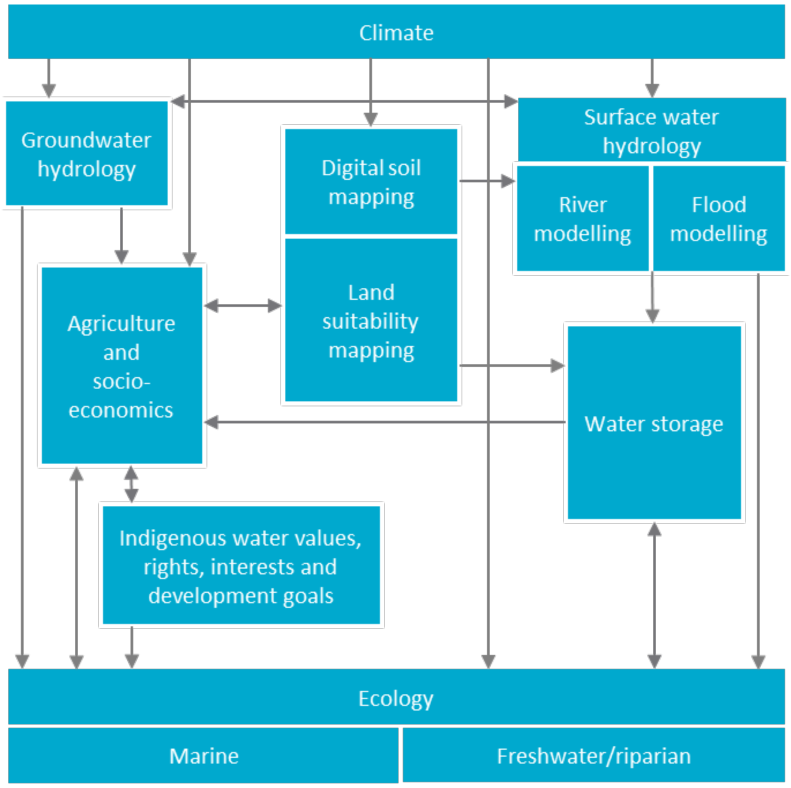
The Assessment was designed to inform consideration of development, not to enable any particular development to occur. As such, the Assessment informs – but does not seek to replace – existing planning, regulatory or approval processes. Importantly, the Assessment does not assume a given policy or regulatory environment. As policy and regulations can change, this enables the results to be applied to the widest range of uses for the longest possible time frame.



Preface Figure 1-1 Map of Australia showing Assessment area

It was not the intention – and nor was it possible – for the Assessment to generate new information on all topics related to water and irrigation development in northern Australia. Topics not directly examined in the Assessment are discussed with reference to and in the context of the existing literature.

Functionally, the Assessment adopted an activities-based approach (reflected in the content and structure of the outputs and products), comprising eight activity groups; each contributes its part to create a cohesive picture of regional development opportunities, costs and benefits. Preface Figure 1-2 illustrates the high-level links between the eight activities and the general flow of information in the Assessment.



Preface Figure 1-2 Schematic diagram of the high-level linkages between the eight activities and the general flow of information in the Assessment.

Assessment reporting structure

Development opportunities and their impacts are frequently highly interdependent and consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports most reliably informs discussion and decisions concerning regional development when read as a whole.

The Assessment has produced a series of cascading reports and information products:

- Technical reports; that present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the eight activities has one or more corresponding technical report.
- A Catchment report; that for the Roper catchment synthesises key material from the technical reports, providing well-informed (but not necessarily-scientifically trained) readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture and other development options.
- A Summary report; that for the Roper catchment provides a summary and narrative for a general public audience in plain English.
- A Summary factsheet; that for the Roper catchment provides key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable the reader to better access information that is not readily available in a static form. All of these reports, information tools and data products are available online at https://www.csiro.au/roperriver. The website provides readers with a communications suite including factsheets, multimedia content, FAQs, reports and links to other related sites, particularly about other research in northern Australia.

Executive summary

Elsey National Park, NT is an area of significant groundwater discharge from the Cambrian Limestone Aquifer (CLA) to the headwaters of the Roper River. However, the exact area of groundwater dependency and sources of tree water uptake are unclear. In support of CSIRO's research activities for the Roper River Water Resource Assessment project, this study undertook targeted investigations of tree water uptake in and nearby Elsey National Park. The overarching aim was to assess the potential vulnerability of groundwater-dependent ecosystems to potential hydrological changes – either from climate variability or future water resource development. The specific objectives were to evaluate the contribution of different water sources (soil water at different depths, groundwater from the CLA) to tree water uptake and investigate the possibility of a depth threshold for groundwater use in the area.

Using stable isotopes of water (oxygen-18 (^{18}O) and deuterium (^{2}H)) as tracers of tree water sourcing, as well as soil matric potential and pre-dawn leaf water potential measurements, the study found high spatial heterogeneities in soil properties and water availability, which resulted in highly variable patterns of tree water use, even at small scales. Deep soil horizons and capillary fringes (at a depth >3 metres (m)) were identified as important sources of moisture for trees, although water sources tended to differ within and between individual tree species.

Likely groundwater users and soil water users co-existed at locations where the watertable was less than 5 to 7 m deep. Certain savanna trees (e.g. *Erythrophleum chlorostachys*, *Corymbia bella*, *Hakea arborescens*) were found to access water from deep capillary fringes, but further research is required to determine whether these trees are facultative or obligate groundwater users. It is possible that the availability of this capillary fringe serves as an important buffer during periods of low local recharge and incomplete refilling of soil water storage.

Overall, the findings are consistent with previous investigations and further demonstrate that groundwater users occur in areas beyond the Elsey National Park. Furthermore, this work highlights the complexity and heterogeneity of ecohydrological processes in the region and suggests that potential hydrological impacts to groundwater-dependent ecosystems will depend on both location and species.

