CENTRAL LAND COUNCIL

Submission to the Northern Territory Environmental Protection Agency

SINGLETON HORTICULTURE PROJECT

Referral of proposed action submitted by Fortune Agribusiness Funds Management Pty Ltd and published by the NTEPA on 23 November 2022

ACKNOWLEDGEMENT

*The Central Land Council (**CLC**) acknowledges the traditional owners of the Northern Territory who, with their ancestors, have been custodians and stewards of the Territory and its resources for tens of thousands of years.*

INTRODUCTION

1. The Central Land Council (**CLC**) welcomes the opportunity to respond to the referral documents submitted by Fortune Agribusiness Funds Management Pty Ltd (**Fortune**) to the Northern Territory Environmental Protection Agency (**NT EPA**) under the *Environment Protection Act 2019* (NT) (**EP Act**). These documents have been submitted to determine the appropriate environmental impact assessment (**EIA**) method for the proposed Singleton Station agricultural development (**Proposed Development**) under the EP Act and *Environmental Protection Regulations 2020* (NT) (**EP Regulations**).

2. The Proposed Development is located at Singleton Station in the arid zone and falls within the Western Davenport Water Control District, which is in turn divided into three 'Management Zones' under the relevant Water Allocation Plan or **WAP**.[1]

3. The Proposed Development's ultimate objective is the cultivation of 3,300 hectares of irrigated fruit and vegetables. This objective being underpinned by the following elements:

    a. a water extraction licence[2] for up to 40,000 ML year extracted with 144 bores[3] (**Singleton Licence**) from aquifers underlying the Central Plains Management Zone. It is well-documented that the Singleton Licence is the largest groundwater licence ever granted in the NT and in all likelihood the entire country;

    b. an application and proposed application to clear 4,037 hectares of native vegetation (with this being additional to the loss of groundwater dependent ecosystems or **GDEs** caused by drawdown of aquifers);[4]

    c. infrastructure, accommodation and a solar farm.

4. The CLC is a Commonwealth Statutory Authority established under the *Aboriginal Land Rights (Northern Territory) Act* (Cth) 1976 (**ALRA**), with statutory responsibilities for approximately 780,000 square kilometres of land in the southern half of the Northern Territory (**NT**). The CLC has functions including:

    a. ascertaining and expressing the wishes and opinion of Aboriginals living in the area of the CLC as to the management of Aboriginal land in the area;[5]

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[1] Western Davenport WAP 2021-22. The Draft Western Davenport WAP 2022-2032 will soon be released for public comment.
[2] The Singleton Licence has been granted (Licence No WDCP10358), but is currently subject to legal proceedings in the NT Supreme Court.
[3] A total of 144 bores have been approved: 2 for domestic use and 142 for horticulture.
[4] Fortune has submitted both a Land Clearing Application (**LCA**) and application for a Non-Pastoral Use (**NPU**) permit under the *Pastoral Land Act 1992* (NT) (**PL Act**), which are yet to be determined.
[5] ALRA, s. 23(1)(a)

b. protecting the interests of traditional Aboriginal owners of Aboriginal land;[6]

c. assisting Aboriginal people to take measures likely to assist in the protection of sacred sites on land (whether or not Aboriginal land);[7] and

d. consulting with traditional Aboriginal owners of Aboriginal land about any proposals relating to the use of that land.[8]

5. The CLC also administers a range of programs for the benefit of constituents in relation to environmental management, community development, governance, economic participation, cultural heritage, and customary practices.

6. The CLC is the recognised representative Aboriginal/Torres Strait Islander body for the southern region of the NT pursuant to section 203AD of the *Native Title Act 1993* (Cth) (**NTA**). The CLC's area includes Singleton Station.

7. Singleton Station is subject to a Native Title consent determination by the Federal Court in *Rex on behalf of the Akwerlpe-Waake, Iliyarne, Lyentyawel Ileparranem and Arrawatyen People v Northern Territory of Australia* (2010) FCA 911, as varied by Orders made in 2020 in *Mpwerempwer Aboriginal Corporation RNTBC (ICN 7316) v Northern Territory of Australia and Ors NTD42/2018*. Mpwerempwer Aboriginal Corporation RNTBC (Mpwerempwer) is the prescribed body corporate for the purposes of section 57(2) of the Native Title Act. The CLC provides assistance and facilitation to Mpwerempwer.

8. Sacred sites exist on Singleton Station and on adjoining land which Fortune's modelling shows will be affected by groundwater drawdown from the Singleton Licence. Aboriginal people have rights to access and protect those sites under the *Northern Territory Sacred Sites Act* 1989 (NT) (**Sacred Sites Act**), NTA and ALRA.

9. In matters concerning Singleton Station, the CLC acts for Mpwerempwer. The CLC also acts for:

a. Kaytetye Tywerate Arenge Aboriginal Corporation RNTBC, the prescribed body corporate for the northern portion of Neutral Junction Station, which Fortune's modelling shows will be affected by groundwater drawdown from the Singleton Licence;

b. the Iliyarne, Warrabri and Karlantijpa South Aboriginal Land Trusts, each of which Fortune's modelling shows will be affected by groundwater drawdown from the Singleton Licence; and

[6] ALRA, s. 23(1)(b)
[7] ALRA, s. 23(1)(ba)
[8] ALRA, ss. 23(1)(c).

c. Aboriginal people in surrounding communities and nearby outstations affected by the Proposed Development.

10. This submission is made on behalf of those groups.

EXECUTIVE SUMMARY

11. Expert analysis commissioned by the CLC across key areas indicates that the Proposed Development is likely to have a significant impact on groundwater resources, sandplain habitat, culturally-significant GDEs and other sacred sites and values.

12. Further, deficiencies in the analysis, monitoring, modelling and surveying to date by both the NT Government and Fortune has increased the level of uncertainty regarding precisely how significant these impacts will be over time. Flawed and ill-conceived mitigation measures – in particular the 'adaptive management' framework linked to the Singleton Licence – are cause for serious concern. These shortcomings have resulted in Fortune erroneously assigning a 'low' or 'medium' residual risk rating to all affected areas,[9] which is itself indicative of a general failure to undertake sufficiently rigorous up-front EIA.

13. The aforementioned matters, all of which are explored in more detail in the body of this submission and in attached expert reports, trigger, in the view of the CLC, a legal requirement to subject the Proposed Development to a full Environmental Impact Statement (**EIS**) (also known as a 'Tier 3 Assessment').[10] Failure to do so would arguably be inconsistent with the applicable decision-making framework under the EP Act and EP Regulation, which could potentially give rise to judicial review proceedings in the NT Supreme Court.

SCOPE OF SUBMISSION

14. This submission is divided into the following 8 parts which together support the CLC's assertion that the Proposed Development must be assessed by way of a full EIS:

    - **Part 1** sets out the relevant legal framework under the EP Act and EP Regulations, and provides commentary on the application of this framework to the EIA process for the Proposed Development.

[9] GHD, EP Act 2019 Referral Report – Singleton Horticulture Project, 8 November 2022, p. 96 (summary); pp. 93-139 (**Referral Report**).
[10] NT Dept of Environment, Parks and Water Security, Environmental impact assessment and environmental approval in the Northern Territory - Environmental impact assessment guidance (**EIA Guidelines**), pg. 22.

- **Part 2** discusses groundwater and GDEs and associated monitoring, modelling and adaptive management. Supporting expert evidence is included as **Attachments A, B, C and D** to this submission, while supporting peer-reviewed literature is included at **Attachment E**.

- **Part 3** discusses salinity and associated assessment and management actions. Supporting expert evidence is included at **Attachment F.**

- **Part 4** discusses terrestrial ecosystems and associated assessment and management actions. Supporting peer-reviewed literature is included at **Attachments G**, **H, I and J.**

- **Part 5** discusses the nature of, and impacts on, sacred sites and Aboriginal cultural heritage. Supporting expert evidence is included at **Attachments K, L and M**.

- **Part 6** discusses aquatic ecosystems, and in particular stygofauna.

- **Part 7** discusses the purported socio-economic benefits linked to the Proposed Development. Supporting expert evidence is included at **Attachments N, O and P**.

- **Part 8** discusses greenhouse gas emissions.

- **Part 9** applies the relevant legal framework to the evidence and provides concluding remarks.

PART 1: LEGAL FRAMEWORK

15. The Proposed Development is subject to a range of provisions in the EP Act and EP Regulations. These provisions may be divided into the following three areas:

    a. the circumstances in which some form of EIA is required and associated processes and methods;

    b. matters that must be considered and/or applied when making a decision about the appropriate EIA method; and

    c. additional duties incumbent on proponents.

Each of these will be addressed in turn.

1.1 – Circumstances in which EIA required; processes and methods

16. The EP Act specifies that EIA is required for a referred 'action' where that action has the 'potential' to have a significant impact on the environment.[11] Where this is the case, the NT EPA must ensure that the EIA is carried out in accordance with the regulations.[12] The regulations may provide for the 'processes and methods' for the EIA of affected referred actions.[13]

17. Relevantly, 'action' is defined to include any of the following: (a) a project; (b) a development; (c) an undertaking; (d) an activity or series of activities; (e) works; (f) a material alteration of any of the things mentioned in paragraphs (a) to (e).[14] 'Significant impact' is defined as 'an impact of major consequence having regard to: (a) the context and intensity of the impact; and (b) the sensitivity, value and quality of the environment impacted on and the duration, magnitude and geographic extent of the impact.'[15]

18. There are four main EIA 'methods': assessment by referral information; assessment by supplementary environmental report; assessment by environmental impact statement; or assessment by inquiry.[16] These are also referred to as EIA 'tiers' in the EIA Guidelines.

1.2 – Matters that must be considered and/or applied when making a decision about the appropriate EIA method

19. Second, and assuming an action has the potential to have a significant impact on the environment,[17] the NT EPA must choose which of these four EIA methods or 'tiers' ought to be applied to the referred action. In making this determination, it must have regard to the following five criteria:

    a. the significance of the potential impact of the proposed action or the strategic proposal;

    b. the level of confidence in predicting potential significant impacts of the proposed action or strategic proposal taking into account the extent and currency of existing knowledge;

    c. the level of confidence in the effectiveness of any proposed measures identified in the referral to avoid, mitigate or manage potential significant impacts of the proposed action or strategic proposal;

[11] EP Act, s.55.
[12] EP Act, s. 57(1).
[13] EP Act, s. 57(2).
[14] EP Act, s.5 (a) – (f).
[15] EP Act, s.11.
[16] EP Regulation, reg. 5.
[17] EP Act, s. 55; EP Regulation, regulation 57(2)(b).

d. the extent of community engagement that has occurred in relation to the proposed action or strategic proposal;

e. the capacity of communities and individuals likely to be affected to access and understand information about the proposed action or strategic proposal and its potential significant impacts (**Key Assessment Criteria**).[18]

20. The NT EPA must interpret the Key Assessment Criteria in a manner that promotes the underlying objects and purpose of the EP Act.[19] The objects are as follows:

a. to protect the environment of the Territory; and

b. to promote ecologically sustainable development so that the wellbeing of the people of the Territory is maintained or improved without adverse impact on the environment of the Territory; and

c. to recognise the role of environmental impact assessment and environmental approval in promoting the protection and management of the environment of the Territory; and

d. to provide for broad community involvement during the process of environmental impact assessment and environmental approval; and

e. to recognise the role that Aboriginal people have as stewards of their country as conferred under their traditions and recognised in law, and the importance of participation by Aboriginal people and communities in environmental decision making processes.[20]

21. These objectives are weighted strongly in favour of environmental protection; recognise Aboriginal rights and interests and the importance of Aboriginal people in environmental decision-making processes; and highlight the role of EIA in promoting environmental protection. It is in this light that other, substantive provisions regarding EIA (including the correct EIA method) ought to be interpreted.

22. The NT EPA should further interpret the Key Assessment Criteria in a manner that promotes the stated ‘purpose’ of the EIA process, which is to ‘ensure that’:

a. actions do not have an unacceptable impact on the environment, now or in the future; and

b. all actions that may have a significant impact on the environment are assessed, planned and carried out taking into account:

[18] EP Regulation, regulation 59
[19] *Interpretation Act 1978*, s.62A.
[20] EP Act, s.3(a)-(e).

i. the principles of ecologically sustainable development (**ESD**); and

ii. the environmental decision-making hierarchy; and

iii. the waste management hierarchy; and

iv. ecosystem-based management;[21] and

v. the impacts of a changing climate; and

c. the potential for less environmentally damaging alternative approaches, methodologies or technologies for actions is considered; and

d. the community is provided with an opportunity to participate, and have its views considered, in decisions on proposed actions; and

e. the potential for actions to enhance or restore environmental quality through restoration or rehabilitation is identified and provided for to the extent practicable.[22]

23. Of further relevance to the decision-making process undertaken by the NT EPA in relation to the correct EIA method for the Proposed Development are the principles of ESD. Specifically, [a] decision-maker must consider and apply these principles in making a decision under this Act.'[23] Note that 'under this Act' extends to decision-making under the EP Regulations.[24] The principles of ESD that must be both considered *and* applied are as follows:

a. The decision-making principle. First, decision-making processes should effectively integrate both long-term and short-term environmental and equitable considerations. Second, decision-making processes should allow for community involvement in relation to decisions and actions that affect the community.[25]

b. The precautionary principle. Decision-making should be guided by (a) a careful evaluation to avoid serious or irreversible damage to the environment wherever practicable; and (b) an assessment of the risk-weighted consequences of various options.[26]

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[21] Defined in s.4 of the EP Act as 'management that recognises all interactions in an ecosystem, including ecological and human interactions.'
[22] EP Act, s.42(a) – (e).
[23] EP Act, s. 17(1), (2).
[24] *Interpretations Act 1978* (NT), s. 21.
[25] EP Act, s.18(1), (2).
[26] EP Act, s. 19(1), (2).

c. Evidence-based decision-making. Decisions should be based on the best available evidence in the circumstances that is relevant and reliable.[27]

d. Inter-generational and intra-generational equity. The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of present and future generations.[28]

e. Principle of sustainable use. Natural resources should be used in a manner that is sustainable, prudent, rational, wise and appropriate.[29]

f. Principle of conservation of biological diversity and ecological integrity. Biological diversity and ecological integrity should be conserved and maintained.[30]

g. Principle of improved valuation, pricing and incentive mechanisms.[31]

24. In making a decision 'in relation to actions that affect the environment', decision-makers (as well as proponents and approval holders) must apply the 'environmental decision-making hierarchy.' This hierarchy consists of three elements which must be applied in the following order: first, ensure that actions are designed to avoid adverse impacts on the environment; second, identify management options to mitigate adverse impacts on the environment to the greatest extent practicable; third, if appropriate, provide for environmental offsets in accordance with this Act for residual adverse impacts on the environment that cannot be avoided or mitigated.[32]

<u>1.3 – Additional duties incumbent on proponents</u>

25. As a proponent of an 'action', Fortune is subject to the following 'general duties' under an EIA process:

a. to provide communities that may be affected by a proposed action with information and opportunities for consultation to assist each community's understanding of the proposed action and its potential impacts and benefits;

b. to consult with affected communities, including Aboriginal communities, in a culturally appropriate manner;

c. to seek and document community knowledge and understanding (including scientific and traditional knowledge and understanding) of the natural and cultural values of areas that may be impacted by the proposed action;

d. to address Aboriginal values and the rights and interests of Aboriginal communities

[27] EP Act, s. 20.
[28] EP Act, s. 21.
[29] EP Act, s. 22.
[30] EP Act, s. 23.
[31] EP Act, s. 24, (1)-(4).
[32] EP Act, s. 26(1)(a)-(c).

in relation to areas that may be impacted by the proposed action;

e. to consider the principles of ecologically sustainable development in the design of the proposed action;

f. to apply the environmental decision-making hierarchy in the design of the proposed action;

g. to consider the waste management hierarchy in the design of the proposed action.[33]

26. In summary, the decision-making framework contains multiple elements. However, the Key Assessment Criteria set out in regulation 59 must be read in light of the EP Act's objects (which are strongly weighted in favour of environmental protection) and the stated 'purpose' of the EIA process (which seeks to ensure that an EIA under the Act is sufficiently rigorous to maximise environmental protection). Additionally, as an administrative decision-maker, the NT EPA must both consider *and* apply the principles of ESD, as well as the environmental decision-making hierarchy.

27. When considered together, the various provisions that comprise the applicable decision-making framework impose a requirement on the NT EPA to ensure that EIA is commensurate with the scale, complexity and potential impacts of a given 'action', with this being designed to maximise environmental protection and the rights and interests of Aboriginal peoples. Actions that are large and impactful, designed to operate over decades, about which there are large knowledge gaps (including due to inadequate underlying monitoring, modelling and surveying) will invariably require more detailed EIA to meet the obligations set out in the EP Act.

PART 2: GROUNDWATER AND GDES

28. Part 2 of this submission will provide commentary on:

    a. the scale of the Proposed Development and its likely impacts on groundwater resources and GDEs;

    b. deficiencies of first, the groundwater modelling and monitoring undertaken by the NT Government in the Western Davenport region and second, the groundwater modelling undertaken by Fortune for the Proposed Development itself;

    c. flaws in Fortune's proposed mitigation strategy, in particular in relation to the 'adaptive management framework' that applies to the Singleton Licence.

29. Our commentary in this section is based on three expert reports, a submission and peer-reviewed literature (which are included at **Attachments A, B, C, D and E** to this submission.

[33] EP Act, s.43(a)-(g).

30. These submissions are also in accordance with the alternative course proposed by the Water Resources Review Panel appointed by the Minister following applications to review the water licence granted to Fortune by the Water Controller:

> *Alternatively, the Review Panel suggests that these factors may be better informed by a comprehensive assessment process that is enabled through referral under the EP Act and therefore set aside the groundwater extraction licence WDPCC10000 and substitute a decision refusing the Licence.*[34]

2.1 – Scale and impacts

31. It is now well-documented that the Singleton Licence is the largest groundwater licence ever granted in the NT and in all likelihood the entire country. Indeed, the CLC and its experts have been unable to find any direct comparison with other large-scale developments (that is, we have been unable to identify any other development extracting or diverting up to 40GL/year from groundwater resources). This highlights the unusual nature of the Proposed Development and potential for significant, and potentially unpredictable and irreversible, impacts.[35]

32. To put its scale in perspective, it has been noted that:

> *the ten largest groundwater licences in the state of NSW range from approximately 7GL to 15GL with these licences being spread across three different catchments. The number of bores associated with these individual licences ranges from 3 to 11*.[36]

33. Comparisons between the volume of water that will be diverted under the Singleton Licence and mining developments reveal that even large-scale open cut coal mines divert a fraction of the water authorised under this Licence. By way of example:

> *…the proposed McPhillamys Gold Mine in the Lachlan Catchment in south-western NSW, which will comprise a pit of some 450 metres in depth, is projected to divert a maximum of 580ML/year or 0.58GL/year from the aquifers through which it will be cut. This is 0.0145% of the Singleton Licence. The proponents of McPhillamy's Gold Mine, like most mining proponents, are required to undertake environmental impact assessment* [by way of a full EIS][37] *in accordance with the relevant statutory framework.*[38]

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[34] Water Resources Review Panel report to Minister dated 14.10.2021, at [93]. Available online at: https://depws.nt.gov.au/__data/assets/pdf_file/0007/1069657/wrrp-advice-to-minister-wdpcc10000.pdf (accessed 13.02.2023)
[35] See Attachments A, B, C and D to this submission.
[36] Submissions by the Environmental Defenders Office on behalf of the Arid Lands Environment Centre and Environment Centre NT to the Panel reviewing the Singleton Licence under s.30 of the *Water Act 1992* (NT), pg. 3. Available online at: https://www.edo.org.au/publication/submissions-to-the-water-resources-review-panel-singleton-licence/ (accessed 08.02.2023).
[37] https://pp.planningportal.nsw.gov.au/major-projects/projects/mcphillamys-gold-project (accessed 08.02.2023).
[38] Submissions by the Environmental Defenders Office on behalf of the Arid Lands Environment Centre and Environment Centre NT to the Panel reviewing the Singleton Licence under s.30 of the *Water Act 1992* (NT), pg.

34. The likely impacts of the Singleton Licence on affected groundwater resources in the Central Plains Management Zone include:

    a. significant drawdown, including in areas where GDEs are located (up to 50 metres in certain areas over 30 years);[39]

    b. where the baseline depth to groundwater is less than 15 metres:

        i. 26% of alluvial GDEs and 13% of sandplain GDEs on the Singleton Station may be impacted; and

        ii. 25% of alluvial GDEs and 15% of sandplain GDEs on the Central Plains Management Zone may be impacted after 40 years.[40]

35. These impacts must be considered within the context of rules that, in the absence of a declared water allocation plan (the current scenario), allow up to 80% of total aquifer storage to be extracted over a 100-year period, which is in essence a form of 'managed depletion' rather than 'sustainable management.'[41] Even with a declared water allocation plan, rules based on recharge rather than ***net*** recharge lead to drawdown of the aquifer, and it is that drawdown which can have a significant impact upon GDEs.