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1 Introduction

Groundwater-dependent ecosystems (GDEs) are natural ecosystems that rely on groundwater, either year-round or intermittently, to maintain their essential functions and services (Eamus and Froend, 2006; Richardson et al., 2011). Given the pronounced seasonality of rainfall and high evaporation rates in northern Australia, it is reasonable to assume that certain vegetation types might rely on groundwater to varying degrees. Previous work in northern Australia has focused on understanding the groundwater dependence of dominant vegetation types, including tropical savanna woodlands (e.g. Hutley et al., 2000; Kelley et al., 2007), riparian vegetation (e.g. Canham et al., 2021; Duvert et al., 2022; Lamontagne et al., 2005) and monsoon vine forests (e.g. Cook et al., 1998; Liddle et al., 2008; O'Grady et al., 2006). These studies have shown that savanna woodlands are largely supported by deep soil water sources, whereas riparian and monsoon vine thickets are often groundwater users. However, accurate delineation of groundwater-dependent ecosystems and comprehensive knowledge regarding which dominant tree species rely on groundwater and which do not, are still lacking.

Elsey National Park (NT) is an area of significant groundwater discharge from the Cambrian Limestone Aquifer (CLA) to the headwaters of the Roper River (Jolly et al., 2004; Lamontagne et al., 2021; Watson Resource Consulting, 1999; Yin Foo, 2000). According to the Australian Groundwater Dependent Ecosystems Atlas (Doody et al., 2017) and recent remote sensing studies that show where evapotranspiration rates exceed rainfall (e.g. Crosbie and Rachakonda, 2021), there is a high probability that the extensive seasonal vegetation in Elsey National Park and the riparian vegetation along adjacent creek lines rely on groundwater from the CLA. However, the exact area of groundwater dependency and sources of tree water uptake are unclear. The potential occurrence of a groundwater depth threshold beyond which trees that rely on groundwater are not present is of particular interest. Both the area of groundwater dependency and potential depth threshold are important factors in characterising and quantifying groundwater evapotranspiration from the CLA, an important water resource in the region.

In support of CSIRO's research activities for the Roper River Water Resource Assessment, particularly the groundwater hydrology research by Taylor et al. (2023), targeted investigations of tree water uptake were undertaken in the Elsey National Park area. The work involved using the stable isotopes of water (oxygen-18, ^{18}O and deuterium, ^{2}H) to trace sources of tree water and measuring soil matric potential (a measure of the availability of soil water for plants) and pre-dawn leaf water potential (a measure of plant water stress). The main objective was to evaluate the contribution of different water sources (soil water at different depths, groundwater from the CLA) to tree water uptake along a groundwater depth gradient. This report presents the findings from the targeted investigations.

2 Methods

2.1 Overview

The project involved two sampling campaigns during two consecutive dry seasons. The first sampling campaign (Phase I) was conducted from 29 September 2021 to 15 October 2021, at the end of the dry season when trees are most likely to rely on groundwater. The aim of Phase I was to assess tree water sources at six sites located along a groundwater depth gradient associated with the CLA, from a site within riparian vegetation (site 1; groundwater depth <1 m) to a site of upland savanna woodland (site 6; groundwater depth >20 m) (Figure 2-1A). Sites were selected based on their proximity to existing bores, so that the watertable depth and isotopic signature of the groundwater endmember (source) could be determined at each site (Table 2-1).

Table 2-1 Bore references for groundwater samples collected at each site. Eastings and northings for Universal Transverse Mercator (UTM) zone 53

SITE	ORIGIN OF GROUNDWATER SAMPLE	BORE REFERENCE	COMPLETION DEPTH (m)	EASTING	NORTHING
Site 1	Bottom of soil core	-	-	298335	8331203
Site 2	NT Government (NTG) observation bore	RN034038	14.0	298417	8331558
Site 3	NTG observation bore	RN035926	31.6	298898	8343974
Site 4	NTG observation bore	RN034031	41.4	306203	8339110
Site 5	NTG observation bore	RN035795	73.5	317726	8342095
Site 6	Coodardie cattle station bore	RN035463	97.0	286973	8339546

The second sampling campaign (Phase II) was conducted the following dry season from 19 September 2022 to 22 September 2022. It focused on site 4 from Phase I where the tree species identified included both groundwater and soil water users. The aim of Phase II was to characterise the deep soil profile at this site and to conduct a more in-depth investigation at the transition between savanna woodlands and the seasonal swamp forest. The watertable is likely to be shallower in the swamp than in the savanna (the elevation difference between the savanna and swamp locations is approximately 5 m) (B).

2.2 Vegetation sampling

Large branches were collected pre-dawn from the canopy of trees at each site using a telescopic pruner. Most sampled branches were approximately 10–20 millimetres (mm) diameter. Because previous research showed no significant isotopic differences between tree species in a similar northern Australian riparian environment (Duvert et al., 2022), the variety of dominant species present at each site were sampled. Branches were sealed with parafilm and electric tape and returned to base (an air-conditioned, darkened room) within 30 minutes. Immediately upon return, leaves were taken for pre-dawn leaf water potential (LWP) measurements (see Section

2.5). Stems of the same branch were then cut, sealed with parafilm and electric tape, and cold-stored for later isotopic analysis. For each sampled tree, two replicate stems were collected.