36. In summary, and despite uncertainties arising from deficiencies in the underlying monitoring and modelling undertaken in relation to the affected aquifers and Proposed Development (discussed below), it is highly likely that the impacts on groundwater will be significant due to the sheer volume proposed to be extracted over multiple decades.

2.2 – Deficiencies in monitoring and modelling

37. Expert analysis of the Western Davenport WAP water allocation framework and associated model development is included at **Attachment A** to this submission.[42] In summary, this analysis indicates that the water allocation framework and modelling for the Western Davenport WAP area is undermined by a range of problems, including:

    a. a lack of spatially distributed data on aquifer geometry, lithology, hydraulic properties, water levels and water quality;

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3. Available online at: https://www.edo.org.au/publication/submissions-to-the-water-resources-review-panel-singleton-licence/ (accessed 08.02.2023).

[39] Paragraph 66 of the Statement of Decision by the Water Controller for the Singleton Licence dated 08.04.2021 (**Statement of Decision**). In her decision to grant the Singleton Licence on 15.11.2021, Minister Worden relied on the Statement of Decision.

[40] Paragraph 101 of the Statement of Decision.

[41] Northern Territory Water Allocation Planning Framework (Arid Zone – Aquifers), p.2.

[42] Western Davenport Plan, Associated Documents and Groundwater Model Review, dated 16.07.21. Note this is based on an analysis of the modelling underpinning the Western Davenport WAP 2018 – 2021 which was the WAP that was in force at the time the Singleton Licence was approved. The replacement WAP will be released in draft form shortly. However, we are advised that in the absence of significant, additional monitoring of groundwater resources in the WAP area (over a minimum of five years), any replacement modelling will not rectify the underlying deficiencies identified by the CLC and its experts. Until such time as a new WAP is declared, the Arid Zone rules apply, which permit the managed depletion of the aquifer by 80% of the stored resource over 100 years.

b. a dearth of water level data and associated time series (within the context of long-term predictive modelling) for much of the model domain (especially for the regolith, which is only inferred rather than based on measured data); and

c. aquifer testing data is sparse and generally restricted to short duration, single borehole tests which cannot determine aquifer storage properties.

38. This means that key baseline data regarding the characteristics of the affected aquifers is absent, which in turn exacerbates the level of uncertainty regarding the impacts associated with the extraction of such a large volume of water over time.

39. Additionally, the Western Davenport WAP 2011-2021 itself identifies key limitations in the underlying modelling. These are articulated in a submission prepared by the CLC in 2021 seeking Ministerial review of the Singleton Station Licence.[43] This submission is included at **Attachment B** to this submission.

40. **Attachment C** to this submission is an expert sensitivity analysis with indications of predictive uncertainty of the groundwater modelling relied on for the purpose of the Proposed Development. It highlights a range of serious problems, including:

a. The baseline data available to construct a reliable groundwater model describing the impacts of the project is limited. The datasets are lacking in several areas including: spatial coverage, detail of geological classifications (types of soil/rock, depths of soil/rock, thickness of aquifers etc.), and field measurement of parameters that would assist in parameterising a groundwater model.

b. Building/configuring any model requires a degree of data interpretation by the modeller. Since the available baseline datasets are limited (as per subparagraph a, above), the application of the data to build a model is open to interpretation by the modeller e.g. the area, depth and volume of aquifer layers. The model that Fortune is relying on has one plausible interpretation of the datasets, but there could be other reasonable interpretations. The model results could be affected by this interpretation.

c. The accuracy and range (referred to in the document as 'uncertainty' usually expressed as a median value +/- a range e.g. for groundwater levels 10m AHD +/- 5m) of plausible model results can be significantly influenced by the numerical parameters chosen for the model. The choice of these model parameters can be guided by calibration to measured historical data (e.g. variations in depth to groundwater). In a sophisticated model like MIKEShe, there are numerous model parameters. A criticism of Fortune's model is that they have adopted one combination of model parameters amongst many possible parameter combinations which might reproduce the historical data.

[43] Submission seeking ministerial review of Water Controller’s decision to grant the new water extraction licence WDPCC10000 to Fortune Agribusiness, 7 May 2021, pp 5 to 9 inclusive.

d. The numerical uncertainty of a model can be tested by varying the model parameters - known as model sensitivity analysis. A key criticism of Fortune's model is that the sensitivity analysis presented in the EIA is limited. The CLC's experts have conducted a broader sensitivity analysis and demonstrated that Fortune's model could be far more sensitive to the choice of model parameters than reported.

e. The CLC's experts have indicated that the predicted impacts of water extraction by the project could have been underestimated by up to 30m in groundwater depth with an associated large increase in the spatial footprint of potentially impacted areas. The potential underestimation of modelled groundwater impacts has significant implications for potential underestimation of impacts to GDEs, vegetation, stygofauna etc.

41. Furthermore, the CLC and its experts have identified serious legal, ecological and cultural deficiencies in the assumption that 30% of GDEs in the Western Davenport Water Control District can be impacted.[44] For example, this figure has no discernible scientific basis; nor does it take into account the potential, relative value of a particular landform (meaning that 30% of the most ecologically and culturally significant GDEs could in theory be degraded or destroyed). It does not take into account that GDEs are frequently associated with cultural values in general and sacred sites in particular. No damage to sacred sites (be they GDEs or otherwise) is permitted under the Sacred Sites Act. The CLC asserts that Fortune's assessment of interconnected cultural values is flawed (see **Part 5** of this submission for further details).

42. Finally, expert analysis of the materials submitted by Fortune as part of its referral under the EP Act and EP Regulation and included at **Attachment D** to this submission highlight a range of ongoing problems, including that:

    a. on balance, there is very little new information pertaining to, *inter alia*, hydrology, hydrogeology and impact assessment, and no new information that would rectify the deficiencies and limitations identified in the expert reports attached to this submission;

    b. monitoring and adaptive management plans are generic and lacking in necessary detail; and

    c. the risk assessment is not underpinned by good data and analysis, rendering it qualitative and subjective.[45]

43. As a consequence, the expert reviewer recommends that the NT EPA ensure that the Proposed Development is subject to a full EIS (Tier 3 assessment). This is particularly important given the assessment undertaken to date by Fortune is, in our view and that of

[44] As per the following policy document: *Limits of acceptable change to groundwater dependent vegetation in the Western Davenport Water Control District.*
[45] Singleton Station Horticulture Project – EIS and Appendices, Focussed Review

our advising experts, more consistent with a pre-feasibility study than proper EIA.

2.3 – Mitigation measures – adaptive management

44. The CLC, on the evidence of experts engaged by it, has persistently argued that the uncertainty around the possible impacts of the Proposed Development on groundwater, and GDEs in particular, could and should be reduced by undertaking more fulsome monitoring and modelling and a full EIS. However, and as a substitute for these necessary steps, Fortune has sought to rely on so-called 'adaptive management' to purportedly mitigate the inherent uncertainty and possible magnitude of the impacts on groundwater and GDEs. Indeed, 'adaptive management' provisions have been built into the conditions for the Singleton Licence.

45. Expert evidence commissioned by the CLC (**Attachments A and D**) makes it abundantly clear that this 'adaptive management' regime is fundamentally flawed for the following (non-exhaustive) list of reasons:

    a. adaptive management is often inappropriately relied upon to justify approval of complex projects for which there is insufficient understanding of risks to the environment;

    b. adaptive management requires a strong understanding of the affected water resource(s), biodiversity, GDEs and cultural values to be potentially successful. However, the monitoring, modelling and surveying work undertaken in relation to these matters by Fortune is manifestly deficient; and

    c. given the infrequent and small amount of groundwater recharge in the area, if impacts occur that are deemed unsuitable, groundwater recovery may take decades - if it occurs at all. Fortune's own groundwater modelling predicts almost no recharge for nearly 60 years.

46. We would further note that the use of an 'adaptive management' framework for water being extracted to grow perennials has been queried by a number of experts.[46] Specifically, once planted, perennials require ongoing watering to stay alive. The notion that Fortune would invest millions of dollars in planting vines and trees – and then agree to reduce extractions and lose part of their investment because impacts had exceeded certain thresholds – seems unrealistic.

47. This is exemplified by the fact that the current draft of the adaptive management plan at Schedule G of Fortune's referral documents does not envisage 'turning the taps off' in response to any trigger. Rather, the identified management actions include relocating bores and artificially watering or off-setting GDEs.[47] The triggers for implementation of those management action remain largely undefined, but may include the spatial extent of

[46] See for example: Submissions by the Environmental Defenders Office on behalf of the Arid Lands Environment Centre and Environment Centre NT to the Panel reviewing the Singleton Licence under s.30 of the *Water Act 1992* (NT), pp. 4-5. Available online at: https://www.edo.org.au/publication/submissions-to-the-water-resources-review-panel-singleton-licence/ (accessed 08.02.2023).
[47] Schedule G: Groundwater Monitoring Program & Adaptive Management Plan, pp 42 – 43

drawdown being 20% greater than anticipated by modelling or 5% destruction of GDEs.[48] Without sufficient baseline studies, triggers defined in that manner will always be vague and open to interpretation. Advice given to the CLC is that once a GDE's health declines visually, it is usually too late to save that GDE. Particularly for GDEs that are also sacred sites, off-setting is an inappropriate response and would not meet Fortune's obligations under the Sacred Sites Act.

48. Finally, peer-reviewed literature regarding the use of adaptive management in relation to groundwater resources (**Attachment E**) has highlighted the vital importance of strong predictive modelling to, *inter alia*, guide management alternatives. It has also reinforced the role of rigorous data collection (drilling, monitoring, geophysical surveys etc.) in addressing 'critical data gaps and the main sources of uncertainty in estimates of project effects and predictions of the efficacy of AGM [adaptive groundwater management] strategies.'[49]

49. We note that these two critical elements – fit-for-purpose modelling and sufficient baseline data about the affected aquifers – are precisely what have been identified as missing from the underlying work undertaken by Fortune and the NT Government in relation to the wider Western Davenport WAP.

PART 3: SALINITY

50. A CLC note of expert analysis (**Attachment F**) of Fortune's Salinity Impact Assessment Report (Appendix L of the referral materials) identified a number of problems. These include a failure to:

    a. report on or model environmental impacts of salinity beyond changes in the groundwater extracted from the pumping bores;

    b. report on salinity at the water table and maximum potential salinity increases; and

    c. report on original soil salinity which could greatly increase salinity levels above predictions.

51. These gaps mean that the risk of increased salinity is much higher than predicted. They also leave critical questions unanswered, including the following:

    a. What is the salinity at the top of the water table?

    b. What are the potential maximum salinity levels due to the development?

    c. Why is a salinity concentration of 1500mg/L assumed as the maximum when initial salinity levels are assumed to be 900mg/L?

[48] Schedule G: Groundwater Monitoring Program & Adaptive Management Plan, pp 39 – 40
[49] Pg. 7.

d. What are the soil salinity levels below 2-3m and how might they impact on increased salinity risks?

52. The aforementioned gaps and uncertainties in turn undermine the suitability of the mitigation measures proposed by Fortune in its Salinity Impact Assessment Report.

PART 4: TERRESTRIAL BIODIVERSITY

53. This part provides commentary on Fortune's Biodiversity Assessment Report (Appendix C of referred materials), and in particular methodological flaws and limitations in the surveying and assessment work conducted to date. We note that the work underpinning the Biodiversity Report was undertaken within the context of Fortune's proposal to clear over 4,000 hectares of native vegetation (sandplain habitat) to facilitate the Proposed Development.

54. The Biodiversity Assessment Report (**Biodiversity Report**) is a desktop analysis,[50] relying on literature reviews and biodiversity surveys conducted in 2019 as part of the 'Mapping the Future' survey,[51] as well as online mapping tools including the Protected Matters Search Tool (**PMST**) and The NT Government Department of Environment and Natural Resources – Natural Resource Maps database (**NR Maps database**).

55. The Biodiversity Report itself notes the limits of this approach, including the fact that:

> *[n]o trapping or targeted threatened species survey was conducted. The level of confidence surrounding the likelihood of occurrence and potential impact on threatened species is limited by the findings of the Mapping the Future Survey (DEPWS, 2022) and advice provided by the NT government dated September 18, 2020 recommending that targeted threatened species surveys were not necessarily required to assess potential impact.*[52]

56. We further note that the Mapping the Future survey is critically limited by the fact that the relevant flora and fauna surveys were conducted during a period of extreme water scarcity (March to October 2019). As noted in the Biodiversity Report, '…unfortunately, the timing of the flora surveys coincided with a period of prolonged severe drought, meaning that only the perennial subset of the herbaceous flora was sampled'.[53]

57. The Biodiversity Report also acknowledges that the extreme climatic conditions that typified the survey period may have affected the detection of certain species, including the Greater Bilby and the Spectacled Hare-Wallaby.[54] For example, the Report states that:

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[50] Biodiversity Report, pp.2, 6.
[51] https://depws.nt.gov.au/programs-and-strategies/mapping-the-future (accessed 10.02.23).
[52] Biodiversity Report, p.2.
[53] Biodiversity Report, p.2.
[54] Biodiversity Report, pp. 50; Appendix C, Table 5, p. 12 (of Appendix). Table 5 notes that 'Range and distribution [of the Spectacled Hare-Wallaby] possibly expands and contracts with resource availability and climactic conditions.'

the Mapping the Future survey was conducted in October 2019, at the time of prolonged dry periods, which coincided with very high temperatures over the summer of 2019/20 (BOM, 2022). This would have contributed to poorer ecological conditions and potentially lower detectability of several species of potential threatened flora and fauna, including Greater bilby.[55]

58. Extensive peer-reviewed literature (see **Attachments G, H, I and J** to this submission) assessing the presence of flora and fauna during climatic 'boom and bust' periods in arid environments confirms that trends regarding species cannot be determined by limited surveying undertaken during 'bust' (or dry) spells. As a consequence, best-practice dictates that surveying must be undertaken over longer timescales that also incorporate 'boom' conditions, which can be brief but significant for biodiversity. Failure to do so will invariably skew survey results.[56] Indeed, this is consistent with the Australian Government's 'Survey guidelines for Australia's threatened mammals – Guidelines for detecting mammals listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth)',[57] as well as the NT EPA's Guidelines for Assessment of Impacts on Terrestrial Biodiversity.[58]

59. This is particularly true for the Greater Bilby, the numbers for which can increase significantly in a given region during 'boom' periods caused by high rainfall. For example, the Australian Wildlife Conservancy (**AWC**) observed that:

From 2021 to 2022, Bilby populations increased across AWC sanctuaries from an estimated 1,230 individuals to 1,480. AWC protects at least 10% of Australia's remaining Bilby[59] *population which is estimated at around 10,000 individuals.*

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[55] Biodiversity Report, p. 50.

[56] See for example: Pavey, C.R. and Nano, C.E., 2013. Changes in richness and abundance of rodents and native predators in response to extreme rainfall in arid Australia. *Austral Ecology*, 38(7), pp.777-785; Pavey, C. R., Nano, C. E., Cole, J. R., McDonald, P. J., Nunn, P., Silcocks, A., & Clarke, R. H. (2014). The breeding and foraging ecology and abundance of the Princess Parrot (Polytelis alexandrae) during a population irruption. *Emu-Austral Ornithology*, 114(2), 106-115.Pavey, C.R., Nano, C.E.M., Waltert, M, 2020. Population dynamics of dasyurid marsupials in dryland Australia: Variation across habitat and time, *Austral Ecology*, 45, 283–290.

[57] Australia Government, *Survey guidelines for Australia's threatened mammals – Guidelines for detecting mammals listed as threatened under the Environment Protection and Biodiversity Conservation Act 1999 (Cth)*, p.6. https://www.dcceew.gov.au/sites/default/files/documents/survey-guidelines-mammals.pdf (accessed 10.02.23).

[58] These guidelines state (at p.9) that for threatened and migratory fauna, '[s]ampling is to occur at suitable times of year and appropriate intensity to determine the presence of the species and obtain estimates of population abundance where the species occur. Search areas, sampling methods, search time/effort, capture effort as appropriate and results are to be reported for each possible threatened or migratory species. The adequacy of sampling needs to be demonstrated.
https://ntepa.nt.gov.au/__data/assets/pdf_file/0004/287428/guideline_assessment_terrestrial_biodiversity.pdf

[59] Note that the terms 'Greater Bilby' and 'Bilby' refer to the same species.

The increase in Bilby populations within AWC sanctuaries can be attributed to the increased rainfall in parts of the country during Australia's second year of La Niña, which replenished the landscape and provided good conditions for breeding.[60]

60. That is, the primary driver of their population increase during this period was not predator control (noting that these are predator-free zones), but a transition out of Australia's worst drought in recorded history and into a period of significant rainfall.

61. While there is very little research on boom-and-bust populations in the Singleton area, nearby regions (Tanami, Simpson Desert, Uluru) have been well-documented in the literature and confirm the vital importance of properly planning surveying to ensure that it includes boom periods.[61]

62. However, and notwithstanding the significant limitations of the surveying relied upon and/or undertaken by Fortune, the Biodiversity Report concludes that:

impacts to threatened species were assessed as 'unlikely' under all criteria. The species assessed are not likely to occupy the Proposal area with any regularity and while the Proposal will remove a large amount of potential habitat, it is not thought to make up core or critical habitat for any species, and the quality and quantity of habitat is somewhat reduced by grazing, weeds and invasive predators such as the feral cat.[62]

63. The CLC contends that this conclusion is based upon data that is likely to be skewed as a consequence of the period during which it was collected. As such, we'd suggest that it is not possible to definitively conclude that the area to be cleared of native vegetation does not constitute critical habitat for boom-and-bust (threatened) species such as the Greater Bilby. Further, the presence of other threats to these species (grazing, weeds, feral cats) *increases* the need to maintain intact habitat (particularly if it may act as refugia).[63]

64. These methodological flaws – including in relation to potential habitat for a federally-listed species[64] – raise serious concerns about the integrity of the biodiversity assessment undertaken by Fortune to date. They further undermine the mitigation and management actions set out in the Biodiversity Report, [65] including because these

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[60] See: https://www.australianwildlife.org/bilby-census-populations-of-australias-threatened-easter-bunny-are-growing/ (accessed 10.02.2023).
[61] See for example: Pavey, C.R. and Nano, C.E., 2013. Changes in richness and abundance of rodents and native predators in response to extreme rainfall in arid Australia. *Austral Ecology*, 38(7), pp.777-785;
[62] Biodiversity Report, pp.55-56.
[63] Pavey CR, Addison J, Brandle R, Dickman CR, McDonald PJ, Moseby KE, Young LI. The role of refuges in the persistence of Australian dryland mammals. *Biol Rev Camb Philos Soc.* 2017 May;92(2):647-664.
[64] The Greater Bilby is listed as 'vulnerable' under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act).
[65] Biodiversity Report, Appendix C, pp. 15-30 of that Appendix.

actions cannot in any way compensate for the loss of up to 4,000 hectares of potential habitat and refugia for boom-and-bust species such as the Greater Bilby.

65. Finally, we note that the Biodiversity Report acknowledges that Thring Swamp, which is classified as having 'high biodiversity value' and as a 'swamp of botanical significance',[66] will be affected by drawdown associated with the Proposed Development. Given the inherent deficiencies and subsequent uncertainties associated with Fortune's groundwater modelling (as per Part 2 of this submission), we would submit that there is scope for the impact to be greater than predicted. This is significant insofar as swamps are of great cultural significance (see Part 5 of this submission and associated expert reports).

PART 5: SACRED SITES AND ABORIGINAL CULTURAL HERITAGE

5.1 – Comparative legislation

66. It is essential to observe the difference in language and obligation between the EP Act and the Sacred Sites Act.

67. The EP Act acknowledges that there may be environmental impacts which cannot be avoided. In such circumstances the EP Act requires application of the environmental decision-making hierarchy described in paragraph 24. That is: first avoid; second mitigate; third off-set.

68. There is no similar hierarchy in the Sacred Sites Act. Rather, the Sacred Sites Act provides absolute prohibitions,[67] subject only to compliance with conditions on an Aboriginal Areas Protection Authority (**AAPA**) Certificate[68] and related defences.[69]

69. That distinction is important for the Proposed Development where many sacred sites are also GDEs. Mitigating or off-setting damage to 'ordinary' GDEs may be appropriate under the EP Act. It is not for 'sacred' GDEs under the Sacred Sites Act. The NT EPA will see from Fortune's referral documents that no complete sacred site survey has been undertaken on the company's behalf nor has the company comprehensively mapped sacred sites against GDEs. Until that work is done, it is not possible to work out which GDEs cannot be damaged at all (under the Sacred Sites Act) or, alternatively, whether damage must be avoided, mitigated or off-set (under the EP Act). The NT EPA ought to require this work to be done as part of an environmental impact statement so that the NT EPA can have confidence about when and how it should apply the environmental decision making hierarchy as opposed to the prohibitions in the Sacred Sites Act.