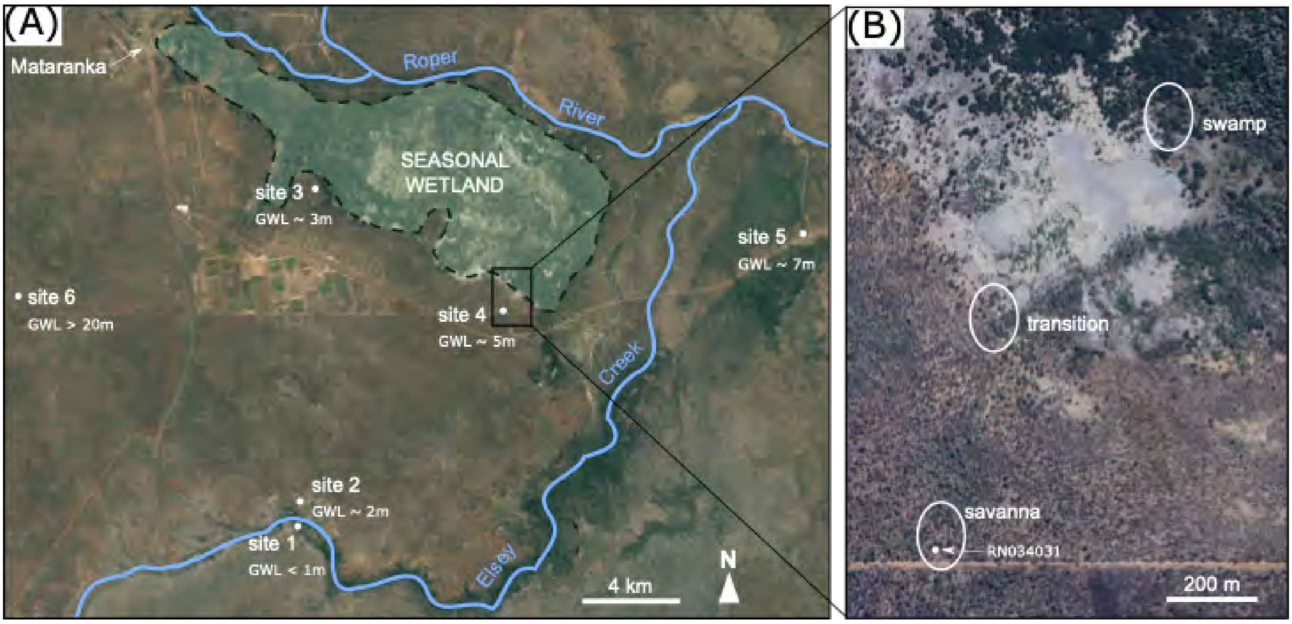

Figure 2-1 Location of the study sites

Panel (A) displays the six sites that were investigated during Phase I with their approximate depth to groundwater (GWL), while panel (B) highlights the specific transect examined at site 4 during Phase II.

During Phase I, stem samples were collected from ten trees at each site, with between one and five species sampled at each site depending on local diversity (Table 2-2). During Phase II, sampling was conducted along a transect, from the savanna area to the swamp area to the north (Figure 2-1B). Note that a large saltpan occurs between the 'transition' and the 'swamp' locations. At the 'savanna' location, stem samples were collected from 15 individual trees (the same five species that were sampled during Phase I). At the 'transition' and 'swamp' locations, stem samples were collected from seven trees (three species) and six trees (two species), respectively Table 2-2).

Table 2-2 Tree species sampled at each site

SITE	NUMBER OF SAMPLED SPECIES	SPECIES NAMES
Site 1	1	*Melaleuca dealbata*
Site 2	2	*Eucalyptus microtheca, Excoecaria parvifolia*
Site 3	4	*Acacia difficilis, Corymbia bella, Hakea arborescens, Melaleuca viridiflora*
Site 4 (*savanna*) (Phases I and II)	5	*Bauhinia cunninghamii, Corymbia bella, Corymbia confertiflora, Erythrophleum chlorostachys, Hakea arborescens*
Site 4 (*transition*) (Phase II)	3	*Corymbia bella, Hakea arborescens, Melaleuca alsophila*
Site 4 (*swamp*) (Phase II)	2	*Melaleuca alsophila, Melaleuca argentea*
Site 5	4	*Corymbia confertiflora, Eucalyptus tectifica, Terminalia arostrata, Terminalia canescens*
Site 6	2	*Eucalyptus tetrodonta, Erythrophleum chlorostachys*

2.3 Soil sampling

In Phase I, soil samples were extracted using a hand auger. The very dry, hard, loose and pebbly nature of soils prevented collecting samples at depth. In Phase II, a small drill rig from the NT Department of Environment, Parks and Water Security (DEPWS) was used to extract deeper soil samples at site 4. Two replicate soil cores were obtained that both reached the maximum depth that can be achieved with the drill rig (i.e. approximately 5.5 m). Soil samples were taken at 0.5 m intervals from 2 to 5.5 m for (1) gravimetric water content, (2) soil matric potential (Ψ_{soil}) and (3) isotopic measurements. In addition, ten samples were taken by DEPWS from the first core for soil testing including particle size analysis and chemistry.

2.4 Groundwater sampling

Groundwater samples were obtained from existing bores at each site using a small submersible pump. Three bore volumes were extracted before sampling. At site 1, two groundwater samples were collected from the bottom of soil cores once the watertable was reached. The bore at site 6 (Coodardie cattle station) is equipped with a solar-powered pump, so the sample was taken directly from the outlet pipe. During Phase II, sampling was repeated for the bore located at site 4.

2.5 Pre-dawn leaf water potentials

A PMS Instrument Company 1000 pressure chamber instrument with nitrogen gas and a mounted eye lens was used for the LWP measurements. Two measurements were made for each branch, plus a third measurement when the difference between the first two measurements was greater than 10%. All LWP measurements were finalised within two hours of sampling.

2.6 Soil analyses

Gravimetric soil water content and Ψ_{soil} were measured on soil samples. Gravimetric water content was determined by oven-drying samples at 105 °C for 96 hours, while Ψ_{soil} was estimated using the filter paper technique (Hamblin, 1981). A filter paper (Whatman No. 42) was placed in an airtight sealed container completely surrounded by the soil sample and was left at constant temperature for 14 days to ensure a matric potential equilibrium between the filter paper and soil sample was reached. Gravimetric water contents were used with the calibration curve in Deka et al. (1995) to obtain Ψ_{soil} in megapascals (MPa).

2.7 Water extraction and isotopic measurements

Due to biosecurity policies, plant and soil materials were first sent to Steritech in Queensland for gamma irradiation before import to WA. Irradiated soil and stem samples were then sent to the West Australian Biogeochemistry Centre (University of Western Australia) for water extraction and isotopic analysis. Water was extracted using cryogenic vacuum distillation following the procedure in West et al. (2006). Samples were heated (>90 °C) under vacuum and water vapour was caught in a liquid nitrogen cold trap. Extraction times were 60 and 90 minutes for soil and stem samples, respectively. In parallel, water was extracted from four different standards following the same procedure for quality control. Extracted water samples were then analysed for $\delta^{18}O$ (the ratio of

^{18}O and oxygen-16) and δ^2H (the ratio of ^2H and hydrogen-1) using a cavity ring-down spectrometer (Picarro Inc., model L2130-I). All the raw isotopic values were normalised to the Vienna Standard Mean Ocean Water scale and are reported in parts per thousand (‰). According to analyses on replicate samples, precision for the entire extraction and measurement procedure was ± 0.5‰ and ± 3.0‰ for $\delta^{18}O$ and δ^2H, respectively. Groundwater samples were analysed for $\delta^{18}O$ and δ^2H at Charles Darwin University using a Picarro L2130-I fitted with a diffusion sampler (Munksgaard et al., 2011), with a precision of ± 0.1‰ and ± 0.5‰ for $\delta^{18}O$ and δ^2H, respectively.

3 Results

3.1 Hydroclimatic context

No rainfall was recorded in the weeks prior to sampling for Phase I, with the last recorded event at Cave Creek (the closest Bureau of Meteorology rain gauge, 4 kilometres (km) from Mataranka) in late April 2021. A 15 mm rainfall event occurred in late September 2021 to the south-west of Mataranka (pers. comm. from Coodardie station owner), which may have affected the measurements at site 6. No rainfall was recorded in the weeks prior to sampling for Phase II, with the last recorded event in July 2022.

The time series of groundwater levels at site 4 (bore RN034031) is shown in Figure 3-1. The survey occurred after two poor wet seasons (2018–19 and 2019–20) followed by an above-average wet season (2020–21). The two poor wet seasons had rainfall totals of 749 mm in 2018–19 and 613 mm in 2019–20 at Cave Creek (the mean annual rainfall from 2003 to 2022 is 1017 mm/year). These two below-average wet seasons resulted in a decline of the dry-season watertable during those years. The wet season 2020–21 had above-average rainfall (1246 mm), which resulted in a higher recharge flux that year, whereas the wet season 2021–22 had below-average rainfall (716 mm), resulting in a much less pronounced rise of the watertable during the wet season. The depths to groundwater during Phase I and Phase II were 4.85 m and 5.02 m, respectively (Figure 3-1).

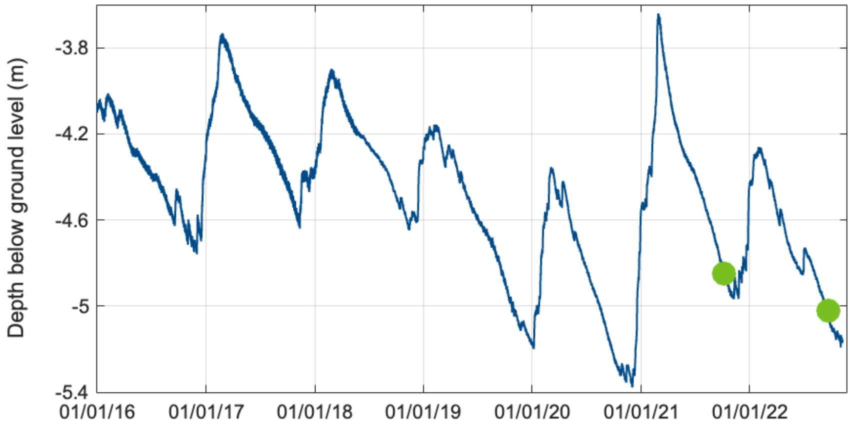

Figure 3-1 Groundwater level series at RN034031, located at site 4

The two green markers represent the depth below ground at the time of sampling for Phase I (late 2021) and Phase II (late 2022).

3.2 Soil profiles

At site 1, the riparian soil was a humid Vertosol (black soil) with high organic content. At this site, the soil matric potential (Ψ_{soil}) was very high throughout the profile (between –0.5 and –0.002 MPa), indicating that shallow soil water was readily available for trees, and the watertable was approximately 1 m below ground level (Figure 3-2). At all other sites, soils were red Kandosols with weak structure and a much lower water content. At site 2, the capillary fringe was about 1 m below ground level, with Ψ_{soil} ranging from −3 to −1.5 MPa. The high clay content may explain the relatively low potentials at this site despite the high-water content at depth. At sites 3 to 6, soil water was held at very high tensions (Ψ_{soil} <<−6 MPa), suggesting that shallow soil water was mostly unavailable to trees at these sites (Figure 3-2). However, the deepest sample collected during Phase I was at 2.7 m, leaving the question of the potential availability of soil water stored in deeper (>3 m) soil horizons unanswered.

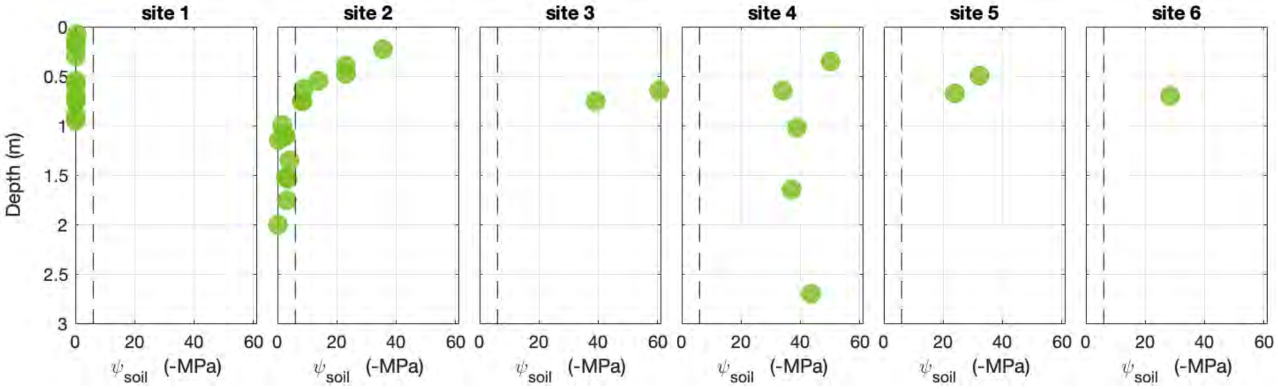

Figure 3-2 Soil matric potential (Ψ_{soil}) profiles for sites 1 to 6

The dashed vertical lines correspond to a matric potential of –6 MPa, below which plants are unlikely to access water (e.g. O'Grady et al., 2009).