[66] Stokeld, D., Leiper, I., Brim Box, J., Jobson, P., Nano, C. and Box, P. (2022). Mapping the Future Project – Western Davenport. Biodiversity assessment of the Western Davenport area. Technical Report 30/2021. Department of Environment, Parks and Water Security. Darwin, Northern Territory; Biodiversity Report, pp. 8.
[67] Sacred Sites Act, ss. 33, 34 and 35.
[68] Sacred Sites Act, s. 34(2).
[69] Sacred Sites Act, s. 36.

5.2 – Overview

70. Part 5 relies on the letter included at **Attachment K** and the expert evidence included at **Attachments L and M**.

71. In its referral documents, Fortune says that after applying its mitigation strategies:

   a. the risk of "*potential impacts to sacred sites or Aboriginal cultural values from water drawdown*" is **MEDIUM**; and
   b. the risk of "*direct impacts to sacred sites of Aboriginal archaeological sites*" is **LOW**.

72. The risk to other cultural values is not assessed.

73. Those risk levels do not match what traditional Aboriginal owners and native title holders have told the CLC and the expert anthropologist engaged by it, Susan Dale Donaldson. Nor do they incorporate the high degree of uncertainty in the groundwater modelling identified by Dr Ryan Vogwill and described above. As set out in this section, the CLC considers that there is a **HIGH** risk of significant detrimental impact to Aboriginal cultural values if the Proposed Development proceeds as currently described. Further, the reliance of the Proposed Development on extracted groundwater renders illusory any distinction between "*indirect*" impacts due to drawdown and "*direct*" impacts from other activities.

74. According to the referral documents, Fortune relies on the following in order to protect Aboriginal cultural values:

   a. AAPA Certificate C2019/083;
   b. a new certificate it will apply to AAPA for covering the balance of the anticipated drawdown area; and
   c. conditions imposed on the Singleton Licence.[70]

75. Each of those documents is problematic for reasons including those set out in subsections 5.3 – 5.5.

76. Apart from protection via a current (and potentially a future) certificate from AAPA and the Singleton Licence conditions, traditional owner and native title holder involvement in mitigation strategies is limited to being consulted by Fortune to ensure the monitoring plan "*includes issues of importance to them*" and having Fortune's "*Engagement Plan … implemented which involves ongoing engagement with the TOs throughout the life of the project*".[71]

[70] Fortune's NT EPA Referral "*Main Document*", p. 127
[71] Fortune's NT EPA Referral "*Main Document*", p. 127

77. This is akin to traditional Aboriginal owners having things done to them. The better alternative is empowerment, as anthropologist Susan Donaldson encourages:

> *Good practice in the field of cultural heritage management includes working in cooperation with Traditional Owners to develop and apply an approach to cultural heritage management inclusive of a broad range of tangible and intangible cultural values. Traditional Owners' cultural values should not only be documented, Traditional Owners themselves should be empowered as active stakeholders and decision makers in matters that affect their land and waters.*[72]

78. In preparing the management plans required by the Singleton Licence conditions precedent, Fortune proposes to rely on the *Draft Environmental factor guidance: Culture and heritage* released for public comment by the NT EPA in 2022.[73] It should be made clear to Fortune that the draft guidance document currently has no force or effect. The CLC relies on its previous submissions to the NT EPA about changes required to that document.

<u>5.3 – Current AAPA Certificate C2019/083</u>

79. On 24 September 2021 the Chief Executive Officer of AAPA, Dr Ben Scambary, wrote to the Minister for Water Security, the Honourable Eva Lawler. A copy of that letter is **Attachment K**. That letter identifies legal and factual concerns which call into doubt the validity of AAPA Certificate C2019/083. A significant cause of the matter appears to be Fortune's failure to provide any information to AAPA about the extent of its proposed water use and groundwater drawdown.[74]

80. Dr Scambary wrote:

> *While the Authority is of the view that C2019/083 operates to prohibit any groundwater drawdown that might damage sacred sites, <u>this is not beyond doubt</u>. Particularly, as the <u>application for C2019/083 was not supported by information or data about the quantity of water to be extracted for the project, or the possibility or level of groundwater drawdown</u>. Therefore, it is arguable the Certificate was issued in relation to an <u>unspecified amount of water</u>.*[75] (underline added)

[72] See Attachment L: Singleton Water Licence Aboriginal Cultural Values Assessment – Public Report prepared by Susan Dale Donaldson dated 01.09.2021, p.13
[73] Fortune's NT EPA Referral "*Main Document*", p. 127
[74] Fortune's application to AAPA described the relevant works as "*water extraction, use and access including dams / watercourse upgrades, bores, drainage*". More information was known to Fortune than was provided to AAPA. This can be inferred from, for example, Schedule Y to the referral documents which summarises the groundwater modelling commissioned by Fortune for the Proposed Development. That CloudGMS Groundwater Modelling Study is dated 2017. An AAPA Certificate was not sought until 2019.
[75] Letter dated 24.09.2021 from AAPA to Minister, p. 2.

81. In addition to concerns about the validity of AAPA Certificate C2019/083, an expert anthropologist engaged by the CLC has identified five sites that are missing from AAPA Certificate C2019/083:

> *Critically, the current assessment identified five sacred sites within the* [AAPA Certificate] *subject land not identified in the AC or overlapped by any of the RWAs.* <u>*These sites are all within the drawdown area and are all associated with GDE features; all are soakages*</u>*. An additional 32 sacred sites were identified outside the AC subject land and within the drawdown zone.*[76] (underline added)

82. Those five soakages receive no protection from AAPA Certificate C2019/083.

83. At no time has Fortune acknowledged these valid concerns about AAPA Certificate C2019/083 by agreeing not to rely upon it. The contrary is in fact the case. Fortune's referral documents make clear that it intends to keep relying on C2019/083, subject only to application for the second certificate described below.

84. Fortune could allay AAPA's, the CLC's, traditional Aboriginal owners' and native title holders' concerns by:

    a. consenting to the withdrawal of AAPA Certificate C2019/083; and

    b. working with the CLC, traditional Aboriginal owners and native title holders through the CLC's sacred site clearance procedures; and

    c. if it wishes to do so, [77] additionally applying for a single AAPA Certificate covering the entire anticipated drawdown area plus a reasonable buffer in case groundwater drawdown limits exceed what has been modelled.

85. Fortune has not done so. In the absence of Fortune taking those steps, there remains a real and significant risk that reliance by it upon AAPA Certificate C2019/083 will allow use of groundwater in a way that damages sacred sites, both inside and outside the subject area of that certificate.

[76] See Attachment L: Singleton Water Licence Aboriginal Cultural Values Assessment – Public Report prepared by Susan Dale Donaldson dated 01.09.2021, p. 70.
[77] We consider that a Sacred Site Clearance Certificate issued by the CLC would provide an equivalent level of statutory protection to Fortune as an AAPA Certificate: see Sacred Sites Act, s. 36

<u>5.4 – Potential future AAPA Certificate</u>

86. Fortune commits in its referral documents to "*engaging AAPA to consult and issue Authority Certificate(s) for any area <u>outside</u> the current Certificate that may in the future be subject to groundwater drawdown*".[78]

87. That proposed step does not mitigate the risks identified in the previous subsection.
    a. First, the new certificate would provide no protection for the five omitted sites identified by Donaldson.

    b. Secondly, as identified in Dr Scambary's letter, it is arguable that unlimited drawdown is permitted under current AAPA Certificate C2019/083. Fortune has not proposed to apply for a new certificate covering both the existing subject area of C2019/083 and the entire drawdown area. Rather it proposes a new certificate that would only apply outside the existing certificate. It is not clear how the two certificates would interact, if one (arguably) permits unlimited drawdown and the other seeks to limit it in order to protect sites. There is potential for conflict between certificates and legal argument could ensue. That is an unsatisfactory position, not only for traditional Aboriginal owners and native title holders, but also for Fortune. The purpose of an AAPA Certificate is to provide certainty for all parties. Having two certificates that interact in unclear ways will not do that.

    c. Thirdly, the drawdown area remains uncertain and will keep expanding over time. By limiting the application for a new certificate to the currently predicted spatial extent of groundwater drawdown, sites outside of that limit will not be protected, even if the predictions are invalid. For the reasons set out in the section addressing the sensitivity analysis and predictive uncertainty of the groundwater model, it is inadequate to limit the extent of a sacred site clearance to the currently predicted drawdown extent. The clearance boundary must exceed the anticipated drawdown extent and allow sites in that outer region to be incorporated now into an appropriate monitoring regime.

88. The impact on sacred sites outside the subject area of AAPA Certificate C2019/083 could be better avoided if Fortune followed the steps set out in paragraph 84 above. Further, undertaking that work now (rather than at a later stage once the groundwater drawdown exceeds the boundaries of C2019/083), would allow those sites to be incorporated into an appropriate monitoring regime and increase the chance of avoiding any impact to them.

[78] Fortune's NT EPA Referral "*Main Document*", p. 127

5.5 – Groundwater Extraction Licence Conditions Precedent

89. Condition precedent 10 (**CP10**) requires Fortune to develop a groundwater depended Aboriginal cultural values impact assessment. It was added to the Singleton Licence by Minister Worden on 15 November 2021 following submissions by the CLC and others about the Controller of Water Resources' failure to consider Aboriginal cultural values. The CLC and its clients had no input into the drafting of CP10. The lack of procedural fairness offered to Mpwerempwer about CP10 (and others) is a matter before the Supreme Court of the Northern Territory. Judgment in that matter is reserved.

90. There are a number of startling features of CP10.

    a. Although the cultural values are those of Aboriginal people, it is left to Fortune to do this work. CP10 imposes on Fortune no obligation to consult traditional Aboriginal owners, native title holders or the CLC. The only restriction is that the assessment must be prepared by a suitably qualified professional. To undertake such an assessment, the professional will need to have a relationship of trust and confidence with traditional owners and native title holders. That is likely to be strained if the person has been contracted by Fortune and is understood to be acting on Fortune's behalf. It would be preferable to direct Fortune to engage with the CLC and properly resource it to undertake some of the tasks identified in CP10.

    b. Furthermore, approval of the assessment is left entirely in Fortune's hands. CP10 requires that Fortune "*develop and submit to the Controller a groundwater dependent Aboriginal cultural values impact assessment*". By contrast, all other conditions precedent (except CP6 re salinity) require Fortune to "*develop and submit <u>for approval by</u> the Controller…*".

    c. The scope of CP10(b), (c) and (d) show the magnitude of the task that remains to be done. First, the Aboriginal cultural values must be identified, mapped and documented. Then reference points need to be identified to be used in modelling the impacts of groundwater extraction on those Aboriginal cultural values. Finally, monitoring parameters, trigger values and limits of change for adaptive management need to be determined.

    d. Any errors or omissions in the baseline studies, links to modelling or selection of monitoring parameters, trigger values and limits of change required by CP10 have real potential to cause significant impacts of the kind described in **Attachment M**.

91. The NT EPA has been asked to decide this referral before the large scope of work required by CP10 has been done. It would be appropriate for the NT EPA to direct Fortune to engage with the CLC about the substantive matters included in CP10, to take

the steps described in paragraph 84 and to mandate inclusion of that material in a full environmental impact statement for proper consideration by the NT EPA.

5.6 – Cultural Values Assessment and Impact Assessment

92. **Attachments L** and **M** are two reports commissioned by the CLC from an expert anthropologist, Susan Dale Donaldson. **Attachment L** is a report dated 1 September 2021 which identifies Aboriginal Cultural Values in the area of Singleton Station. It does not purport to be a definitive or exhaustive assessment: "*It is also possible that other sites exist within the drawdown area that were not identified during this assessment*."[79]

93. **Attachment M** is an addendum to Attachment L and assessed the impact of the Proposed Development upon the identified Aboriginal cultural values.

94. The Aboriginal cultural values identified by Donaldson extend beyond protection of sacred sites. The broad categories of values include:

    a. Following the *Altyerre* Law and cultural obligations;[80] and

    b. Maintaining spiritual connections and protecting sacred sites;[81] and

    c. Undertaking ritual associated with groundwater and GDEs;[82] and

    d. Upholding ecological knowledge associated with collecting natural resources; [83] and

    e. Continuing customary roles and responsibilities;[84] and

    f. Being able to live and travel on country.[85]

95. In its referral documents Fortune focuses solely on potential impacts to sacred sites and archaeological sites. Despite the CLC writing to Fortune and providing a copy of the Donaldson report (2021),[86] Fortune has not made any assessment of the potential impacts the Proposed Development will have on other Aboriginal cultural values. This is a significant omission that must be addressed as part of a full environmental impact assessment.

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[79] See Attachment L: Singleton Water Licence Aboriginal Cultural Values Assessment – Public Report prepared by Susan Dale Donaldson dated 01.09.2021, p. 10.
[80] As above, p. 25.
[81] As above, p. 29
[82] As above, p. 37
[83] As above, p. 42
[84] As above, p. 50
[85] As above, p. 53
[86] By letter dated 21.07.2022.

96. The two Donaldson reports, read together, are far more rigorous than that offered by Fortune in its referral documents. They provide a far more detailed understanding of the breadth of cultural values and their on-going exercise - and by way of extension, of the scope of possible impacts to them. Nevertheless, the author freely acknowledges that the assessment may not be complete.

97. While both reports need to be read in full, a summary of key conclusions in the Impact Assessment Addendum is as follows:

a. The Singleton Licence and associated drawdown has the potential to have significant impacts on each of the identified Aboriginal cultural values.[87]

b. The reduction in groundwater will cause negative consequences to cultural places and values held by Akwerlpe-Waake, Iliyarne, Anerre and Arlpwe people and their neighbouring tribal groups including factors associated with culture and heritage; human health; community and economy; aquatic ecosystems; hydrological processes; and terrestrial ecosystems.[88]

c. The potential impacts will likely or almost certainly result in highly significant cultural values to be lost, degraded and damaged, as well as notably altered, modified, obscured or diminished.[89]

d. Whilst an AAPA Certificate has been issued, the substantive risk of damage to, or interference with sacred sites on or in the vicinity of the AAPA subject land is highly likely, even if the sacred sites are covered by restricted work areas. Another highly likely consequence of harming sacred sites is the distress caused to the Traditional Owners. Both of these potential impacts are significant and not adequately addressed by approvals received under the Sacred Sites Act.[90]

<u>5.7 – Level of understanding and consultations</u>

98. According to Donaldson:

> *There has been extensive community engagement with Traditional Owners and other affected Aboriginal community members in relation to the proposal. The overwhelming community response is one of concern for future generations given the unknowns in relation to how the significant impacts will be managed in order to avoid catastrophic consequences (for people and country).*[91]

[87] See Attachment M: Addendum: Aboriginal Cultural Values Impact Assessment prepared by Susan Dale Donaldson dated 07.02.2023, pp. 27, 29, 33, 35, 38 and 41
[88] As above, pp. 2 and 46.
[89] As above, pp. 2 and 46.
[90] As above, p. 44.
[91] As above, p. 44.

99. That powerful conclusion is based on *her* consultations with traditional owners and native title holders.

100. By contrast, to the best of the CLC's knowledge, there has been very limited consultation of and engagement with Aboriginal people by or on behalf of Fortune.

101. The CLC facilitated one introductory meeting in 2019 to allow Fortune to introduce its representatives and the agricultural project. There was no discussion of the size of the water licence Fortune required to undertake the project. No free, prior or informed consent was given to anything at that meeting.

102. Between October 2020 and February 2021 the CLC consulted with native title holders about the project using information that was publicly available at the time. That information was not complete and was significantly less than has now been made available through the EIA process.

103. Fortune's representatives attended a meeting in Tennant Creek in February 2021. It was a CLC information meeting, not a substantive consultation by Fortune with native title holders.

104. At the February 2021 meeting the CLC was given instructions to scrutinise the Proposed Development and if necessary to take legal action to protect native title holders' rights and interests. Since shortly after that date, the CLC has been pursuing merit review and judicial review proceedings on behalf of Mpwerempwer. With the litigation on foot, it has not been appropriate for the CLC to facilitate consultations between Fortune and native title holders or traditional Aboriginal owners.

105. The CLC is aware of limited consultations by GHD on behalf of Fortune in Ali Curung during 2022. While acknowledging that CLC's information about those consultations is incomplete, some reports that reached us were concerning.

a. The most clear recollection attendees had of the meeting was the "*teaspoon and bucket*" story. Some attendees did not understand the analogy and reported to us that Fortune must surely need more water than that. Other attendees understood GHD to have been saying that if the bucket represents the aquifer, then all Fortune needed was one teaspoon of it.

b. If it is correct that such an analogy was used, that is concerning. The vivid image would stick in attendees minds while conflating the difference between aquifer storage and recharge, and ignoring the importance a "teaspoon" from the top of the "bucket" may make to key depth to groundwater measurements. Such an analogy is culturally inappropriate, misleading and oversimplifies complex groundwater matters.

c. There were mixed reports of representatives door knocking in the community and perhaps being asked to leave. It is not clear to us whether that occurred.

Nevertheless it is important to understand that consultations of this nature should be done collectively in a public space, not individually in a private house.

d. While reports given soon after the meeting were relatively clear (especially about they teaspoon and bucket), recollections have faded in the months since. That demonstrates that underlying understanding of the Proposed Development based on consultations done by Fortune is inadequate for a project of such magnitude.

106. Donaldson concludes:

The capacity of affected community members to access and understand information about the proposal and the management of potential significant impacts is hindered by a lack of information required to enable informed decision making. As such, the level of community confidence in predicting and managing potential significant impacts to sacred sites and other important cultural values is low.[92]

107. While the CLC is prepared to facilitate consultations with traditional Aboriginal owners, native title holders and other affected Aboriginal people, it needs to do so in a way that empowers native title holders and does not exacerbate those issues identified by Donaldson. To consult properly, CLC must be armed with complete information about the Proposed Development well before consultations are scheduled. Full information must be provided freely by Fortune, but should also be tested by independent sources (such as by experts engaged by the CLC, but funded by Fortune) and the EPA through a full EIS. It must be done alongside the matters raised in the previous section about protection of cultural values and the empowerment of native title holders through that process. It must be done after the ongoing litigation has been resolved. It must be done with no pre-conceived outcome in mind if free, prior and informed consent is to be obtained.

PART 6: AQUATIC ECOSYSTEMS

108. The CLC notes that Fortune has only undertaken a desktop analysis to determine the possible presence of stygofauna in aquifers affected by drawdown. This analysis concluded that their presence was 'likely' [93] and that impacts could include 'localised extinctions and reduction in populations and communities' as a consequence of the 'predicted water level drawdown.' It went on to note that 'the species and community assemblages of stygofauna found within the aquifer will inevitably dictate the extent of the impact on the stygofauna community.'[94] Notwithstanding these conclusions, the referral documents ultimately concludes that the residual risks with respect to aquatic

[92] See Attachment M: Addendum: Aboriginal Cultural Values Impact Assessment prepared by Susan Dale Donaldson dated 07.02.2023, p 45.
[93] Referral Report, p. 82.
[94] Referral Report, p. 105.

ecosystems (including stygofauna) is ‘low’.[95] The CLC submits that these two elements – the possibility of extinction and a ‘low’ risk profile – are difficult to reconcile.

109. The referral documents state that the assessment was confined to a desktop study due to the absence of suitably located registered bores from which to conduct appropriate monitoring and evaluation.[96] However, the CLC contends that the results of the desktop assessment, rather than being sufficient, actually indicate that further field work is required to properly determine the likely presence and potential impacts of the Singleton Licence. Existing bores (of which there are 110) in the local area could be used, or additional ones drilled if necessary. Indeed, this is precisely the sort of matter that ought to be properly investigated as part of a full EIS.

PART 7: GREENHOUSE GAS ASSESSMENT

110. The CLC notes that Fortune’s greenhouse gas (**GHG**) assessment fails to include all Scope 1 and 2 GHG emissions for both the construction and operational phases. The GHG assessment omits at least:

a. burning of cleared vegetation during the construction phase (as detailed in Site Preparation and Establishment Plan);

b. emissions from landfill associated with the Community Hub;

c. fuel consumption for field operations to produce the crops (ploughing, planting, spraying, harvesting); and

d. the use of nitrogen (N) fertiliser for crop production (this should be included as a Scope 1 direct and indirect N2O emissions).