The use of a drill rig at site 4 during Phase II permitted sampling of deeper soil layers approaching the capillary fringe. Two soil cores were obtained, about 20 m (horizontal distance) from each other. Both cores were characterised by red Kandosol soils with weak structure. Core 1 was dry in the top 3 m, with some moisture around 3.5 to 5.5 m (Figure 3-3). The capillary fringe was likely reached around 3.5 m, when the Ψ_{soil} values increased to –0.7 MPa. In contrast, core 2 was relatively dry down to the bottom (5.5 m) and the capillary fringe was not reached, with Ψ_{soil} consistently less than –7 MPa, despite the watertable standing at 5.0 m below the ground according to the nearby groundwater bore. Note that the elevation of core 2 was approximately 0.5 m higher than that of the bore and core 1.

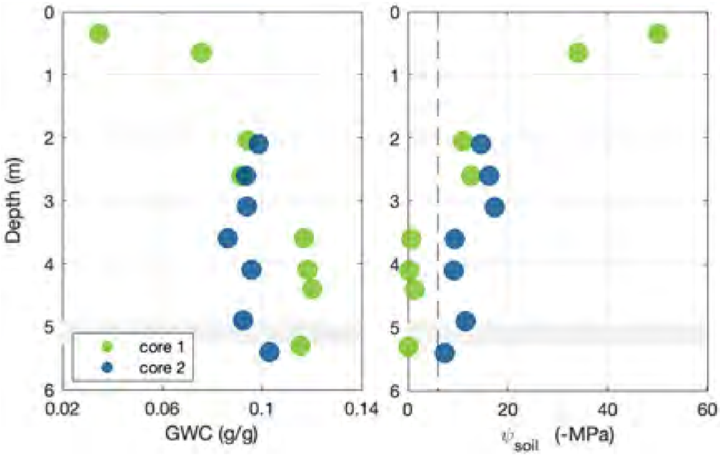

Figure 3-3 Gravimetric water content (GWC) and soil matric potential (Ψ_{soil}) for the two deep cores drilled during Phase II at site 4

The dashed vertical line corresponds to a matric potential of –6 MPa, below which plants are unlikely to access water (e.g. O'Grady et al., 2009). The grey horizontal area represents the likely depth of the watertable.

3.3 Leaf water potentials

The pre-dawn leaf water potentials (Ψ_{leaf}) were highly variable both within and across sites (Figure 3-4). At site 1, the Ψ_{leaf} measured on *M. dealbata* were very high (mean –0.24 MPa) and consistent with high availability of soil and/or groundwater at this riparian site. At site 2, the relatively low Ψ_{leaf} (mean –1.7 MPa) of *E. microtheca* were in agreement with the low soil potentials measured at this site, even within the capillary fringe, due to the high clay content. At sites 3, 4 and 5, the measured Ψ_{leaf} appeared to be highly species-specific (Figure 3-4). Some species had highly negative potentials around –2 MPa (e.g. *A. difficilis* at site 3, *B. cunninghamii* and some *E. chlorostachys* at site 4), likely indicative of water-limited conditions, whereas the potentials of some other species were much less negative – above –0.5 MPa (e.g. *H. arborescens* at sites 3 and 4, *C. confertiflora* at site 4, *T. arostrata* at site 5). Sites 3, 4 and 5 may support a combination of (1) species that use shallow soil water held at high tension in the soil matrix and (2) other species that access more abundant water from the capillary fringe. The large variations in Ψ_{leaf} observed at site 4 for *E. chlorostachys* (Figure 3-4) suggests that individual trees of the same species may access different water sources, depending on their position in the landscape and/or heterogeneities in the subsurface.

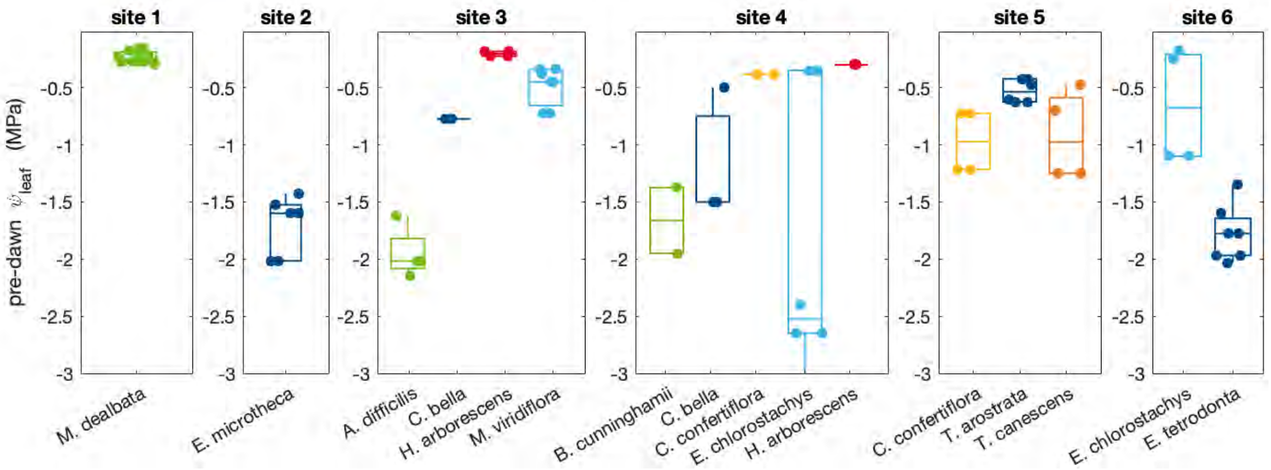

Figure 3-4 Pre-dawn leaf water potentials (Ψ_{leaf}) at the six Phase I sites

Each data point corresponds to the mean of two to three measurements for one individual tree.

The second round of measurements at site 4 (Phase II) yielded similar results to those in Phase I (Figure 3-5). The same five species were sampled at the 'savanna' location, with patterns consistent with those of Phase I except for *E. chlorostachys*, which did not show the highly negative Ψ_{leaf} that had been measured previously. The individual trees sampled in Phase II differed from those sampled in Phase I, which might explain the discrepancies between the two campaigns.

Generally, both the 'savanna' and 'transition' (i.e. edge of the saltpan) locations appeared to support a mixture of groundwater users and soil water users (Figure 3-5) . At the 'transition' and 'swamp' locations, the high salt content in the soil is likely to have lowered the osmotic potential, which might in turn affect tree water uptake. This osmotic effect may explain some of the variability within and between species at these two locations, and why some trees (e.g. *M. alsophila* at the 'transition') are under water stress conditions despite the proximity of the watertable (Figure 3-5).

Overall, the observed variability across species is likely related to differences in rooting depth – for instance, it is highly plausible that *B. cunninghamii* has relatively shallow roots which prevents this species from accessing deeper water from the capillary fringe. The variability within species can be explained by the high spatial heterogeneities in soil matric and osmotic properties that influence plant water availability.

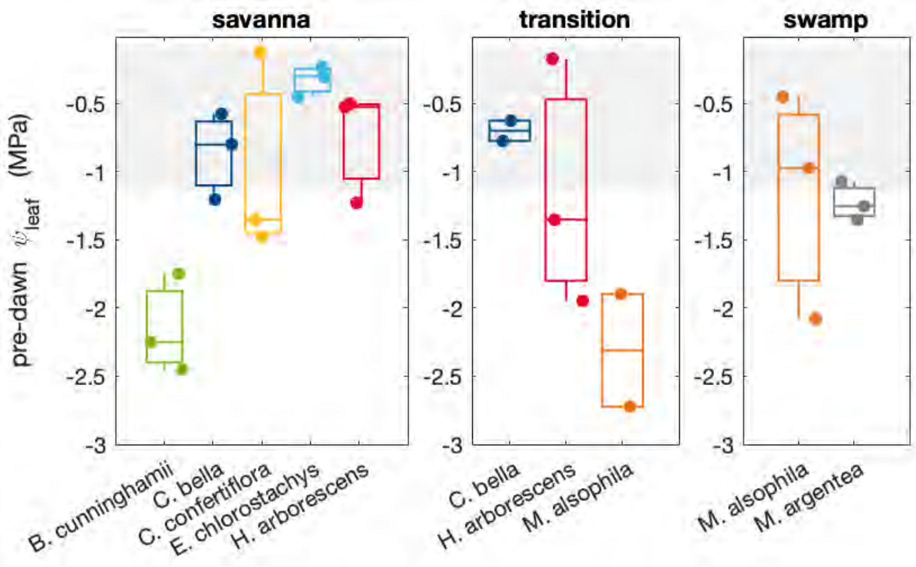

Figure 3-5 Pre-dawn leaf water potentials (Ψ_{leaf}) at site 4 as measured during Phase II

Each data point corresponds to the mean of two to three measurements for one individual tree. The grey area corresponds to the range of soil matric potentials measured in core 1 between 3.5 and 5.2 m depth.

3.4 Isotopic composition of stem water, soil water and groundwater

Figure 3-6 presents the isotopic composition of tree water sources (soil water, groundwater) for the six study sites, together with the isotopic composition of stem water in different tree species. The Mataranka local meteoric water line (LMWL) developed as part of the Geological and Bioregional Assessment Program (2021) was also added to the plots. The groundwater samples all plotted next to the LMWL, with perhaps the exception of site 1 where groundwater might have undergone some degree of evaporation due to the very shallow watertable. Some soil water samples plotted close to groundwater (sites 1, 4), while at other sites, soil water followed a clear evaporative pattern (sites 2, 3). Water extracted from stems had a broad range of isotopic compositions, but all plotted much lower than the source water samples (Figure 3-6).

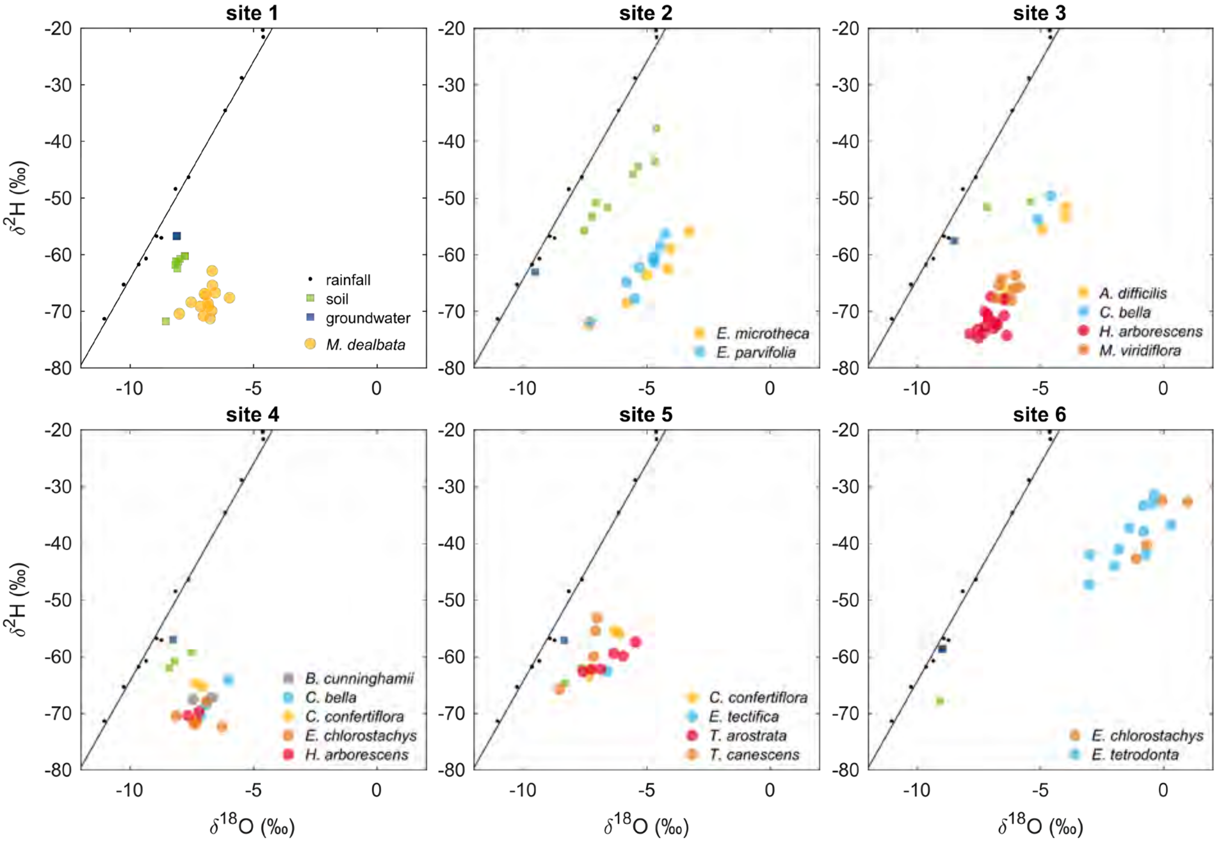

Figure 3-6 Dual isotope plots for the six surveyed sites during Phase I

Note that the deeper soil horizons were not sampled during this first sampling campaign. The black line represents the Mataranka local meteoric water line (Geological and Bioregional Assessment Program, 2021).