111. Unanswered questions include:

a. What would total GHG emissions estimates be if all Scope 1 and 2 GHG were covered (burning cleared vegetation, landfill from Community Hub, fuel use for field operations and the use of nitrogen fertilizer) through all phases of the project, using the Full Carbon Accounting Model (FullCAM) as consistent with the National Greenhouse Accounts (DISER 2021)?

b. What is the real value of land clearing emissions, when reported separately and not obscured by offsets which should be reported separately according to National Greenhouse and Energy Reporting standards?

[95] Referral Report, p. 118.
[96] Referral Report, p. 104.

c. What is the large amount of biomass composted in the Construction phase and why does this end during Operational phase?

d. What data assumptions have been used to verify transport and electricity emissions?

112. These matters are relevant to the Key Assessment Criteria for the decision currently before the NT EPA. They go to the level of confidence in the work undertaken by Fortune to assess the significance of impacts of the Proposed Development.

113. Fortune's referral documents mention a future PV solar plant which will reduce emissions. However construction and operation of a solar plant will necessarily require land clearing. No land clearing application made to date includes this component of the Proposed Development. The NT EPA ought to require all components of the project (particularly ones already foreshadowed, foreseeable and required to meet emissions targets) to be referred together, so that the cumulative impacts of the Proposed Development can be assessed.

PART 8: ECONOMIC ANALYSIS

114. Expert evidence included at **Attachments N, O** and **P** of this submission critically review the economic and social impact assessments supporting the business case for the Proposed Development.

115. **Attachment N** is an expert review of the Proposed Development's water entitlement provision costs benefits and employment impacts published in July 2022.[97] **Attachment O** is a peer review of Attachment N.[98]

116. In January 2023, the CLC asked the authors of Attachment N whether the Social and Economic Impact Assessments included in Fortune's referral documents caused them to change the views expressed in Attachment N. Their review of relevant referral documents is **Attachment P**,[99] which concludes:

a. the Economic Impact Assessment does not meet the NT and Commonwealth governments' standards, nor does it adhere to guidelines for Economic Impact Assessment of proposed projects;

[97] Attachment N, Review of the Singleton Horticulture Project's water entitlement provision costs, benefits and employment impacts, released by Connor J et al in July 2022.
[98] Attachment O, Peer review by Professor Quentin Grafton of UniSA's Economic Analysis report of the Singleton Horticulture Project, updated 7 July 2022
[99] Attachment P, Singleton Project Economic Impact Analysis: review in reference to the Connor et al (2022) critical review, by Connor, J et al.

b. optimistic assumptions were used to estimate public benefits, leading to overstated public benefit forecasts;

c. the Economic Impact Assessment omits social costs, including potential loss of groundwater-dependent cultural and spiritual benefits, thereby effectively assigning them a value of ‘zero’;

d. the Economic Impact Assessment did not account for the value of water entitlements that would be provided free of charge to Fortune;[100]

e. the Economic Impact Assessment uses unsubstantiated assumptions about potential flow-on benefits, which suggests exaggerated flow-on impact estimates;

f. the Economic Impact Assessment overstates employment benefits, which questionably assumes that there is, currently, a large pool of available skilled labour in the Barkly Region; and

g. the economic impact assessment contains vague statements about the Proposed Development’s public service and benefit provision without providing any financial commitment to support these claims.

117. These conclusions undermine the assumption that the purported economic benefits flowing from the Proposed Development justify or somehow ‘counterbalance’ its significant environmental and cultural impacts (and impacts on future generations). They also reinforce the need for far more rigorous EIA in the form of an EIS to ensure that economic analysis of the Proposed Development conforms with relevant guidelines – and that the methods applied and results obtained are made publicly available and are subject to further public comment.

PART 9: LEGAL ANALYSIS AND CONCLUDING REMARKS

118. In making these submissions, the CLC relies on the full text of each of the attached reports and other documents. The analysis presented in Parts 2 to 8 of this submission and in supporting expert evidence and literature demonstrates that:

a. the likely impacts on groundwater resources, GDEs, Aboriginal values and wellbeing, and biodiversity (including sandplain habitat) are likely to be significant and mostly irreversible;

[100] We note that this is inconsistent with one of the principles of ESD espoused in the EP Act, notably the principle of improved valuation, pricing and incentive mechanisms (s.24).

b. the underlying monitoring, modelling and surveying undertaken in relation to these matters is not based on best-practice and is not sufficiently rigorous, particularly given the unparalleled scale of water extractions associated with the Singleton Licence. As a consequence, impacts could far exceed those predicted. These matters require far more detailed and rigorous monitoring, data collection etc.;

c. there are fundamental flaws in the assessment undertaken in relation to salinity and the GHG assessment leaving key questions unanswered. Again, this could mean that impacts could exceed those predicted;

d. only a desktop analysis was undertaken to determine the presence of stygofauna and that based on this analysis, their presence is considered 'likely'. If they are present, the drawdown associated with the Proposed Development could result in localised extinctions. It is entirely feasible to undertake proper assessment via fieldwork (using existing or if necessary, new bores);

e. the adaptive management regime approved under the Singleton Licence is not a suitable mechanism for addressing the significant uncertainties associated with groundwater extractions of up to 40GL/year from 144 bores. In effect, it is being used as a substitute for rigorous, up-front EIA (which would simply not be acceptable in most other Australian jurisdictions);

f. the cultural values assessment work undertake by Fortune is substandard. Work commissioned by the CLC amply demonstrates that impacts on Aboriginal cultural values, sacred sites and wellbeing are more extensive and serious than acknowledged by Fortune in its referred documents. Further, the CLC's expert considered it highly unlikely that affected Traditional Owners had had the opportunity to properly grasp the scale of the development and its likely impacts on their country; and

g. the Economic Impact Assessment conducted by Fortune is based on a number of optimistic and/or erroneous assumptions and omits key facts and data. Overly optimistic assumptions about the likely socio-economic benefits flowing from the Proposed Development have been used to justify its significant environmental and cultural impacts, which is fundamentally flawed.

119. The evidence presented in this submission therefore demonstrates that:

a. impacts are likely to be significant – regulation 59(a);

b. there are unacceptable bands of uncertainty around the precise extent and nature of this significance due to insufficient and/or flawed monitoring, modelling and surveying – regulation 59(b);

c. mitigation measures are inadequate and/or ill-conceived, including in relation to groundwater, GDEs and cultural values – regulation 59(c);

d. community engagement by Fortune with affected Aboriginal people is limited – regulation 59(d);

e. affected Aboriginal communities do not have sufficient information at their disposal to fully grasp the scale and impact of the Proposed development – regulation 59(e).

120. It further demonstrates that there is a real risk of irreversible damage to groundwater, GDEs, sandplain habitat and cultural values and sacred sites, and that as a consequence, a precautionary approach must be taken (EP Act, s.19). These impacts also pose a threat to inter-generational and intra-generational equity (EP Act, s.21) and clearly undermine the conservation of biological diversity and ecological integrity (EP Act, s.23) and the sustainable and prudent use of natural resources (s.22). Notably, the best-available and most reliable evidence in the circumstances (the circumstances including the sheer scale of the Proposed Development and its likely impacts) has not been presented (EP Act, s. 20). The evidence also makes it clear that if EIA is to occur in a manner that promotes the objects of the EP Act (EP Act, s. 3) and the stated purpose of EIA (EP Act, s.42), far more rigorous assessment is required. Hence, and in light of the foregoing analysis, the CLC has formed the view that the NT EPA is legally obliged to undertake EIA in the form of a full EIS.

END

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ATTACHMENT A:

WESTERN DAVENPORT PLAN, ASSOCIATED DOCUMENTS AND GROUNDWATER MODEL REVIEW

Prepared by Dr Ryan Vogwill of Hydro Geo Enviro Pty Ltd

16 July 2021

WESTERN DAVENPORT PLAN, ASSOCIATED DOCUMENTS AND GROUNDWATER MODEL REVIEW

PREPARED FOR | Central Land Council - Northern Territory

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DATE | 16/07/2021

Proprietary Information Statement

Document Information

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Reviewed by:		**Date:**
Approved by:		**Date:**
Client distribution:		**Date:**

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Contents

Definition of Terms

Depth of Groundwater (DGW): The depth from the ground surface to the water table. Synonymous with depth to groundwater (DTW).

Environmental (or ecological) water requirement (EWR): Descriptions of the water regimes needed to sustain the ecological values of water-dependent ecosystems at a low level of risk (Richardson et al., 2011).

Groundwater dependant ecosystem (GDE): Natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis so as to maintain their communities of plants and animals, ecological processes and ecosystem services (Richardson et al., 2011).

> **Aquatic GDE**: Ecosystems dependent on the surface expression of groundwater, also known as Type 2 GDEs (Richardson et al., 2011).
>
> **Terrestrial GDE**: Ecosystems dependent on subsurface presence of groundwater, also known as Type 1 GDEs (Richardson et al., 2011).

Hydrograph: Graphical representation of river or stream discharge or of groundwater-level fluctuations in a well (Richardson et al., 2011).

Regolith: The entire unconsolidated or secondarily recemented cover that overlies more coherent bedrock, that has been formed by weathering, erosion, transport and/or deposition of the older material. The regolith thus includes fractured and weathered basement rocks, saprolites, soils, organic accumulations, volcanic material, glacial deposits, colluvium, alluvium, evaporitic sediments, aeolian deposits and ground water (Craig et al., 2001).

Watertable: The top of the water surface in the saturated zone of an unconfined aquifer (Richardson et al., 2011).

Sources:

Richardson S., et al., 2011, Australian groundwater-dependent ecosystem toolbox part 1: assessment framework, Waterlines report, National Water Commission, Canberra

Craig M., Caritat P., Field J., Gibson D., Greene R. & Hill S., Jones M., Lintern M., Mcqueen K., Pain C., Pillans B. & Robertson I., 2001, The Regolith Glossary - Surficial Geology, Soils and Landscapes. Cooperative Research Centre for Landscape Environments and Mineral Exploration, Perth Editor: R. A. Eggleton ISBN: 0 7315 3343 7

Introduction

1. This report is a high-level review of the Water Allocation process in the Central Plains area as defined in the Western Davenport Water Allocation Plan 2018-2021 encompassing environmental water requirements (EWRs) for groundwater dependant ecosystems (GDEs), environmental impact potential, current impact assessment groundwater model and the Fortune Agribusiness application for a 40GL/yr allocation on Singleton station. It must be noted that the review of the modelling herein does not constitute a full model review as per the Australian Modelling guidelines (Barnett et al, 2012) which would be much more detailed with respect to the modelling. During a full model review the reviewer will typically have access to the model files if they request it.
2. My more than 20 years of technical expertise encompass groundwater modelling, water resource planning and recovery of hydrologically impacted ecosystems, with a focus on applying research to sustainable groundwater management and environmental impact/risk assessment. My curriculum vitae is in Appendix 3. This report contains my independent and expert views about the subject matter contained in the report. Within the limitations stated herein, I have made all the inquiries I believe are appropriate about the subject matter. No matters of significance which I regard as relevant have been withheld in the report.
3. As stated in the contract the purpose of the consultancy is:
    - To identify the assumptions underpinning the Fortune Agribusiness modelling for the Singleton water licence application
    - To assess the veracity of those assumptions and the reasonableness of extending the range of those assumptions beyond existing data.
4. A number of specific questions were also posed in my contract. These are set out in Appendix 4, and answered later in this report.
5. The next sections of the report are specific points identified during the review of various relevant documents followed by a summary. In the review sections for the various reports, the text in italics is that which has been extracted from the various documents which will be followed by my comments. Note that page numbers refer to the PDF file page numbers, not the page numbers in the footer of the document.

Summary

6. Fortune Agribusiness Pty Ltd (Fortune Agribusiness) have applied for and have been provisionally granted a licence of 40 GL/yr at Singleton Station which is to be released for use in 4 stages. The first stage is 12.788 GL/yr, second stage is an additional 10.057 GL/yr, third stage is an additional 8.934 GL/yr and the final stage an additional 8.221 GL/yr. These stages are proposed to be released every two years. The first stage of this licence is the largest of the proposal and is also the single largest allocation granted in the Central Plains area.
7. Water Allocation planning and model development for the Western Davenport Central Plains has been hampered (in terms of rigor) by a lack of spatially distributed data on aquifer geometry, lithology, hydraulic properties (particularly storage properties), water levels and water quality. Water level data with any useful time series (in the context of long-term predictive modelling) is lacking over much of the model domain, particularly in the regolith which is only an inferred (i.e. not based on any measured data) groundwater resource. Aquifer testing data is sparse and is typically restricted to short duration, single borehole tests which cannot determine storage properties. Storage properties are a key control on the relationship between abstraction and groundwater level change (drawdown) which is the key focus of the modelling and allocation planning.
8. The water resource and impact assessment presented is simplistic. From a water resource/hydrogeological and environmental impact perspective the biggest issues are:
    - Lack of drilling and aquifer testing in the Singleton Station area. Most of the previous groundwater investigations have been undertaken in the central and eastern parts of the Central Plains. Given the different aquifers in this area (which appear less prospective for groundwater i.e. Hooker Creek Formation etc) groundwater investigation results from the other parts of the Central Plains area are not transferrable to the project area.
    - Storage estimates are based on modelling alone (with no direct measurements of the aquifer's storage properties and ability to produce sufficient water at the site). If these estimates are too high then the basin's storage will be reduced substantially and drawdown impacts greater than predicted. Also, the storage properties are assumed uniform throughout all aquifers of the basin, which they will not be. The value of specific yield is likely too high for the fractured rock areas and too low for sediments near the surface including the alluvium. The bulk of water stored in the basin will be in the fractured bedrock. Confined aquifer conditions may also be present in the deeper aquifers so specific yield is not relevant as dewatering of confined aquifers does not occur, only changes in pressure storage.
    - Total storage is being quoted as a basis for an allocation limit but total storage (especially when so uncertain) is misleading as it's only the groundwater to 100-150m depth that is economically viable to abstract. Better to quote allocation in terms of accessible storage. This would reduce the relevant storage (accessible) to approximately 36,000 GL. If the total storage of the basin is 138,314.2 GL and the modelling indicates that no more than 3.9% of this can be depleted this equates to 5394.25 GL of depletion, which is 14.98% of the accessible storage across the entire Central Plains.
    - The regolith aquifer, which accounts for 30.7 GL/yr of the total of 112.7 GL/yr of sustainable yield, is based on no data as this has not been investigated directly. It is difficult to see how incorporating this in the available water resources for allocation is justified.
    - Lack of understanding of region-specific vegetation groundwater dependent ecosystems (**GDEs**) drawdown impact criteria and the use of criteria that are not consistent with those used in other jurisdictions. In the WDWAP and Guidance Document: *Limits of acceptable change to groundwater dependent vegetation in the Western Davenport Water Control*

District, all GDE areas with a depth to groundwater of 10m or less are lumped together with the same drawdown magnitude and rate impact criteria. Areas with considerably shallower depth to groundwater than 10m will be more highly groundwater dependant, hence impact criteria need to be more stringent. The Gnangara Mound GDE work from Western Australia done by Ray Froend and others, is seen as best practise and often applied in other areas. These management criteria have different drawdown rate and magnitude criteria for 10-6m, 6-3m and 3-0 m depth to groundwater areas with total drawdown and rate of drawdown criteria becoming more stringent as the depth to groundwater decreases. There is no justification presented for all GDEs with a depth to groundwater of 10m or less having the same drawdown impact criteria. There is also potential for groundwater dependence of vegetation at depth to groundwater of 20m or more.

- No assessment of risks to aquatic GDEs. A major gap in the allocation planning and impact assessment currently exists as aquatic GDEs have not been included and numerous sites with potential to contain aquatic GDEs exist. Aquatic GDEs are typically those with the greatest sensitivity to drawdown, particularly wetlands, springs, soaks etc which are often the sites of greatest biodiversity and highest cultural value. Impacts to Stygofauna also need consideration. According to the Bureau of Metrology GDE atlas (http://www.bom.gov.au/water/groundwater/gde/) there are numerous sites with potential to contain aquatic GDEs, a map of this is shown in Appendix 2.

9. Essentially it is unclear why the proponent needs to have a licence for nearly 13 GL/yr prior to having completed what would be considered the basic work required in other jurisdictions.
10. Allocation planning (as presented in the WAP and GDE-Guidance document for Western Davenport) presents estimated sustainable yield which involves aquifer depletion so by definition is not truly sustainable. Managed depletion is a more appropriate term for the overall philosophy of groundwater management, which is a more risky but commonly used philosophy in areas of low and/or episodic recharge. An assumption of 30% impact to GDEs from drawdown being acceptable seems like an arbitrary figure. No robust reasoning behind this is presented but may be in the references which are not publicly available. Until more detailed work is undertaken to determine which sites have the highest floristic/biodiversity values and if a 30% decrease in the distribution of these GDEs would have undesirable impact at a regional scale accepting impact to 30% seems a bit premature.
11. Environmental water requirements (EWRs) for terrestrial groundwater dependant ecosystems (GDEs) are presented based on work from other jurisdictions including the Ti Tree basin (more appropriate) and banksia woodlands (less appropriate) on sandy soils (Gnangara Mound). Vegetation community and soil type specific EWRs (namely rate and magnitude of drawdown criteria) need to be determined as the criteria being used are currently of only limited applicability. Application of some of the research that is being used for EWRs (for example the WA banksia work by Ray Froend and others as cited in Cook and Eamus (2018b)) is reasonable in the absence of better information but there will still be high levels of uncertainty about the applicability of these criteria and hence terrestrial vegetation GDE impacts. When approaching 100% allocation, robust site and species specific vegetation EWRs should be used.
12. The banksia woodland criteria from Gnangara Mound were developed based on 20 years of vegetation condition and groundwater level change information which gives an indication of the research effort required to determine these criteria with any degree of rigor.
13. To fill the environmental impact gaps identified herein will require (in my opinion) at a minimum:
    1. Ranking of relative importance of terrestrial vegetation GDEs that will likely require considerable additional survey/mapping work and subsequent analysis.
    2. Assessment of aquatic GDEs location, biodiversity and cultural value and EWRs.

3. This should be set in in combination with a regional groundwater investigation (including geophysics) and monitoring regime covering water levels and quality which will require additional drilling. It is important that monitoring of hydrology, hydrogeology and biology is done at the same sites and at a frequency/timing that ensures consistent overlap of these two datasets.
4. Determination of appropriate vegetation community specific and aquatic GDE EWRs
5. Development of an improved groundwater model to assess impact on new, robust EWRs.

14. I have worked on water allocation planning in areas of low data availability before and I empathise with the issues that the DENR are grappling with here. However, allocation of groundwater to anywhere close to the "sustainable yield" (approximately greater than 50% of the existing limit) will be high risk at this level of understanding. Especially considering that this level of allocation is predicted to result in depletion of water storage in the aquifer.
15. The allocation of groundwater is best done when the level of use is kept below the sustainable limit minus the level of uncertainty as shown in Appendix 1. The approval of the Fortune Agribusiness, Neutral Junction and other pending licences would exceed this safety margin considerably and the area would be near full allocation if the Strategic Aboriginal Water Reserve was taken up. Approval of all pending allocations would align with the allocation line A in Figure 1 of Appendix 1, not the desirable line B where allocation stays below the sustainable limit minus the level of uncertainty.
16. Adaptive management in the context of near full allocation limit immediately, with the current level of data and analysis, is fraught with risk that may result in undesirable impacts to the environment or big reductions in allocations that may have serious project feasibility or negative economic outcomes. The Murray-Darling is a good example of what happens and the cost of recovering water when areas are highly allocated prior to a rigorous understanding.
17. It may be useful for context to compare the Northern Territory process with the Western Australia Department of Water and Environmental Regulation (DWER) process. Western Australia is seen as a world leader in groundwater management due to that jurisdiction's high degree of dependence on groundwater. The first stage of acquiring a licence from WA DWER would be obtaining a 26D licence to install a bore and undertake aquifer testing. This work is required to be done before any licence decision. The level of assessment required from a proponent depends on a number of factors covered in Table 1 from Operational policy no. 5.12- Hydrogeological reporting associated with a groundwater well licence, Department of Water, Perth, November 2009.
18. My assessment of this project against those criteria for Stage 1 alone is as follows:
    - **Volume** for Stage 1 12.788 GL/yr any allocation larger than 2.5 GL/yr requires an H3 level of investigation. This equates to 20 points;
    - Current **level of allocation** (pre Fortune licence) is near 0 which is 0 points;
    - **Impacts to other bore** users likely is 5 points;
    - **Impacts to GDEs** likely is 5 points; and
    - **Salinity** is fresh (<500 mg/L) to marginal which is 4-3 points
19. This is a total 33-34 points and anything over 19 points requires an H3 level of investigation, which the current analysis competed by the proponent falls well short of.
20. H3 Tasks that are missing are the drilling, aquifer testing (hydraulic properties and water quality), GDE assessment (particularly aquatic GDEs) and more rigorous modelling than is currently presented. The WA DWER would also request that the model was peer reviewed as per Australian Groundwater Modelling Guidelines but this hasn't occurred in the Singleton case either.

21. It is only after all this work was provided to and approved by the regulator that a groundwater licence would be issued, even if that was for only 2.5 GL/yr, less than 20% of what has been licenced to Fortune Agribusiness in Stage 1 alone.
22. The modelling is not unreasonable but nor is it backed up by a rigorous dataset, in fact there are more gaps than there are areas with a high level of understanding. Many of the assumptions in the model (although not unreasonable) cannot be tested due to a lack of data. The model has not had a peer review, but it has been undertaken by an experienced modeller, however a formal peer review as per the Australian Groundwater Modelling Guidelines is appropriate given the allocation decisions being based on it.
23. Given the model has a very high level of uncertainty, as do the GDE impact criteria, it seems premature to do such a precise impact assessment of where impacts will occur and where they won't. Considerable conceptual uncertainty exists as many areas haven't been explored for groundwater (drilled and tested) so the numerical model's conceptual basis will likely need considerable refinement. Low amounts of time series data to calibrate against is also a serious concern for a long-term predictive model.
24. I would suggest use of the groundwater model and spatial predictive uncertainty analysis to get a feeling for maximum and minimum draw down predictions or even assess the range in drawdown predictions probabilistically. The modellers have produced uncertainty analysis for one hydrograph only – see figures at the end of this section. In that hydrograph the model predictions for 100 different hydraulic parameter sets are shown, this indicates the variability in drawdown predictions across a reasonable range in hydraulic parameters. PEST will automate this and produce a distribution of drawdowns and the probability of their occurrence across the entire model domain. This still has limitations due to the considerable conceptual model uncertainty but will give a better feel for best, worst and expected case drawdown predictions under the current conceptual model and a reasonable range of hydraulic parameters. The model files were requested so this could be undertaken but this has been refused by DEPWS. A simple definition of conceptual model uncertainty is that which arises from the model's design being inaccurate with respect to the actual aquifer geometry and processes that are relevant to the aquifer in question. A simple description of numerical model uncertainty is that which comes from the error in measurements and lack of data in time/space in the data used to build and calibrate the model. The reader is directed to Section 7.2 and 7.3 of the Australian Groundwater Modelling Guidelines (Barnett et al. 2012) for a more detailed description.
25. In the Western Davenports Water Allocation Plan it states on page 9: "Approvals for large groundwater entitlements greater than 2,000 ML/year are recommended to be subject to staged increases in groundwater entitlements."
26. I would agree this approach is prudent in a data poor area such as this, possibly the large allocations could be staged in 5 GL/yr entitlements with increases assessed every 5-10 years as better data becomes available. The Fortune Agribusiness licence is staged with increases occurring approximately every 2 years with nearly 13 GL/yr allocated in the first stage.
27. It is unclear if an Environmental Impact Statement (EIS) is to be prepared for the Northern Territory Environmental Protection Authority but I would strongly encourage this to be the case given the state of the current analysis and environmental and cultural values at risk. The EIS will need to be extensive and involve significant investigations to address current shortcomings.
28. Adaptive management is an over utilised framework to address project approval when insufficient understanding of impact risk exists. It is fraught with problems and there have been serious issues in this context in other jurisdictions. Adaptive management needs a really strong understanding of the water resource, biodiversity/cultural values and GDE impact potential to be successful, particularly in the long term. This project does not currently have this and it is unclear

if investigations proposed as part of Stage 1 will provide an appropriate level of understanding as the proposed investigations are not presented with any operational detail.

29. 5-10 years of data will be required to understand groundwater-environment-cultural linkages in sufficient detail to develop strong management criteria. Impacts may take considerable time to manifest (10+ years) but by then it will be difficult to restrict/reduce the project's water allocation as approval for the full licence will occur in a similar timeframe.
30. Given the infrequent and small amount of groundwater recharge in the area, if impacts occur that are deemed unsuitable, groundwater recovery may take decades if it occurs at all. Their own modelling predicts almost no recharge for nearly 60 years (2016 to 2076 Figure 10 of the WAP). Given the high degree of uncertainty independent peer review of the adaptive management framework (including all documents underpinning it) should be completed and distributed to stakeholders before it is accepted. It is difficult to see how any adaptive management framework will be able to deal with the current level of uncertainty prior to substantial additional investigations being completed. In my opinion such investigations will take 5-10 years to progress, if the required financial resources are available and the investigations were under way now.
31. Key stakeholders such as traditional owners need to be kept informed of and involved in this process in my opinion. Relying on proponents to complete regional assessments of cultural and biodiversity values is in my opinion a mistake, this work is best done by government to preserve confidentiality for both proponents **and** key stakeholders such as the CLC. Traditional owners and conservation groups are unlikely to want to work with a private company in the context of biodiversity and cultural values.
32. In short I have concerns over how this project will impact the area in the context of such a large allocation, for even Stage 1 of the project. I also have concerns over what seems a rushed approval process, with conditional license approval given prior to what would be considered the basics of investigation required in other jurisdictions.

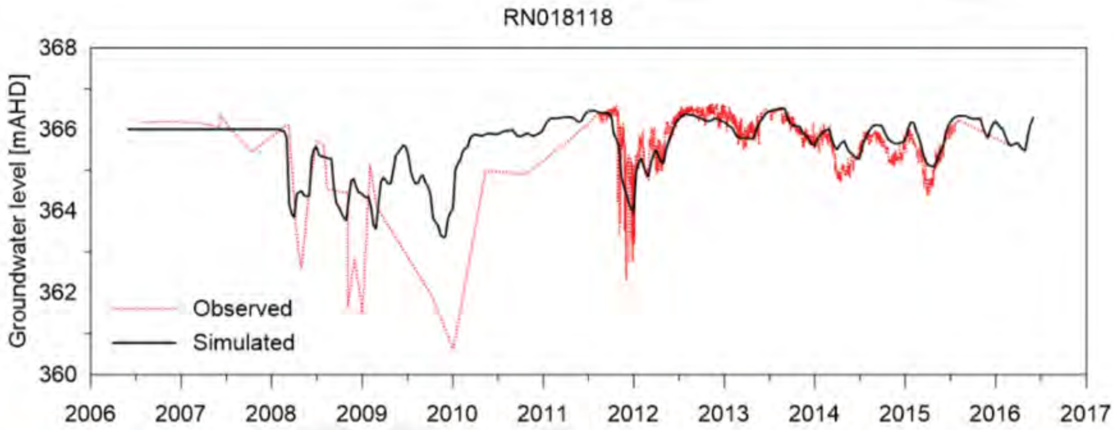


Figure 3-14 RN018118 groundwater level hydrograph showing response to groundwater abstraction with simulated groundwater response.

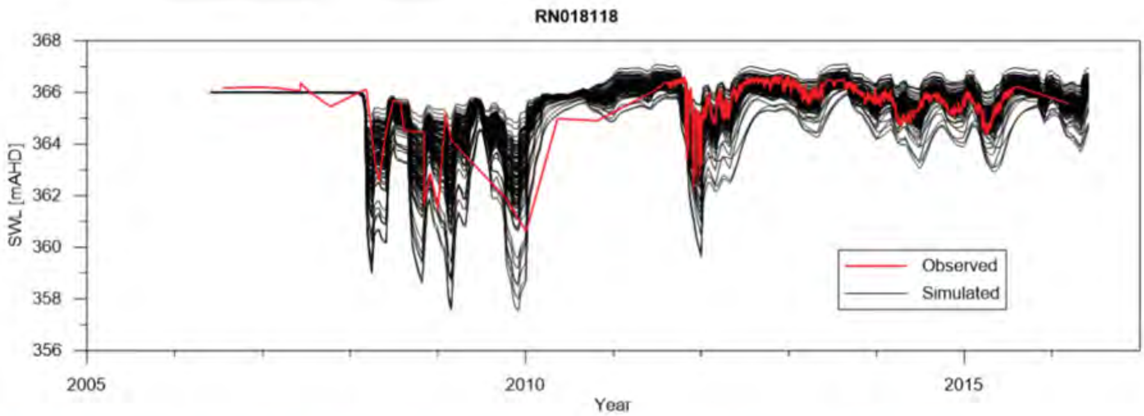


Figure 12-2 Results from 100 runs using null space projected random parameter sets.

Upper figure is the observed verses model simulated hydrograph for bore RN018118 (note the under prediction of drawdown) and the lower figure shows the observed data verses the range in model predictions under the PEST range of "plausible" hydraulic parameters.

Key Documents Review

Western Davenport Water Allocation Plan

Northern Territory Government (2018) Western Davenport Water Allocation Plan 2018-2021. Department of Environment and Natural Resources: Northern Territory, Australia.

> *Page 7 "It is recommended that accessing the consumptive pool for beneficial uses should not result in the depletion of aquifer storage by more than 3.9% over the next 100 years."*

33. 3.9% of storage depletion sounds small but what if this all happens in one small area? This will result in excessive water table declines which the WAP agrees can impact GDEs on page 27.

> *Page 8 "WDWAP recommends the following limits to change in groundwater conditions at GDEs caused by proposals to extract groundwater:*
>
> *• The maximum depth to groundwater does not exceed 15 metres.*
>
> *• The magnitude of change in the depth to groundwater is not more than 50%.*
>
> *• The rate of change of the groundwater table is not more than 0.2 metres per year."*

34. Depth to Water (DTW) maximum of 15m may not be appropriate at all GDEs and magnitude of change of DTW at 50% isn't widely used. This may be a surrogate for change in DTW and rate of change for the various antecedent depth to groundwater categories. Rate and absolute limit of drawdown (i.e. the other 2 criteria) are what other jurisdictions use but are presented as categories by which a risk can be prescribed to the drawdown (see table on the next page). It is important to note in this context that criteria should not be "all or nothing" in terms of impacts either side of a criterion. Greater magnitude and rate of DTW decline present greater risk of impact.
35. Section 5.2.1 Environmental water use identifies the research where the criteria are sourced from but these are not applicable for soaks, springs or wetlands (i.e. aquatic GDEs) which are a different type of GDE, typically more susceptible to drawdown, hence have more stringent drawdown criteria with often little to no drawdown acceptable at an aquatic GDE.

> *Page 9 "The onus will be upon proponents, through extraction volumes and design and management of proposed bore fields to demonstrate that groundwater extraction proposals can occur within the assessment criteria established in the WAP to protect GDEs and cultural values."*
>
> *"Approvals for large groundwater entitlements greater than 2,000 ML/year are recommended to be subject to staged increases in groundwater entitlements."*

36. The assessment criteria do not consider aquatic GDEs at all. A staged approach for large allocations is highly supported but the stages of 12.8GL/yr, then 22.8GL/yr, then 31.8 GL/yr, then 40GL/yr are very large. I would recommend smaller stages, preferably steps of 5GL or less.

> *Page 18 "The most significant groundwater resources are the Lake Surprise Sandstone, Arrinthunga Formation, Chabalowie Formation, and Dulcie Sandstone aquifers underlying the Central Plains Management Zone. Water stored in these aquifers is very old, having been in long-term storage for thousands of years."*

37. I don't agree, this is a bit simplistic, most groundwater maybe (particularly the deep groundwater) is old but there is clearly going to be some modern water around rivers wetlands

etc. where recharge is occurring and the water table is shallow. Section 4.3.1 Groundwater recharge talks about modern recharge occurring.

Table 2: Risk of impact level and magnitude of permissible change (m) for phreatophtyic vegetation.

Phreatophytic category	Low	Moderate	High	Severe
0-3m (wetland)	0-0.25	0.25-0.5	0.5-0.75	>0.75
0-3m (terrestrial)	0-0.75	0.75-1.25	1.25-1.75	>1.75
3-6m	0-1.0	1.0-1.5	1.5-2.25	>2.25
6-10m	0-1.25	1.25-2.0	2.0-2.75	>2.75

Table 3: Risk of impact level and rate of permissible change (m/year) for phreatophytic vegetation.

Phreatophytic category	Low	Moderate	High	Severe
0-3m (wetland)	0-0.1	0.1-0.2	0.2-0.3	>0.3
0-3m (terrestrial)	0-0.1	0.1-0.25	0.25-0.5	>0.5
3-6m	0-0.1	0.1-0.25	0.25-0.5	>0.5
6-10m	0-0.1	0.1-0.25	0.25-0.5	>0.5

Table of Gnangara Mound EWR criteria. Source Dr. R. Froend, R. Loomes, Dr. P. Horwitz, M. Bertuch, Dr. A. Storey and M. Bamford, 2004, Study of Ecological Water Requirements on the Gnangara and Jandakot Mounds under Section 46 of the Environmental Protection Act - Task 2: Determination of Ecological Water Requirements. Centre for Ecosystem Management, ECU, Joondalup.

Page 27 "The best available information (from banksias in Western Australia) suggested that woody plants can follow declining water tables at a rate of decline of 20 cm per year. Cook and Eamus (2018b) suggested that this is reasonable in the absence of better information."

38. This is risky as these are very different species (banksias primarily) and a very different soil type (deep sand typically). I've talked with Ray Froend about this numerous times (and was involved in doing groundwater modelling for his study on Gnangara mound) and he is very concerned how often his EWR and root elongation work gets used outside of its range of applicability (R. Froend, 2021, personnel communications, 15th of July). Ray also added he would have commented as follows about root elongation in the Central Plains area "This rate of root elongation is cited as one of the very few studies informed by direct measurement of root responses to declining water tables. More realistic rates for the study species/area would need to consider specific growth traits, water availability patterns and soil density. However, in the absence of site-specific data, the rates quoted should only be used as a tentative guide to what root response may be possible."

Page 33 Section 6.2

39. Estimated sustainable yield seems more like acceptable or managed drawdown as it clearly results in aquifer depletion and drawdown of nearly 20m. This could have significant impacts to GDEs and involves a storage loss so by definition is not "sustainable".

Page 35 Section 7.2

40. Agreed but should include an even greater focus around drainages/rivers, wetlands and other areas where groundwater seeps and springs will occur.

Page 36 "The inference that declining water levels would impact vegetation is based upon considerable evidence from other locations. There are no published experimental data available for <u>Australian</u> species that examine the impact of different rates of increase in depth-to-groundwater."

41. Should Australian in the paragraph from page 27 (underlined above) be changed to Northern Australian? The Froend work referred to on page 27 is difficult to apply in areas that are not the Swan Coastal Plain and banksia dominated woodlands on sandy soils but is work on Australian species. The species in the WAP area will have different environmental water requirements (EWRs) so I would recommend that the regulators move towards some local research to get more robust EWRs. This is identified in the text but is a plan in place? The Froend work required multi decadal data on groundwater levels and vegetation condition so it's a significant research effort over a long-time frame to achieve this.

Page 37-38 Section 7.4.5

42. This is a good list of additional work required to refine the modelling. I agree with it all but more investigations will be required to refine this modelling to the high level of understanding needed for the proposed level of allocation.

Page 38 Uncertainty in calculation of the ESY from regolith

43. The regolith is a critical issue as it is the connection between the surface and the groundwater (both ways) so is important for recharge estimates and understanding GDE vulnerabilities. There is no regolith targeted drilling, water level or water quality monitoring of groundwater to justify it as a basin wide aquifer with such a substantial proportion of the estimated sustainable yield. The regolith will exist but not everywhere and not with a uniform thickness.

Page 38 "Possible dependency relationships between GDEs and regolith resources could further limit the availability of this resource."

44. Totally agree.

Page 39 "In accordance with the NT Water Allocation Planning Framework, at least 95% of natural flow in Arid Zone waterways should be allocated to the beneficial uses of environment and non-consumptive cultural."

45. This is a surface water criterion. Note that 95% as a rule of thumb is ok but in the context of low flows being impacted consumption of 5% of natural flow (during a period of low flows) could still cause significant impacts. Important to recognise this as % of annual flow is a fairly coarse way to identify EWRs for surface water systems where intra-annual water distribution may be critically important.

Page 40 Section 8.1.3

46. The comment immediately above (para 45) applies to 8.1.3 also.

"For waterways it has been defined via modelling by Knapton (2017), as no more that 5% of total overland flow discharging from the respective management zone."

47. Table 12 should identify that the timing of water take may also be critically important for dependant ecosystem protection.

Page 43 "The Department of Environment and Natural Resources will monitor groundwater drawdown and the health and condition of a set of GDE reference sites to monitor the effectiveness of GDE protection approaches and refine the understanding of GDE groundwater interactions and dependence."

48. This is appropriate and could form the basis of more robust EWR criteria for vegetation communities that I've discussed above. Probably need 10+ years of data to give this scientific rigor. Is there a funded investigation plan in place?

Page 44 Section 8.2.3 monitoring triggers

49. Very terrestrial GDE focussed (vegetation); needs more consideration of aquatic GDEs such as rivers receiving baseflow, wetlands, soaks, springs, seeps etc.

Page 46 "Assessment of licence applications should be based upon modelling of the cumulative impact of groundwater extraction on aquifer levels."

50. Does this mean cumulative impact of only Singleton bores or all neighbouring bores (other groundwater licences) as well?

Page 46 "Rural dams with a bank height less than 3 metres and a catchment area of less than 5 km^2 are exempt from permit requirements. In accordance with the NT Water Allocation Planning Framework it is recommended that the interception volume of surface water on any property should be no more than 5% of the total estimated median annual run-off exiting that property."

51. Noting again that in some cases such as low flow years 5% of median annual runoff could have a significant impact on flows and dependant ecosystems. 5% of the median annual flow might be the entire surface water flow if it's only a 5% of median flow year.

Guideline: Limits of acceptable change to groundwater dependent vegetation in the Western Davenport Water Control District.

Page 6 "the probability of groundwater dependent vegetation (GDV) occurring has been modelled across an extensive area of Central Plains, based on time-series of relevant "greenness" and "wetness" indices derived from Landsat 8 satellite imagery."

52. Is a report detailing the methodology available? Is this the "Singleton Horticulture Project Groundwater Dependent Ecosystem Mapping and Borefield Design" report by GHD? If so the methodology is only briefly discussed.

Page 6

53. It would be good to see the full detail of how the revised criteria were produced. Although the criteria acknowledge that different depth to groundwater classes would have different susceptibility to drawdown (i.e. differing degrees of dependency), why no criteria specifically for less than 5m?

Page 7

54. Has the depth to groundwater (DGW) data been generated by a model or contouring? It would be good to see the actual data points on these maps to give an impression of where this is constrained by data and where it isn't. Given the regional nature of the data set this DGW data is going to be inaccurate at a local scale. Also, the depth to groundwater areas <5m will likely be even more highly groundwater dependant than the 5-10m areas. The groundwater around the drainages running through the area likely have areas with a shallower depth to groundwater than 5m. There is also a strong likelihood of aquatic GDEs (wetlands, seeps, soaks etc) that no criteria have been presented for. The aquatic GDEs and depth to groundwater less than 5m will be the most sensitive areas for impacts from drawdown. The reasoning for this is well laid out in the Froend et al., (2004) report available here: https://www.water.wa.gov.au/__data/assets/pdf_file/0018/4644/82422.pdf.

Page 8

55. What is the basis for the 70% of GDEs must be protected threshold? Is this based on anything or a rule of thumb? Good to see some consideration to high value GDEs but agree it's going to be hard to assess what is high value until a considerable effort is made in terms of survey work.

Page 9

56. With respect to the 10-15m GDEs it is unclear why no maximum depth to water criteria (i.e. 15m) has been proposed as for the 10m category? There needs to be an absolute limit for water table depth at GDEs with a current depth to groundwater of 10-15m. If the depth to groundwater increases beyond the absolute limit (which is species/ecosystem specific) then vegetation will lose access to groundwater with typically severe impacts (vegetation condition decline and mortality). This is especially the case if groundwater decline occurs rapidly or during periods of reduced soil water availability. Also, these criteria do not make sense in the context of shallow DGW GDEs being more sensitive to drawdown, but the % decline criteria indicate otherwise.
57. For example, according to the GDE criteria on page 9 of this document for sites with DGW between 10 and 15m, a 36% decline relative to a baseline of no pumping for a 10.5m DGW site (impacted DGW 14.28m) is considered unacceptable. For GDEs occurring where the depth of groundwater is less than or equal to 10m, a 50% decline relative to a baseline of no pumping for a

9.5m DGW site (impacted DGW 14.25m) is considered acceptable. These are almost identical antecedent DGW but the shallower site experiences 4.75m of drawdown (acceptable) while the deeper site experiences 3.78m (unacceptable). Yes, the deeper site breaches one of the other criteria (10m DGW) but the % component of the criteria make no sense. There are other inconsistencies, for example a 9.9m DGW site would breach the criteria if it experienced a 0.2m drawdown. The shallower DGW sites are less tolerant of drawdown according to Froend et al., (2004) and would be at greater risk. If anything, these percentages should be reversed with 35% for the <10m DGW and 50% for the 10-15m DGW, but I would discourage the use of percentages at all.