This negative δ^2H offset of stem water relative to source water occurred in virtually all stem water samples (Figure 3-7). This offset is consistent, although variable, across sites and species, and is on average –15‰. Of note is the consistently less negative offset at site 5. Recent literature has highlighted the occurrence of such offsets in stem water (e.g. Barbeta et al., 2019; de la Casa et al., 2022; Duvert et al., 2022; Tetzlaff et al., 2021), but there is no consensus as to whether this δ^2H depletion results from a water extraction artefact (Chen et al., 2020), or a fractionation mechanism that might occur during tree water uptake (Barbeta et al., 2022; Barbeta et al., 2020).

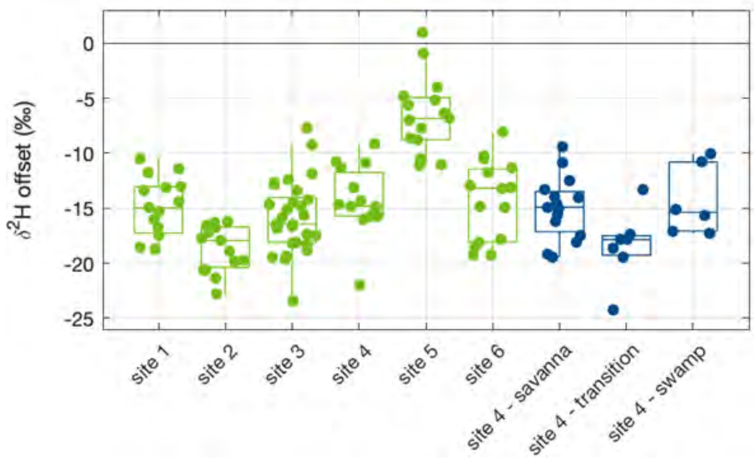

Figure 3-7 Distribution of δ^2H offsets in stem water relative to source water at each site

Green boxplots correspond to data from Phase I while blue boxplots correspond to data from Phase II.

Given the observed δ²H offset in stem water, the δ²H data were excluded for the interpretation of sources of water used by vegetation. Instead, discussions are based on the δ¹⁸O data only.

Water extracted from stems had a broad range of δ¹⁸O compositions, with low (–9 to –6‰; sites 1, 3, 4), intermediate (–6 to –4‰; sites 2, 3, 5), to much higher values (–3 to 1‰; site 6) (Figure 3-6). Generally, it is reasonable to assume that stem water samples with low δ¹⁸O are more likely to originate from groundwater or from the capillary fringe, while stem water samples with higher δ¹⁸O are more likely to originate from soil water that has undergone evaporative enrichment. Based on this reasoning, all trees at site 1 and a subset of trees at sites 2, 3, 4 and 5 (i.e. sites where the watertable is less than 10 m below ground level) may be groundwater users, while all trees at site 6 and a subset of trees at sites 2, 3, 4 and 5 may preferentially use soil water. Exclusive soil water use is expected at site 6 as the watertable stands at a depth of greater than 20 m below ground level at this site. This depth would likely prohibit root occurrence based on root excavation undertaken by Eamus et al. (2002).

In terms of patterns of tree water use across species, *M. dealbata* was an exclusive groundwater user (site 1), consistent with the fact that this species is commonly observed in swamp and seasonally inundated areas. *H. arborescens* also appeared to be a groundwater user (sites 3, 4), despite being a typical savanna species. Other species seemed to use either soil or groundwater or a combination of the two sources, such as *C. confertiflora* (sites 4, 5), *E. chlorostachys* (sites 4, 6), and *C. bella* (sites 3, 4).

Soil water extracted along the two soil cores at site 4 (Phase II) was analysed for stable isotopic composition (Figure 3-8). The two soil cores had relatively stable values throughout, with lower values in core 1 (mean δ¹⁸O –8.3‰, mean δ²H –61.0‰) than core 2 (mean δ¹⁸O –7.7‰, mean δ²H –56.2‰). Importantly, there was no clear distinction between the soil water isotopic composition and that of nearby groundwater. The similarity between isotopic signatures of different water sources complicates the interpretation of tree water uptake at this site.

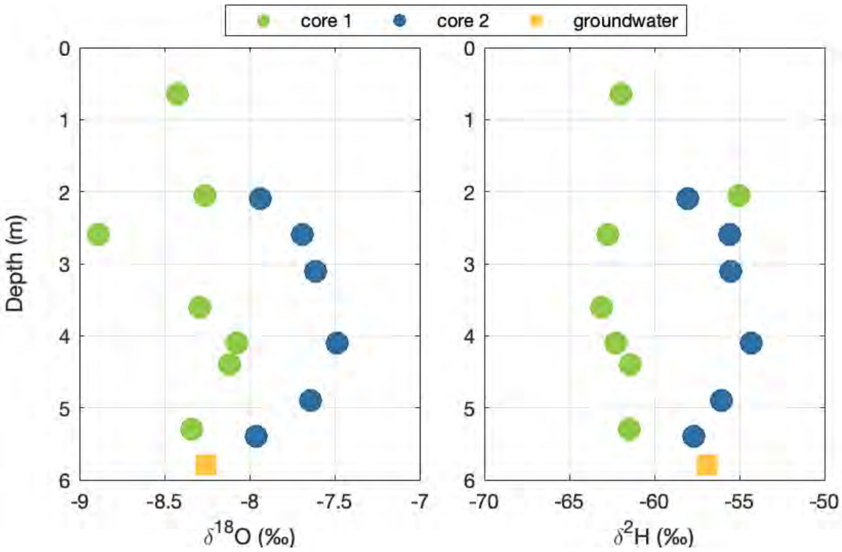

Figure 3-8 Soil isotopic profiles at site 4 (Phase II)

The groundwater sample (yellow square) was collected from nearby observation bore RN034031.