58. Also given that the % criteria are relative to a natural baseline scenario with no pumping, this entails the use of groundwater modelling to separate the natural baseline from the pumping impacts. The current model cannot do this with any degree of rigor. EWR criteria are best focussed on measured data only as models are inaccurate, particularly when developed with little data. In terms of terrestrial vegetation GDE EWRs I would recommend the use of rate and magnitude of drawdown only, but for at least 3 classes of DGW (possibly 0-5m, 5-10m and 10-15m).

> *Page 10 "it is important that robust monitoring is implemented where changes may occur. Monitoring the health of GDEs may allow for the adaptive management of water extraction regimes, provided such adaptive management accounts for the potential time lags before significant negative impacts are detectable."*

59. Agreed, it's also important that good quality baseline data exists prior to any changes to ensure any impact areas are compared with the pre impact state. Is there an investigation/monitoring plan in place for this?

GHD, 2020, Singleton Horticulture Project Groundwater Dependent Ecosystem Mapping and Borefield Design.

> *Page 5 "The borefield configuration and pumping regime described in this report complies with DENR's criteria for acceptable impacts to GDEs."*

60. Unclear if this means in terms of adopting the criteria themselves or if the project meets those criteria (i.e. unacceptable impacts to GDES).

> *"This report provides an assessment of the percentage area of impact of groundwater drawdown on GDEs on Singleton Station and surrounding areas, across both sandplain and alluvial landforms based on the following inputs:"*

61. This should be terrestrial GDEs as they have not assessed aquatic. To assess aquatic GDEs requires an understanding of the seasonal proportion of the ecosystem's water inflow provided by groundwater, how the proposed abstraction would change that water availability and what the impact to the GDE will be of this altered water availability. The reader is directed to the National Water Commission's GDE Toolkit for more information on this complex subject area. http://www.bom.gov.au/water/groundwater/gde/GDEToolbox_PartOne_Assessment-Framework.pdf

"Currently understood depth to groundwater (DGW) contours provided by DENR"

62. Currently understood is a key point, worth noting that these are based on a coarse data set and at a local scale significant DGW discrepancies are certain.

Page 7-8

63. Why are there no absolute depth limit criteria for 10-15m DGW as there is for the 10m DGW GDEs? What about less than 5m DGW GDEs?

Page 9 "of relevant "greenness" and "wetness" indices derived from Landsat 8 satellite imagery" and Appendix A.

64. Unclear exactly how this methodology was applied, areas where relatively high normalized difference vegetation index (NDVI) and/or leaf area index (LAI) do not change significantly over time are often used as indicative of terrestrial GDE potential. This is particularly important to look at areas remaining with high NDVI/LAI after a prolonged drought.

"This had been set primarily at 70% and a secondary level at 50%."

65. 50% and 70% of what? Do you mean 0.7 and 0.5?
66. Also given the drawdown extends well outside of Singleton Station why has the landform mapping stopped at the station boundaries? Landforms should be mapped across the entire Central Plains to ensure that protected areas are representative at that scale, not the scale of the station.

Page 12 "The regional impacts of the proposed Singleton Station abstraction and the cumulative impact associated with existing neighbouring developments at Neutral Junction and Ali Curung"

67. Good that they have assessed cumulative impacts of these major allocations.

Page 19 Figure 4-1

68. What are the purple dashed lines on Figure 4-1?

Page 73 "It is clear from the analysis that the overall GDE impact of Scenario 28 does not exceed 20% in total, and the impact on the extensive sand plains landform remains comfortably below 20%. The alluvium however, whilst relatively small in area, is largely located in a small portion of the property near Wycliffe Creek and Thring Swamp, east of the Stuart Highway. It has been necessary to reposition the bore field further to the west than would be preferred, in order to reduce the impact on these alluvials to below the 30% threshold."

69. Yes, but the amount of uncertainty in the modelling (both conceptual and numeric) is considerable. This may be better done in the context of some groundwater model predictive uncertainty analysis so the probability of various levels of groundwater drawdown can be cross referenced with the terrestrial GDE maps and criteria.
70. A comment about impact figures and % generally. Given the model has a very high level of uncertainty, as does the GDE criteria, it seems premature to do such a precise impact assessment. Considerable conceptual uncertainty exists as many areas haven't been explored for groundwater (drilled and hydraulically tested) so the numerical model's conceptual basis will likely need considerable refinement (different parameter zones etc). Low amounts of adequate frequency time series data to calibrate against is also a concern.

CloudGMS, 2016, Development of a Groundwater Model for the Western Davenport Plains version 0.2

Page 3 "In the event that current and/ or projected consumptive use exceeds the threshold levels of 80% of the consumptive pool for aquifers, or groundwater discharges to groundwater dependent ecosystems are impacted, new groundwater licences will not be granted unless supported by directly related scientific research into groundwater dependent ecosystem/cultural requirements."

71. No new licences would be one action but surely decreasing abstraction for existing licence would be required to reduce drawdown and allow for watertable recovery? At this point the system is nearing 100% allocated and we should have a much better understanding of regional hydrogeology and GDE interaction including dependant biodiversity and cultural values.

Page 3 "Based on the classification scheme outlined in the Australian Groundwater Modelling Guidelines (Barnett et al. 2012), the groundwater model presented herein is deemed to be Class 2. Based on the objectives of the modelling study this is considered appropriate."

72. Is it Class 2 in the context of a lack of regional or time series data and a restricted understanding of GDEs their connectivity and EWRs? Aquatic GDEs have not been assessed. I think the model as Class 2 is debatable. After reviewing Table 1 I would suggest that some of the criteria could be debatable between Class 1 and Class 2. It also looks as though this model has not had a full peer review which I would recommend to ensure its construction meets industry best practise. Class 1 models have a simple level of complexity, Class 2 models are moderate complex and Class 3 are highly complex. Given the large volume of the allocation, the complex hydrogeology of the area and the abundant GDEs a Class 2 to Class 3 model is recommended. The reader is directed to the Australian Modelling Guidelines for a full description of model Class types and groundwater modelling generally: https://consultation.dplh.wa.gov.au/communications/14d86ef9/supporting_documents/Australiangroundwatermodellingguidelines.pdf

Page 3 "The extents of the modelled area have been determined from the surface water catchment that overlies the major aquifers in the central management zone of the Western Davenport Water Control District."

73. Given the fractured nature of bedrock is this really a true no flow groundwater boundary?

Page 4 "The average root mean square error value of hydraulic head for the steady state model of the Western Davenport WCD groundwater system was 7.34 metres and the scaled RMS is 3.7%."

74. RMS (RMSE) is ok but that is a high average error for a steady state model. Root Mean Square Error (RMSE) is the standard deviation of the model's prediction errors or residuals. Residuals are a measure of how far from the line of best fit data between observed and predicted data individual model predictions are. The high error of 7.34m in the steady state model shows that the current understanding is not accurately reflecting the water table elevation. Watertable elevation is of critical importance as it will control the distribution of areas identified as GDEs by their depth to groundwater.

Page 5 "The very large volume in storage is expected to provide a buffer to the impacts from groundwater abstraction provided development is not too close to areas sensitive to *groundwater level decline. The robust nature of the aquifer system means an adaptive management approach can be applied where 5 – 10 year reviews of the water allocation plan would be appropriate."*

75. Not near areas of intense abstraction where impacts can manifest much quicker than 5 years especially in areas where the model is later proved to be inaccurate due to a lack of data.

Page 43 "Whilst many bores have been drilled across the WDWCD they are not uniform in total depth, separation or reliability of the data, and, as such, do not provide an overall understanding of the extent, variability and characteristics of the main aquifers. There are clusters of bores in localised areas e.g. Alekarenge and Wycliffe Well, and only a relatively limited number of bores drilled into the deep Chabalowe and Arrinthrunga Formations aquifers."

76. This then limits the robustness of the model over a considerable area. Looks as though the regolith is not well covered as well.

Page 43-44 "Only a limited number of high yielding production bores have been drilled and test-pumped for short durations."

77. This very much restricts the accuracy of hydraulic property estimates at a regional scale.

Page 44 "The majority of bores have only been airlifted at completion of drilling. Such air-lift yields tend to underestimate the yield of the aquifer and are of little use in determining aquifer sustainable yields (and wellfield yields or capacity)."

78. Agreed, hence storage properties are very uncertain as these cannot be calculated from single borehole tests (i.e. are based purely on PEST calibration). Storage properties will be a critical control on abstraction verses drawdown, i.e. high storage reduced impacts; low storage greater impacts.

Page 81

79. No limits put on storage properties during PEST/calibration? Table 35 in the appendix indicates they were.

Page 114 - Transient Calibration

80. No graph of observed verses predicted head for transient calibration is presented and this would help understand if the RMSE of 1.98m is a good fit or not. This is a much better RMSE than for the steady state model. The way predictive data match the observed data and if the trend is following the line of best fit at individual bores are all important, but only predicted verses observed hydrographs are presented. This is likely due to the fact that the way the model's calibration has been focussed on key hydrographs (RN018118 for example which looks to be slightly underestimating drawdown impacts) due to a lack of spatial and temporally continuous data.
81. Looking through the calibration hydrographs in Appendix A there are concerns over some of the hydrographs where observed and predicted data do not match particularly well. This would be something that a full model review would look at in more detail.

Page 139 - Conclusions "Specific yield averaging 0.04 in the model domain have been determined through calibration."

82. One of the biggest concerns I have about the model is the storage properties as this is a critical control on the relationship between abstraction volumes and drawdown. If the specific yield is lower, then drawdown impacts will increase. Given the variation in lithology, specific yield will vary as well but there isn't enough data to get to this level of hydraulic parameterisation.

Page 139 "The calculated values for hydraulic conductivity and specific yield do not represent a unique modelled solution, but are considered the best estimates from the available data."

83. Agreed, what is the range in drawdown impacts under a reasonable range in ALL saturated hydraulic parameters (K, Kx/y, Sy Ss at a minimum).

Page 139 "There is no evidence that the groundwater flow system is constrained by aquitards or structural feature with the groundwater moving freely across the different formations. The basin aquifers can be regarded as a relatively contiguous system that responds isotropically to recharge and pumping stressors"

84. Given the lack of basin wide geophysics investigation and spatially distributed, appropriate quality aquifer testing (i.e. not single borehole air lift tests) this is still uncertain. Fractured rocks will definitely have at least some form of anisotropy (ie hydraulic conductivity (K) varies in different directions x,y,z). Some longer-term aquifer testing data could help identify recharge and barrier boundaries also.

Page 139 "Demand will be met primarily from storage.

Total groundwater storage in the area modelled is large, and is estimated to be around 145,000 GL at the end of the natural model scenario in 2015. The majority of groundwater is stored in the central zone and is estimated to be 141500 GL.

Assuming a maximum economic depth of groundwater abstraction of 150 metres below ground level, the accessible volume in storage in the saturated zone is about 36000 GL."

85. Yes, but storage properties are the least robust of all the model's hydraulic properties in the saturated model. Again, how does this storage vary under a reasonable range of storage properties?

Page 140 - 10.3 System sustainability.

86. Under this set of hydraulic parameters the report is drawing this conclusion, but given that PEST has been run can sustainability not also be assessed probabilistically as a range of drawdown predictions under a reasonable range of hydraulic parameters? This is a very non unique solution and the author clearly recognises this.
87. Final Point: Note that this review does not constitute a full model review as per the Australian Groundwater Modelling Guidelines.

Department of Environment, Parks and Water Security (2021) Groundwater extraction licence resource assessment - AG06221 - Singleton Station

> *Page 29 - The quality of the underlying groundwater available to Singleton Station, specifically in terms of salt content, may be considered to be significant. Sampling of bores on and near Singleton Station indicate groundwater salinity is approximately 700 to 900 mg/L (as total dissolved solids). For this application, the irrigation of 40,000 ML p.a. of groundwater would bring 28,000 to 36,000 tonnes of dissolved salts to the surface annually.*
>
> *Nonetheless, it would be prudent to undertake a study of salt availability and its potential movement in the unsaturated zone. A recent study near Alice Springs (see Cook et al., 2017) indicated that the mobilisation of unsaturated zone salts could present an issue to the long term viability of the water supply if it is sourced from beneath the crops, as well as representing a threat to the integrity of the groundwater resource.*
>
> *Recent deep drilling on Singleton (RN019452) and Murray Downs (RN019681) indicates that the salinity of the groundwater increases with depth. The density difference of the higher salinity water at depth creates a potential for vertical movement (upconing) under a groundwater pumping regime. The potential impact of this is not quantified due to limited data and knowledge of the system at depth.*

88. Important estimate of salt load reinforcing the need for a detailed assessment for both soil salinity and groundwater salinity under irrigation. Salinity interface upconing will need purpose designed monitoring infrastructure. The regulator has requested this be done, but it is unclear what the scope is.

> *Page 30 - Data and knowledge gaps have been identified through the assessment, model development and output analysis processes. Some of the critical issues are identified below:*
>
> *• There is inadequate spatial coverage of groundwater levels across the model domain.*
>
> *• There are limited monitoring bores with data coverage that spans the planning timeframe. This data is critical to the eventual analysis of modelling output presented in this report.*
>
> *• Metered groundwater- extraction data is limited.*
>
> *• There are gaps in knowledge regarding the basement topography, and continuity and consistency of the aquifer across the region. This affects the aquifer's hydraulic characterisation and representation in the model.*

89. These dot points all indicate an insufficient investigation, data and analysis.

> *Page 33- Due to limited stratigraphic drilling this groundwater system, aquifer thicknesses and hydraulic properties (storage and permeability) are poorly constrained. This uncertainty will ultimately result in modelling uncertainty that cannot be easily quantified.*

90. This again indicates insufficient data. The conceptual uncertainty is difficult to quantify yes but the numerical uncertainty can be quantified across the model domain but hasn't. Figure 12-2 in Cloud GMS (2016) shows that some elements of uncertainty analysis have been completed but only one hydrograph is presented. To undertake an analysis of numerical uncertainty requires access to the model files and suitable software to undertake the analysis such as PEST. A useful description of model uncertainty is given in Middlemis and Peeters (2018) Explanatory Note,

Uncertainty Analysis in Groundwater Modelling. They identify four sources of scientific uncertainty affecting groundwater model simulations:

- Structural/Conceptual - geological structure and hydrogeological conceptualisation assumptions applied to derive a simplified view of a complex hydrogeological reality (any system aspect that cannot be changed in an automated way in a model);
- Parameterisation/Numerical - hydrogeological property values and assumptions applied to represent complex reality in space and time (any system aspect that can be changed in an automated way in a model via parameterisation);
- Measurement error/Numerical – combination of uncertainties associated with the measurement of complex system states (heads, discharges), parameters and variability (3D spatial and temporal) with those induced by upscaling or downscaling (site-specific data, climate data);
- Prediction/Scenario Uncertainties - guessing future stresses, dynamics and boundary condition changes (e.g. mining, climate variability, land and water use change).

91. The reader is directed to both Middlemis and Peeters (2018) and the Australian Groundwater Modelling Guidelines (link previously provided) for a full description of these concepts.

Cook and Eamus (2018a) The Potential for Groundwater Use by Vegetation in the Australian Arid Zone

> *Page 5 - In arid zones, use of groundwater by vegetation is likely to be much more widespread than in more humid climates, due to the scarcity of other water sources.*

92. Agreed and an important point to consider in the context of greater GDE impact risk in arid zones.

> *Page 5 - Soil water potential data suggests that many trees have roots concentrated within the top 6 – 8 m of the soil profile, but also provides evidence of water extraction by roots to 15 m depth in areas where water tables are more than 20 m deep.*

93. This statement is indicating evidence of groundwater use at 20m depth to groundwater. Therefore, is 15m really the most appropriate cut off depth for groundwater dependence? 20m is a more conservative approach. Areas with depth to groundwater of up to 20m should be included in the GDE impact assessment. See comment below on page 7 of this report.

> *Page 6 - The results show clear evidence of groundwater use throughout the basin in areas with water tables of 12 m or less, and evidence of soil water uptake from 15 m depth in areas where the water table is deeper. Although there is some evidence of soil water use from deeper than 15 m, the volume of groundwater extracted from these depths is likely to be small.*

94. Volume of groundwater use is small at groundwater depths greater than 15m but again this suggests 20m might be a better cut off.

> *Page 6 - E. camaldulensis also access groundwater, and tend to occur in riparian areas and where perched shallow aquifers are present.*

95. Alluvial aquifers are not necessarily perched. Perched implies there is a disconnected aquifer that the vegetation is dependent on. In the case of the Western Davenport area there is no site specific drilling or other evidence presented to indicated this is the case. I think perched aquifers in riparian areas would be the exception not the rule as they are in my experience rare. The perched aquifer referred to is in the Ti Tree Basin (Woodforde River) not Western Davenport. It is not justified to assume that all riparian areas are perched aquifers and this is possibly why they have excluded aquatic GDEs from their assessment.

> *Page 7 - The Ti Tree results are supported by studies at Rocky Hill, south of Alice Springs, where soil water potential profiles show extraction of soil water to at least 10 m in places, with some evidence of extraction to 20 m;*

96. Again, this supports groundwater dependence potential to 20m depth to groundwater.

> *Page 9 - A conceptual framework for management of groundwater-dependent ecosystems (GDEs) has been devised for Australia (Clifton and Evans, 2001), and comprises four steps: (i) identify potential GDEs, (ii) establish the natural water regime of GDEs and their level of dependence on groundwater, (iii) assess the environmental water requirements of GDEs, and (iv) devise water provisions that will deliver these environmental water requirements. Subsequent work has further developed this framework, and also compiled and summarised the various tools that can be used for GDE assessments (Clifton et al., 2009; Richardson et al., 2011). However, despite these efforts, GDE assessments have generally stalled at the first*

stage of the process, and have not progressed through the three subsequent steps of the conceptual framework.

97. I'm very familiar with all of this literature and the Western Davenport is yet another case of a GDE assessment stalled at the first stage of the process. What are the plans from government or the proponent to complete the rest of the stages? The Cook and Eamus report gives an excellent overview of the techniques that should be applied.

Page 16 - For relatively fine textured soils, such as clay loams and silty clay loams, upward fluxes of more than 1 mm y^{-1} *can occur even where the base of the root zone is more than 10 m above the water table.*

98. These would be the common soils in many parts of the Western Davenport area away from the alluvium. This again reinforces that groundwater use might be occurring up to 20m depth to groundwater.

Page 19 - Dresel et al. (2010) were able to identify all pixels across a catchment that had a very high probability of being a GDE. Significant ground truthing was required to assess the validity of this method.

99. Likewise, with the methods applied in the Western Davenport area, what are the plans to validate and ground truth the remote sensing data/analysis?

Page 30 - Plant longevity was significantly and independently correlated with depth-to-groundwater. Thus, as depth-to-groundwater increased the proportion of perennial species increased and the proportion of annual species decreased.

100. If groundwater access is removed through drawdown then perennial vegetation may see condition decline and/or mortality but understorey species may not recruit at these sites and grasses/weeds would become dominant. If this happens important understorey vegetation species may become reduced in its distribution or locally extinct, impacting floristic biodiversity values directly. Grasses and weeds may not support fauna species dependant on individual GDEs causing further biodiversity impacts.

Page 59 - Consequently we do not know whether changing the natural groundwater depth regime at any site with depths less than 10 m will induce significant changes in ecophysiology or ecology. Only an experimentally induced change in depth that is maintained for many years will offer insight to the changes that may occur in response.

101. This highlights the long term (many years) and complicated nature of determining GDE impact from groundwater drawdown.

Page 59 -

For example, two recent reviews based on water balance approaches concluded that groundwater uptake ceased when depths exceeded 7.5 m (Benyon et al., 2006) or 8–10 m (O'Grady et al., 2010; Figure 32). Kath et al. (2014) identified thresholds of groundwater depth of between 12.1 and 26.6m across 118 sites in south-eastern Australia (within the Murray-Darling Basin) for two tree species. Thus, the existence of a threshold appears reasonable – but it appears to be site and species specific.

102. This reinforces the fact that thresholds are site and species specific. Groundwater use is entirely possible (until disproved at a particular site) to depth to groundwater of 20m or more based on this Cook and Eamus report.

Cook and Eamus (2018b) Treatment of GDEs in the Ti Tree and Western Davenport Water Allocation Plans.

Page 3 - This report reviews recent DENR attempts to map groundwater-dependent vegetation (type III GDEs, using the classification above) and assess likely impacts of pumping on vegetation in the Western Davenport region.

103. This confirms that the EWRs are focussed on groundwater dependant vegetation only with no consideration of type I or type II ecosystems which are also possible in the Central Plains area. The other two types of GDEs are:

(I) Aquifer and cave ecosystems where stygofauna reside. This class also includes the hyporheic zones of rivers and floodplains. The hyporheic zone is the region of porous sediment beneath and alongside a stream bed, where there is mixing of shallow groundwater and surface water.

(II) Ecosystems reliant on surface expression of groundwater. This includes base flow rivers, streams and wetlands, springs and estuarine seagrasses.

Page 4 - Indirect methods for mapping groundwater-dependent vegetation have three main limitations. The first is that areas of relatively high growth rate or good vegetation condition might exist for reasons other than access to groundwater. Possible alternative explanations include variations in soil type, or areas which receive surface water run-on from adjacent areas.

The second limitation is the spatial mismatch between the pixel size of widely available remote sensing imagery and the size of some GDEs. This can be problematic for mapping small wetlands associated with springs, and small waterholes that can be less than a few square metres in aerial extent.

It is also likely to be a problem for the open woodland systems that are characteristic of arid Australia, as it may only be individual species within the ecosystem that are groundwater dependent, and the canopy of an individual tree may be insufficient to influence the signal. In these landscapes, seasonal variability is often dominated by a dynamic herbaceous grass layer and this is strongly coupled to the timing and amount of rainfall, not groundwater availability. This strong seasonality of the grass layer can mask any GDE signals from the tree layer, thereby making the detection of GDEs problematic.

104. This highlights some of the limitations with the indirect techniques (remote sensing used by GHD) for identifying GDEs in the project area. They also talk about perched aquifers but we still have no proof that these exist in the project area. If an aquifer is perched then it won't be impacted by regional groundwater drawdown but to prove this requires evidence.
105. The type of GDEs identified in the second paragraph above are likely to have high degrees of biodiversity and cultural significance. The third paragraph suggests that not all species in a particular vegetation community or occurrence may be groundwater dependant so they may not show a high continuous vegetation density, hence will be missed by the currently applied methods.

Page 5 -Decile ranking values of 4-7 were chosen as diagnostic of GDEs, as these values would reflect areas that have a moderate reflectance in June-August 1994. The logic for this approach is unclear, as groundwater dependent vegetation would be expected to have lowest greenness during the period of lowest rainfall (relative to other years), albeit higher greenness than vegetation that are not using groundwater (see Figure 1). A better approach may have been to examine the variance of reflectance across the baseline period, and identify pixels with lowest variance over that period of time.

106. I agree with these points as the choice of June-August 1994 (the driest season on record) is not the most appropriate period for this method of GDE identification. The GHD (2020) study uses a data set from 2014-2019. Have Cook and Eamus reviewed the GHD (2020) study?

Page 6 - The Green Island mapping uses Landsat imagery, with a pixel size of 30 m x 30 m. Based on analysis of Google Earth imagery, the crown size of overstorey trees within open woodlands of the Ti Tree and Western Davenport regions is mostly 5 – 10 m diameter. This is likely to pose limitations on the analysis as outlined above.

Duguid observed that pixels identified as 'persistently green' by Green Island mapping were mostly areas where there was a cluster of potentially groundwater-dependent vegetation (e.g., C. opaca), but that apparently similar clusters of trees were not identified. This probably partly reflects the scale of the remote sensing method, which is too coarse to identify individual groundwater-dependent trees, and will only identify clusters of trees if they cover a large proportion of individual pixels (Figure 2).

However Duguid (2017b) also notes that some trees that are identified in the Green Island mapping are understory shrubs (including Acacia species) or ironwood, none of which are currently suspected of being phreatophytic. The Green Island mapping may therefore just be detecting pixels that have a high proportion of evergreen trees relative to bare soil or grass cover.

107. The techniques GHD have applied have the same spatial resolution shortcomings.

Page 7 - Persistently green vegetation overlying groundwater deeper than 15 m is assumed to be dependent on surface run-on rather than groundwater, and are hence classified as IDEs.

Use of water table depth is a pragmatic approach for discriminating between GDEs and IDEs, but requires accurate water table depth maps. In the Western Davenport Basin, bore data is scarce in some areas, and so the accuracy of the water table depth maps may be low, but is difficult to quantitatively assess.

108. IDEs are inflow (surface water) dependant ecosystems which I agree could be creating "green islands" picked up by the remote sensing. However the poor watertable elevation data coverage is likely to be introducing significant errors in the extrapolated watertable elevation data. So areas currently not identified as having a depth to groundwater <15m may meet this criterion and be groundwater dependant but are just not being identified. Other issues with the current depth to groundwater mapping are identified on page 7 of Cook and Eamus (2018b) and I agree with these issues.

Page 8 - Prioritising GDEs for Protection

Prioritisation of GDEs would appear to be particularly important in arid regions, where groundwater-dependent vegetation could be widespread across Water Allocation Plan areas. This approach is beginning to be adopted in NSW, where GDE mapping seeks to identify "high-value groundwater dependent ecosystems", and these are prioritised for management purposes (e.g., NSW DPI, 2017). Four criteria are used for assessing value: diversity, distinctiveness, naturalness and vital habitat (NSW DPI, 2016).

Criteria used for prioritisation of GDEs may vary across jurisdictions, and depending on GDE type, but should include:

- *Rarity of ecosystem and any fauna that it supports (e.g., presence of endangered or endemic species or subspecies)*
- *Pristine nature of ecosystem (current level of degradation)*
- *Cultural values of ecosystems*

Page 12 - There is some species-level knowledge of GDEs within the Ti Tree basin, although there has not been any mapping or prioritisation of ecosystems. The focus of the work to-date has been identifying species which are groundwater-dependent, rather than their distribution across the region.

109. Agreed and have raised this point previously. This has not been addressed and I see no evidence of it being addressed in the licence conditions.

Page 9 - Whilst theoretically it would be expected that roots should increase their rate of elongation in response to increases in water table depth, the Canham et al. (2015) study in Australia found little evidence that this was true.

Of course, it should be noted that timelags between declines in groundwater level and ecosystem impact can occur, as access to groundwater may only be important at certain stages of plant growth and/or during periods of very low rainfall. This means that the absence of observable declines in ecosystem condition in areas with declining water tables should not be taken as evidence that such declines in groundwater level will not eventually impact dependent ecosystems.

110. These are important points that I agree with. The rest of page 9 talks about the rate of root elongation that is a critical control for rate of drawdown criteria and how there are large gaps in this research for Australian species.

Page 10 - Thus, the method assumes that lowering the water table from 5 m to 13 m will not impact vegetation, but that lowering the water table from 14 m to 16 m will have a negative effect. The proposed approach thus poses a risk to GDEs in areas with shallow water tables (0 – 8 m), and probably over-estimates the risk to ecosystems in areas of intermediate water tables (10 – 15 m).

Page 11 -Although with current knowledge, the magnitude of the permitted decline is likely to be somewhat arbitrary, it should follow the principle that GDEs in shallow water table areas are likely to be more sensitive to water table decline than GDEs overlying deeper water tables.

111. Agreed and again I have raised this issue previously in that more depth to groundwater categories are required and the shallower the depth to groundwater the higher the degree of

dependency is, consequently drawdown (both rate and absolute change) need to be more stringent for shallow GDEs.

Page 11 - In the absence of detailed and species specific studies on acceptable rates of decline in the water table for central Australian species, the best way of setting rates of decline may be to examine bore data and determine historical rates of decline (for each season) that did not appear to induce negative impacts on vegetation structure and function (assessed through concurrent RS analyses).

112. This is a good approach but I don't think has been applied. It's likely that there is not enough data to undertake this however.

Page 12 - It is recommended that the WAP proceed on the basis that there is insufficient knowledge to determine the locations of GDEs, the timing and extent of dependency, the sensitivity of each GDE to changes in depth-to-groundwater or the risk to them, and specify that allocation and licence decisions will be conditional and subject to amendment as new hydro-ecological and GDE knowledge becomes available.

113. Agreed but also would add that there is not enough data on GDE condition or depth to groundwater to currently improve our understanding to a level I believe is appropriate for groundwater management. Substantial amounts (10 years +) of hydrogeological and biological data collection at existing and new sites will be required to improve this in my experience.

Cook and Eamus (2018c) GDEs in the NT Arid Zone Further Investigations, Monitoring and Research.

114. No specific points from this report are raised as it would make the review herein more repetitious as much of this comes from their other two document but this is an excellent summary of the work required to get to an appropriate level of understanding for groundwater management. Only recommendations 1 and 4 in Cook and Eamus (2018c) have been addressed to any degree in the GHD (2020) study but the rest haven't had any progress from what I can see. Recommendations 1 and 4 have only been progressed to some degree. Many of the Cook and Eamus (2018c) recommendations require data that doesn't currently exist and will take years (10+ in my opinion) to collect and analyse. Little detail on the investigations required is contained in the licence conditions so this leaves little certainty as to what is proposed to breach these considerable knowledge gaps.

Northey, Smith, Clark, Hostetler, Parige, McPherson, & Clarke, 2020, Exploring for the Future—geological and hydrogeological investigations in the Western Davenport region: Northern Territory.

> *Page 13 - Although the Wiso and Georgina basins are inferred to be continuous across the WD region (e.g. Kruse et al., 2013), there are multiple lines of evidence that suggest that this may not be true.*
>
> *This hampers any assessment of stratigraphic continuity between basins and has led to the boundary between them being arbitrarily defined as a straight line in the vicinity of the road and rail corridor.*
>
> *Finally, although some inter-basin lithostratigraphic correlations can be made, stratigraphy varies between the Lander and Dulcie troughs of the Wiso and Georgina basins, respectively.*
>
> *Thus, although it is likely that the Wiso and Georgina basins are continuous beneath Cenozoic cover in the WD study area, further data are required to confirm this.*

115. This highlights the lack of hydrostratigraphic units which bridge the two basins but the groundwater modelling has this as an assumption. If this is not the case and there is a flow boundary, or less productive aquifers in the Wiso Basin, drawdowns could be much higher than currently predicted around the proposed Singleton bore field. A hydrostratigraphic unit is a body of rock that forms a distinct hydrologic unit with respect to the flow of ground water and exhibit similar hydraulic properties.

> *Page 52 - There is evidence from the neighbouring Ti Tree Basin of significant groundwater use by vegetation in areas where the water table is 12 mbgl [metres below ground level] or less, with some evidence of groundwater use at depths of 15 mbgl to 20 mbgl (Cook & Eamus, 2017).*

116. Agreed which is further corroboration of vegetation’s groundwater dependence potential at depths to groundwater of up to 20m.

Answers to Questions in Brief

The questions are repeated below for ease of reference and the answers are below each question (a).

1. Is there sufficient data to base a 40 GL allocation decision?
    a. This is a subjective question but in my opinion it's marginal for this allocation alone but when considered in combination with all other currently proposed allocations and the lack of understanding of environmental impact risk my answer is no. The lack of data, the current uniform storage assumed for all aquifers, lack of robust EWRs, lack of identification and inclusion of aquatic GDEs in the impact assessment and lack of predictive uncertainty analysis poses an unacceptable level of risk to the water resource, the environment and cultural values.
2. What are the ranges of plausible assumptions associated with the application? There is no drilling data to confirm aquifer characteristics are as assumed, particularly in Cambrian aquifers west of highway.
    a. I think I have covered this in the specific points raised in review of the various documents and the summary. With the current lack of data (see the summary) there is considerable uncertainty in all model predictions and aspects of the conceptual model.
3. What if the Wiso basin Cambrian is a much poorer aquifer than model assumes, for instance less storage, poorer hydraulic conductivity would be greater drawdown etc.
    a. Yes all of those scenarios would result in greater drawdown and change the area of impact.
4. What evidence exists for assumptions of direct recharge across aquifer? If in reality direct recharge is limited to creek lines in the Cainozoic then realistic recharge estimates would be much smaller.
    a. Hydrographs show distinct evidence of episodic recharge away from creek lines, recharge will be higher around creek lines (which receive incident rainfall as well as surface water flow both of which can produce recharge) but there is not data available to assess recharge near creek lines. The direct recharge away from the creek lines is evident from watertable rises post significant rainfall-runoff events. Northey et al., (2020) presents data which shows that recharge is highly variable between 0 and 12 mm/yr and is highly episodic. The CloudGMS modelling predicts nearly 60 years of no recharge.
5. Are there any other instances where so much water has been given away with so little supporting data?
    a. Yes, but that doesn't make it a good idea.
6. The Ti Tree model 100 km south had an average recharge of 1.1mmyr over whole model domain, what is the average recharge for the Western Davenport District? If the Western Davenport recharge is considered to be significantly higher than Ti Tree then what underpins that assumption? For example the Murray basin has recharge halved since 2000.
    a. There will be some distributed recharge but I think most of the recharge is coming from the focussed discrete high intensity rainfall-runoff recharge events at surface water features as modelled. I'd need to review the Ti Tree model but focussed verses distributed recharge modelling are different styles of modelling. But in reality, recharge from both sources (distributed and focussed) will be occurring, it's just a question of what is dominant where. The current level of groundwater monitoring (spatial and frequency) prohibits a robust understanding of recharge dynamics

across the model domain. Chloride mass balance only gives very long-term averages. You need monthly data to really start to get into this level of recharge assessment. Northern Australia's climate change impact and predictions are much less certain than for the Murray-Darling or south west Western Australia. I think recharge in the NT is more stable than in the Murray-Darling or south west Western Australia, bearing in mind that recharge is more episodic and sporadic as in most arid areas.

7. The allocation is apparently based on recharge estimate from model. So while supposedly calibrated, the sparsity of actual records of recharge i.e. water table rise in vast areas of the model and in all different aquifers, suggest that different equally plausible assumptions could be made. Is this an accurate assessment?
    a. Yes other plausible assumptions could be made. I think the difference here is the level of proposed allocation and the fact that the WAP is accepting loss of storage. Most allocation plans would not accept a decline in storage without a very high level of understanding.
8. Is it a better practice approach to run the model under various different assumptions and use the worst case scenario as the basis for a licence decision until more evidence becomes available?
    a. In my opinion yes, this could be done with the existing model and PEST predictive uncertainty analysis. It should be noted that this does not assess conceptual uncertainty, only parametric and numeric uncertainty.
9. It seems that there is a distinct lack of detailed information about the aquifer characteristics (a lack of drilling) so it appears to be based particularly on assumptions about characteristics. What is the minimum level of base information about a hydrogeological system that is required to inform a decision of this nature – has that minimum level been satisfied in this example?'
    a. Yes I agree with your statement and in my opinion no, the minimum level has not been satisfied. Appendix 1 will give you an idea of the required level of understanding for various levels of allocation. More information on this in my other text.
10. Likewise there appears to be some substantial questions about the calibration of the model and whether there have been sufficient recharge events to understand the characteristics of the aquifer in order to represent it reliably in a model – again there might be a good question in asking what the minimum requirements for model calibrations of this nature are, and have those requirements been met? What are the levels of uncertainties in the outputs – have these been documented/considered? Is the scale of the model fine enough to draw conclusions at the specific GDE locations etc.
    a. The calibration is "ok". I'd like to see some more transient calibration output but the (lack of) transient data that is being calibrated against is the issue. The minimum amount of data required is a bit subjective. I think to get anywhere near full allocation they would need an R4 level of understanding (according to Appendix 1). Currently level is R1 with some elements of R2. Obviously, this is a Western Australia Government document but I think it has merit in all jurisdictions.
11. What testing is needed to verify the underlying assumptions in relation to estimating aquifer recharge, storage and discharge, and confirming that the processes in the model are appropriate (e.g. rainfall, evapotranspiration, infiltration, through-flow and movement between aquifers).

    a. These processes are all covered at least somewhat. It's only the uncertainty in the conceptual hydrogeological model, numerical model parametrisation and predictions that are an issue.

12. The protection of biodiversity values and potential habitats found in groundwater dependent ecosystems is discussed and seems to underpin some of the justification. The Report states that the Department has looked at a GDE probability of occurrence of 70% and that Singleton has also looked at GDE probability of occurrence of 50%. Given there doesn't appear to have been field verification/mapping of GDEs, is the approach to modelling potential GDEs appropriate (i.e. what were the inputs into the model and do they make logical sense).
    a. I haven't seen the reasoning for 50%, their method is a rough first pass at locating GDEs and as described in this report field data is required.
13. The allowable impact to GDEs has been based on rates and quantum of groundwater drawdown as defined by the Government, and a definition that there can be impact of up to 30% of GDEs. What parameters were included in the model to determine the level of impact? Was the model based on a historic climate data series or a future scenario that considers likely climate change impacts on GDEs (both in terms of rainfall, heat and the resultant impacts to recharge). Without development and only looking at climate change impacts, are the GDEs that we would expect to see at full development (say 30 years in the future) be the same as what we see now, or should the impact on GDEs have been modelled from a different base? What requirement is there for government to consider climate change impacts in assessing water extraction licences – especially in the arid zone where there is meant to be an assessment covering at least 100 years into the future.
    a. Climate for the predictive model is the historical record repeated. Given the uncertainty over the climate change impact for Northern Australia this is a logical approach. To do better requires better climate predictive models i.e. out of the scope of what they could be expected to do.
14. I note that the NTG has a climate change response policy that states 'The Territory Government will use water monitoring data, real time weather observations and seasonal data, and projected climate change impacts to manage the sustainable use of water in the Territory.' Does the model adequately consider 'projected climate change impacts' for Central Australia, in accordance with NTG policy (northern-territory-climate-change-response-towards-2050.pdf).
    a. No but see answer above.
15. Does the GDE component of the modelling rely on the same information as was used to inform the recharge.
    a. No, the data used for these two purposes is different. GDE's were assessed using remote sensing data while recharge has been estimated via modelling and the small amount of time varying groundwater level data that is available. There is a lack of data to assess unsaturated zone hydrology and plant water use directly in the context of recharge/groundwater level fluctuations.

Appendix 1 – Allocation Planning Process in Western Australia.

Note that this text and figures are adapted from Department of Water (2011) Water allocation planning in Western Australia – A guide to our process. Water resource allocation planning series, Government of Western Australia. ISBN 978-1-921789-96-0.

The allocation planning process assesses risk to the environment and the water resource sustainability in order to determine allocation limits. However, different levels of scientific rigor are applied depending on the amount of use as a proportion of the allocation limit. The Category/Response Model is used to assess the required level of assessment (R1-R4) as function of level of use (C1-C4), as shown in Table 1. Table 2 further summarises the level of investigation required as a Management Response (Department of Water, 2011).

The level of uncertainty during the early parts (C1-R1) of this iterative allocation planning process is high, consequentially there is considerable uncertainty over the allocation limit, and no plan is produced, only an allocation limit. The level of uncertainty then becomes reduced as the level of scientific rigor is increased. For other areas (C2-C4 and R2-R4) the Department of Water produces three types of water allocation plans (Department of Water, 2011):

(1) Standard plans, which are developed for medium-demand areas (C2); these require a low level of planning investment. C2 plans are based on the use of existing information, applying simple, local management rules, and existing state-wide policies.
(2) Intensive plans are developed where demand is high (C3 and C4) during which new studies are commissioned to reduce uncertainty in the allocation limit; these will include water resource and ecohydrological modelling and broad stakeholder consultation. An important part of C3 level planning is to establish environmental water regimes or environmental water requirements (EWRs). Over half of the proclaimed water areas in the state are at, or approaching, full allocation (C3) (Department of Water, 2011).

Although this process is considered to be generally sound, the level of scientific investigation and subsequent rigor in the allocation limit can create issues in areas where there is rapid changes in water demand/licences. Figure 1 shows a problematic (A) and ideal (B) water use verses allocation limit trajectory. Under trajectory A the level of allocation rises rapidly during the initial period where the links between cause and effect are poorly understood. This has the potential to jeopardise the sustainability of the resource, risking loss of human value associated with impacts to dependent biota and water. Under this trajectory there may be a need for an urgent correction accompanied by environmental, social and economic consequences. Trajectory B is the desired course where the level of use stays within not only the allocation limit but the uncertainty of it at every level of management response. There will always be some level of uncertainty and risk but this process is about minimising this risk and making the process as transparent as possible.

Table 1 - Category/response water allocation planning model, taken from Department of Water (2011).

Category (C)				Response (R)							
Licensed % of allocation limit		Impact from further licences	Risk to in-situ values	Licences required		Plan type	Maximum availability from resource	New information developed for plan	Allocation limits protect in-situ values	Specific rules protect values	Specific regimes protect values
C1	Low 0 < 30	Low	Low	R1	✓	x	x	x	✓	x	x
C2	Medium 30 < 70	Med	Med	R2	✓	Standard	x	x	✓	x	x
C3	High 70 < 100	High	High	R3	✓	Intensive	✓	✓	✓	✓	✓
C4	Over >100	V high	V high	R4	✓	Intensive	✓	✓	✓	✓	✓

Table 2 - Work required in plan development, taken from Department of Water (2011).