The isotopic data collected during Phase II further highlight the large variations within single locations (Figure 3-9). This is particularly true for the 'savanna' and 'transition' locations, where stem water samples spanned δ¹⁸O values between –8.3 and –5.0‰ and between –6.7 and –3.7‰, respectively. At the ‘swamp’ location, the isotopic composition of stem water was more consistently low for both sampled species, with δ^{18}O values ranging from –7.7 to –6.0‰ (Figure 3-9), suggesting a more prevalent groundwater use at this location. This is not unexpected as the depth to groundwater at this location might be approximately 1 or 2 m, given that the elevation difference between the ‘savanna’ and ‘swamp’ locations is approximately 5 m.

The observed variability also holds for individual species. For instance, *H. arborescens* had trees spanning δ^{18}O values between –7.4 and –3.7‰ across the transect. Again, this may reflect the importance of small-scale heterogeneities in the subsurface and variability in water availability across space, as well as change in topography, elevation and depth to groundwater.

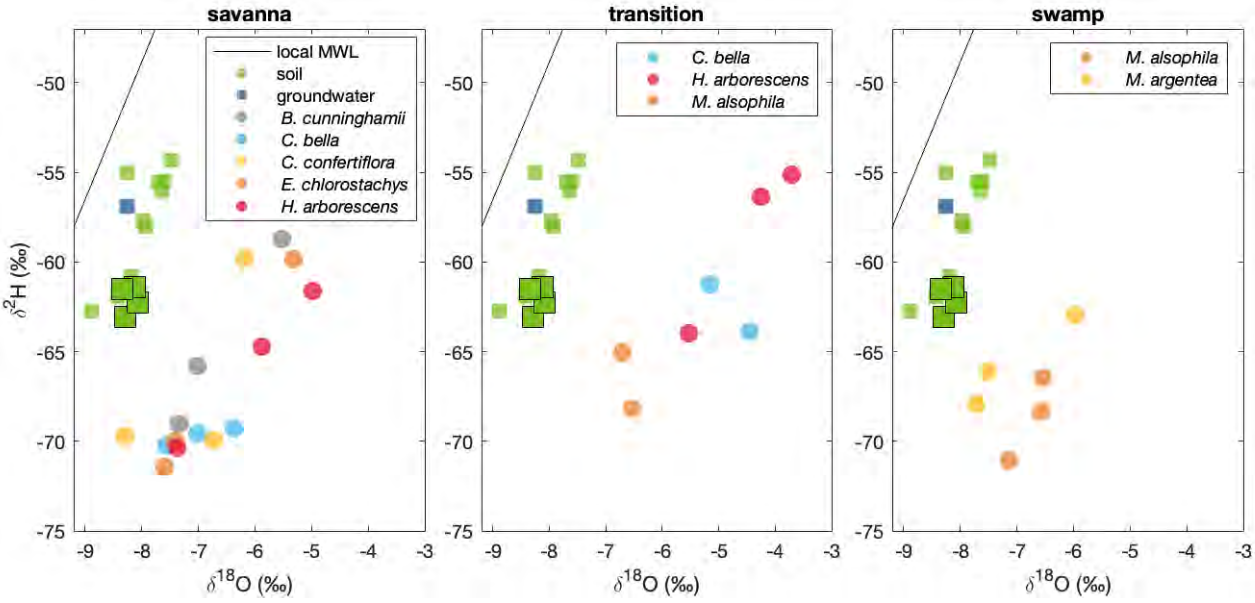

Figure 3-9 Dual isotope plots for the three locations surveyed at site 4 (Phase II)

The larger green squares correspond to soil samples with Ψ_{soil} >–6 MPa, that is, those for which water was likely available to trees.

4 Conclusions

The objective of this study was to determine the contribution of different water sources to tree water uptake in Elsey National Park (NT) and investigate the possibility of a depth threshold for groundwater use in the area. The research findings can be summarised as follows:

1. Patterns of tree water use are highly variable within and between sites, and within single tree species. The data showed that likely groundwater users and soil water users can co-exist at sites where the watertable is less than 5 to 7 m deep.
2. Deep soil horizons (>3 m) were identified as important sources of moisture for trees. Site 4 had a capillary fringe at a depth of approximately 3.5 m, that is, 1.5 m above the watertable. Measurements also revealed the high spatial heterogeneity in soil properties, even at small scales.
3. Certain savanna trees (e.g. *E. chlorostachys*, *C. bella, H. arborescens*) can access water from deep capillary fringes. Further research is required to determine whether these trees are facultative or obligate groundwater users. The availability of this capillary fringe at shallow depth likely serves as an important buffer during periods of low local recharge and incomplete refilling of soil water storage.
4. Consistent with recent research (e.g. Barbeta et al., 2019; de la Casa et al., 2022), this study identified an unexplained deuterium offset in stem water relative to source water. This underscores the need for additional research to elucidate the cause of this offset and explore alternative methods for extracting and more accurately measuring stem water.

Overall, these findings are consistent with previous investigations (Crosbie and Rachakonda, 2021; Doody et al., 2017) and further demonstrate that trees that can access groundwater occur in areas beyond Elsey National Park. Furthermore, this work highlights the complexity and heterogeneity of ecohydrological processes in the region and suggests that potential hydrological impacts to groundwater dependant vegetation will depend on both location and species.

There is a need for further research to refine the understanding of tree water use in and around Elsey National Park. In particular, long-term monitoring and analysis can help characterise the seasonal and climatic variability over multiple years and their effects on tree water use in the area. The investigation of fine-scale topographic variability (e.g. with Light Detection and Ranging, LiDAR), available moisture and soil osmotic properties can also provide additional insights into tree–water interactions in such unique riparian ecosystems with a significant groundwater resource close to the surface.

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Contact us

1300 363 400
+61 3 9545 2176
csiroenquiries@csiro.au
csiro.au

For further information

Environment
Dr Chris Chilcott
+61 8 8944 8422
chris.chilcott@csiro.au

Environment
Dr Cuan Petheram
+61 467 816 558
cuan.petheram@csiro.au

Agriculture and Food
Dr Ian Watson
+61 7 4753 8606
Ian.watson@csiro.au