		Resource assessment		Values			
Response	Aim	Surface water	Groundwater	Ecological	Economic	Social	Cultural
R1 Limits only no plan	Basic approach to avoid potential impact	Flow estimate from gauge data or regional model	Basic rainfall recharge, throughflow or discharge estimate	Existing info Regional mapping	Existing use info Licence analysis	Existing info	Existing info Important sites
R2 Standard plan	Standard approach to avoid impacts and prepare for C3	Flow estimate from gauge data or regional model	Detailed recharge, throughflow or discharge or regional model	Existing info Important sites Risk areas	Existing use info Licence analysis	Existing info	Existing info Important sites
R3 Intensive plan	Detailed approach to maintain C3 status and begin impact management	Flow estimate from gauge data or calibrated, localised model	Regional model and/or local models	Environmental water requirements Buffer zones Scenarios Risk maps	Use analysis Current and future use trends	Sites Flow/level requirements Risk maps	Sites Flow\level requirements Risk maps
R4 Intensive plan	Detailed approach to return resource to C3	Flow estimate from gauge data or calibrated, localised model	Regional model and/or local models	Environmental water requirements Buffer zones Scenarios Remediation measures	Impact/ cost analysis for recoup	Sites Flow/level requirements Remediation measures	Sites Flow/level requirements Remediation measures

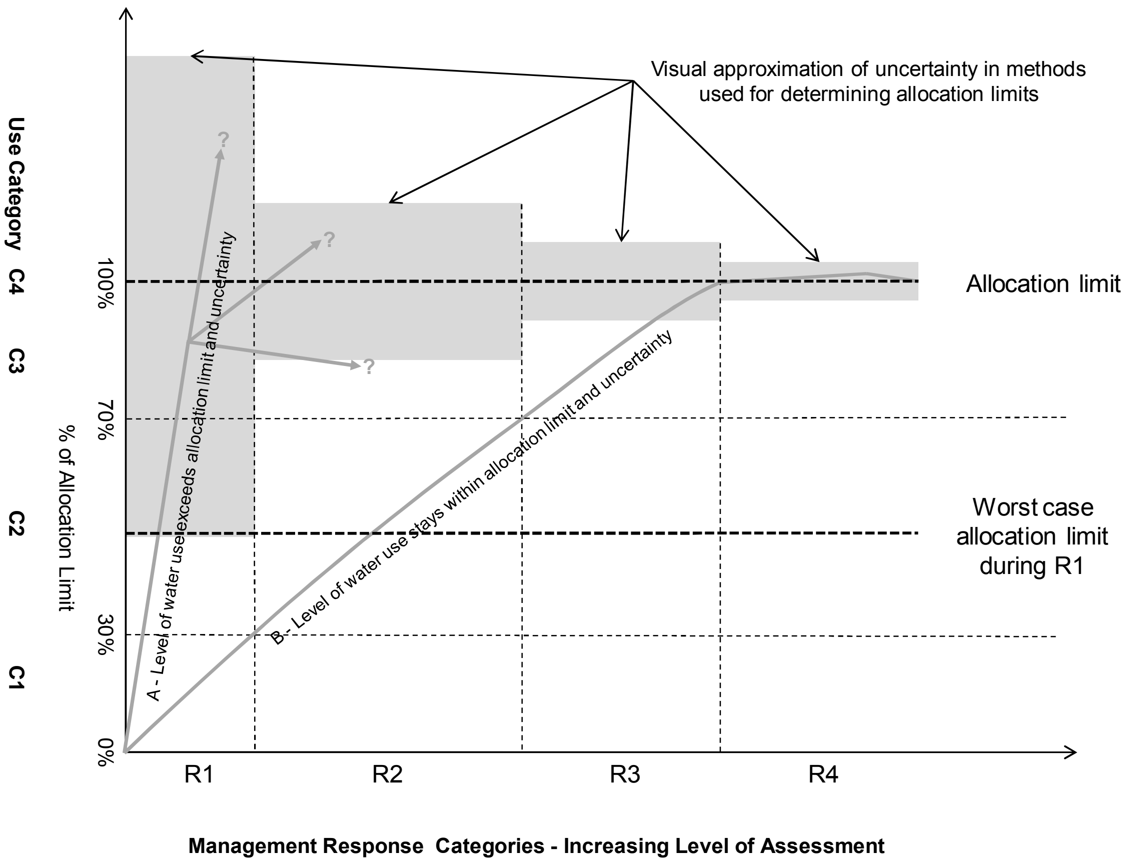
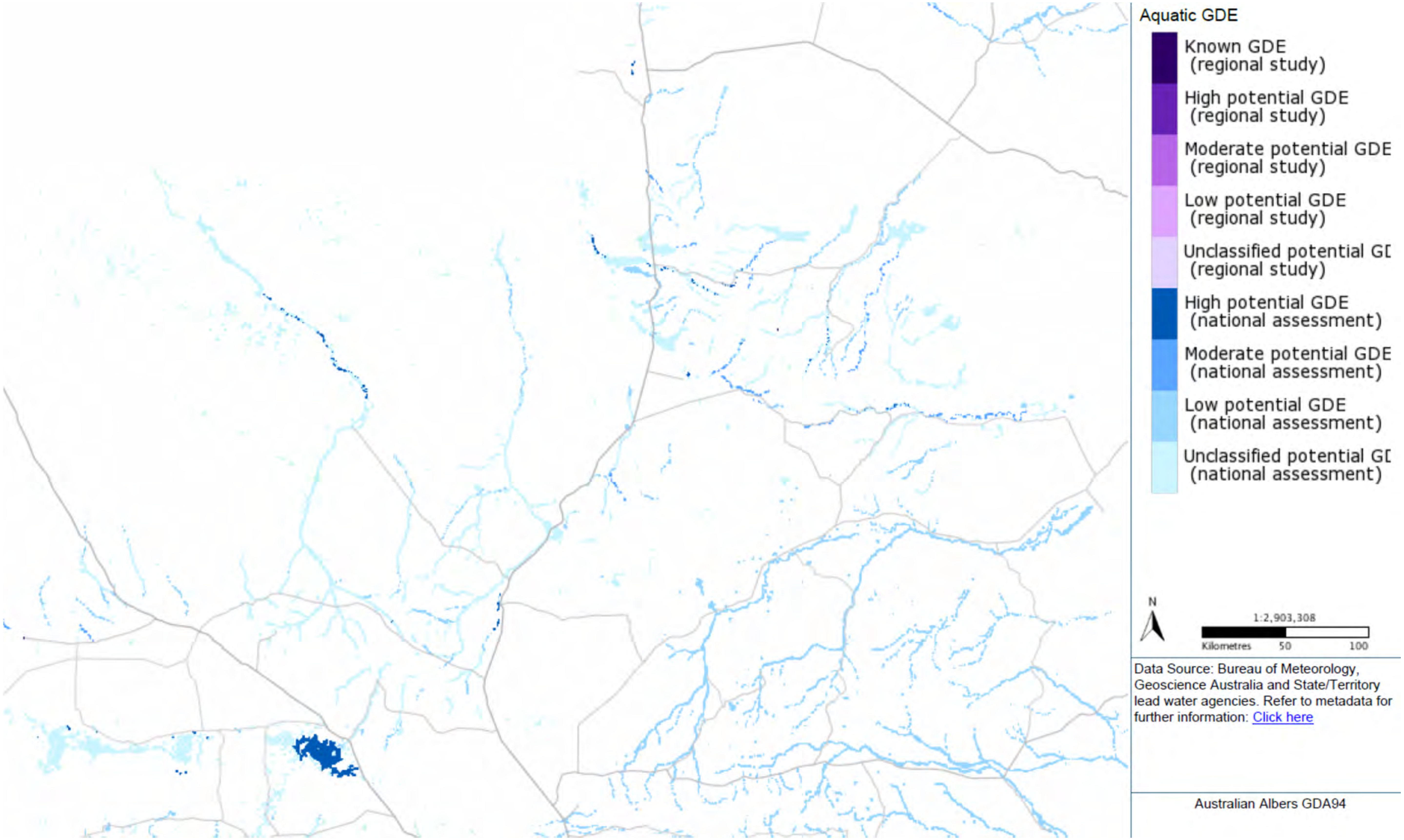


Figure 1 – Visual interpretation of the category/response water allocation planning model including approximate uncertainty at each stage of Management Response.

Undertaking the Resource Assessment in the allocation planning process requires application of a number of scientific techniques of increasing complexity (Tables 1 and 2). Basic desktop style evaluations at low levels of resource evaluation give way to detailed flow gauging, assessments of surface water/groundwater interaction, numerical modelling, ecohydrological assessment and precise determination of groundwater dependence of ecosystems, including EWR's. These are resource intensive and challenging projects that require long-term data sets.

Appendix 2 – BoM GDE Atlas Output.



Appendix 3 – Curriculum Vitae

CURRICULUM VITAE

Dr. RYAN I.J. VOGWILL

ABOUT

Ryan's more than 20 years of technical expertise encompass groundwater modelling, water resource planning and recovery of hydrologically impacted ecosystems, with a focus on applying research to sustainable groundwater management and environmental impact/risk assessment

QUALIFICATIONS

- BSc (Applied Geology) - Curtin University
- First Class Hons (Applied Geology) - Curtin University
- Doctor of Philosophy (Applied Geology) - Curtin University
- Member Australian Institute of Geoscientists

EXPERIENCE

Ryan has been an influential Hydrogeologist in Western Australia for more than 20 years. He has undertaken project work and provided advice regarding the management of groundwater resources and environmental impacts across most business areas and across all regions of WA, but also with national and international based projects. He played a significant role in establishing and the initial application of the Perth Regional Aquifer System Model, a platform for more responsible and informed management of groundwater resources in the Perth region. He also established, coordinated and was the primary lecturer for the Hydrogeology MSc course at UWA. He has worked in consultancy intermittently throughout his career, but this is now full time as of September 2016.

KEY SKIILS & EXPERTISE

- Technical and editorial review
- Regional and local scale water allocation planning including drought contingency planning
- Water quality and ecology (i.e. effluent discharge and algal blooms)
- Sedimentological and geochemical assessment
- Land use re-evaluation
- Environmental risk assessment
- Groundwater Dependent Ecosystems (GDEs) and Environmental Water Requirements (EWRs)
- Dryland salinity
- Groundwater training and education
- Groundwater modelling generally but with a focus on MODFLOW
- Surface water/groundwater interaction modelling including water and solute balances
- Project and staff supervision

AWARDS

Ocean Seas Ocean Hero Award.

Hydrology and Earth Systems Science - Jim Dooge Award 2020

KEY PROJECT EXPERIENCE

PRAMS development and application - a $5M groundwater model of the Perth (Moora to Mandurah) Region

South West Yarragadee groundwater and impact assessment modelling (SWAMS and local area models) review for the Department of Conservation and Land Management

Groundwater Modelling for the East Wanneroo Land and Water Use Re-evaluation

A member of the modelling technical reference groups for Ord Stage 2 - Weaber Plains and the southern river/Murray River MikeSHE modelling projects by CSIRO

Salt Lake Potash - Water supply and production impact assessment and licensing.

Millennium Minerals Limited - Multiple mine dewatering requirements and GDE impact risk assessment

Supervising Hydrologist for the Natural Diversity Recovery Catchment Program

KEY CAREER HISTORY

Director, Principal Hydrogeologist, Hydro Geo Enviro Pty Ltd, Feb 2018 to date

Principal Hydrogeologist (Sole Trader) September 2016 to Feb 2018

Associate Professor Hydrogeology, The University of Western Australia, December 2011 – September 2016

Supervising Hydrogeologist, Nature Conservation Division, Department of Environment, and Conservation, February 2006 – April 2011

Hydrogeologist, Department of Water, Groundwater Hydrology Section, February 2003 – February 2006

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DR RYAN I.J. VOGWILL

PRINCIPAL HYDROGEOLOGIST

Continued…

PROFESSIONAL EXPERIENCE

DIRECTOR AND PRINCIPAL HYDROGEOLOGIST

HYDRO GEO ENVIRO AND SOLE TRADER SEPTEMBER 2016 – ONGOING

Key clients and project during this time include:

- Salt Lake Potash - water supply and production impact assessment/licensing.
- Millennium Minerals Limited - Multiple mine dewatering requirements, surface water management, GDE mapping and impact risk assessment
- City of Kalamunda - Acid sulphate soil management
- Adelaide Brighton Cement - Inorganic contamination conceptual modelling and remediation
- City of Rockingham - Lake Richmond microbialites, hydrology, chemical risk and weed management
- Rottnest Island Authority - Microbialite monitoring plan and impact criteria

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ASSOCIATE PROFESSOR OF HYDROGEOLOGY

THE UNIVERSITY OF WESTERN AUSTRALIA, DECEMBER 2013 – SEPTEMBER 2016

JOINT ASSOCIATE PROFESSOR OF HYDROGEOLOGY

THE UNIVERSITY OF WESTERN AUSTRALIA/CURTIN UNIVERSITY, APRIL 2011 – DECEMBER 2013

SUPERVISING HYDROLOGIST, NATURE CONSERVATION DIVISION

DEPARTMENT OF ENVIRONMENT, AND CONSERVATION, FEBRUARY 2006 – APRIL 2011

Ryan was the key hydrogeologist employed by DEC, providing advice across all business areas. He continued working on GDEs of the Gnangara Mound, dryland salinity and all of the associated issues. Ryan has reviewed, critiqued and presented to the EPA on a number of subjects, including the sustainability of groundwater abstraction from the Gnangara Mound and Southwest Yarragadee project. He has also been heavily involved in many referrals from other government departments and sections of the DEC for many technical reviews of mining applications. Ryan continued to co-ordinate research and projects for the DEC, which involved the interaction of hydrology and biology in the Natural Diversity Recovery Catchments during the first 3 years of his time in academia until the Natural Diversity Recovery Catchment project was shut down.

HYDROGEOLOGIST

DEPARTMENT OF WATER, GROUNDWATER HYDROLOGY SECTION, FEBRUARY 2003 – FEBRUARY 2006

Preparation of modelling scenarios and the associated reporting; Section 46 modelling; Drought Contingency modelling; East Wanneroo Land Use Re-evaluation; graphic presentation of modelling data; database analysis and retrieval for various purposes; development of sampling programs; research proposals; and a large number of modelling/report critiques amongst other duties.

BOOKS AND PUBLISHED REPORTS

- Vogwill R., 2017, Western Australia's Tight Gas Industry - A review of groundwater and environmental risks. Conservation Council of Western Australia. ISBN (13): 978-0-9750708-1-9.
- Vogwill R. (ed), 2016, Solving the Groundwater Challenges of the 21st Century - IAH - Selected Papers on Hydrogeology. CRC Press, Taylor & Francis. ISBN 9781138027473. https://www.crcpress.com/Solving-the-Groundwater-Challenges-of-the-21st-Century/Vogwill/9781138027473.
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BOOK CHAPTERS

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Boulton, A., Brock, M., Robson, B., Ryder, D., Chambers, J., Davis, J., 2014, Australian Freshwater Ecology: processes and management, Wiley and sons. Note Vogwill contribution is a salinity case study on Lake Toolibin. Given this is a published text book, chapters are not attributed specifically but my input has been formally acknowledged in the publication.

THESES

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JOURNAL PUBLICATIONS

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Mendes Monteiro J., Vogwill R., Bischoff K. and Gleeson D.B., 2019, Comparative metagenomics of microbial mats from hypersaline lakes at Rottnest Island (WA, Australia), advancing our understanding of the effect of mat community and functional genes on microbialite accretion. Limnol. Oceanogr. 00, 2019, 1–17 doi: 10.1002/lno.11323

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Coletti J.Z., Vogwill R., Hipsey M.R., 2017, Water management can reinforce plant competition in salt-affected semi-arid wetlands, Journal of Hydrology, doi: http://dx.doi.org/10.1016/j.jhydrol.2017.05.002.

Forbes M. and Vogwill R., 2016, Hydrological change at Lake Clifton, Western Australia – Evidence from hydrographic time series and isotopic data. Journal of the Royal Society of Western Australia, 99(2): 47–60.

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Mitchell, N., Hipsey, M.R., Arnall, S.G., McGrath, G.S., Tareque, A., Kuchling, G., Vogwill, R.I., Sivapalan, M., Porter, W., Kearney, M. 2013, 'Linking eco-energetics and eco-hydrology to select sites for the assisted colonization of Australia's rarest reptile', Biology, 2, 1, pp. 1-25.

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Buntine-Marchagee Natural Diversity Recovery Catchment, Recovery Plan 2007-2027, DEC, 2007. This report has been copy edited to international publication standards and represents a crucial step in developing a new method of recovery planning to reduce salinisation impacts in the wheatbelt. I was responsible for much of the hydrological content and a key input to planning process and research plan.

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Mudgway L., Lacey P. and Vogwill R, 2008, Know what you are measuring—a detailed review of groundwater monitoring at Toolibin Lake and Lake Bryde, 2nd International Salinity Forum, Adelaide 31st Mar – 3rd Apr 2008. (Paper)

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Vogwill R, Cook TF, Appleyard, SJ, Watkins R, 2007, Potential for Negative Ecological Impacts of Current Water and Landuse of Gnangara Mound GQ2007, the 6th International IAHS Groundwater Quality Conference, held in Fremantle, Western Australia, 2-7 December 2007. (abstract and oral presentation).

Noorduijn, S.L., Vogwill, R, Ghadouani, A, and Smettem, K. R. J., 2007, Assessing agroforestry as a tool for sustainable water resources management in western Australia, SSEE International Conference on Sustainable Engineering, 31st Oct-2nd Nov 2007 (oral presentation)

Cook TF, Watkins R, Appleyard, SJ, Vogwill R, 2006, Acidification of groundwater caused by a falling water table in a sandy aquifer in the Perth Region, Western Australia. Proceedings of the 18th World Congress of Soil Science, 9-15 July 2006, Philadelphia, USA. (abstract and oral presentation).

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Appendix 4 – Questions in Brief

As part of the contract the following questions were also posed:

1. Is there sufficient data to base a 40 GL allocation decision?
2. What are the ranges of plausible assumptions associated with the application? We understand there is limited drilling data to confirm aquifer characteristics are as assumed, particularly in Cambrian aquifers west of highway.
3. What if the Wiso basin Cambrian is a much poorer aquifer than model assumes, for instance less storage, poorer hydraulic conductivity would be greater drawdown etc.
4. What evidence exists for assumptions of direct recharge across aquifer? If in reality direct recharge is limited to creek lines in the Cainozoic then realistic recharge estimates would be much smaller.
5. Are there any other instances where so much water has been given away with so little supporting data?
6. The Ti Tree model 100 km south had an average recharge of 1.1mmyr over whole model domain, what is the average recharge for the Western Davenport District? If the Western Davenport recharge is considered to be significantly higher than Ti Tree then what underpins that assumption? For example the Murray basin has recharge halved since 2000.
7. The allocation is apparently based on recharge estimate from model. So while supposedly calibrated, the sparsity of actual records of recharge i.e. water table rise in vast areas of the model and in all different aquifers, suggest that different equally plausible assumptions could be made. Is this an accurate assessment?
8. Is it a better practice approach to run the model under various different assumptions and use the worst case scenario as the basis for a licence decision until more evidence becomes available?
9. It seems that there is a distinct lack of detailed information about the aquifer characteristics (a lack of drilling) so it appears to be based particularly on assumptions about characteristics. What is the minimum level of base information about a hydrogeological system that is required to inform a decision of this nature – has that minimum level been satisfied in this example?
10. There are substantial questions about the calibration of the model and whether there have been sufficient recharge events to understand the characteristics of the aquifer in order to represent it reliably in a model. What the minimum requirements for model calibrations of this nature, and have those requirements been met? What are the levels of uncertainties in the outputs – have these been documented/considered? Is the scale of the model fine enough to draw conclusions at the specific GDE locations.
11. What testing is needed to verify underlying assumptions in relation to estimating aquifer recharge, storage and discharge, and confirming that the processes in the model are appropriate (e.g. rainfall, evapotranspiration, infiltration, through-flow and movement between aquifers).
12. The protection of biodiversity values and potential habitats found in groundwater dependent ecosystems is discussed and seems to underpin some of the justification. The Report states that the Department has looked at a GDE probability of occurrence of 70% and that Singleton has also looked at GDE probability of occurrence of 50%. Given there doesn't appear to have been field verification/mapping of GDEs is the approach to modelling potential GDEs appropriate (i.e. what were the inputs into the model and do they make logical sense).
13. The allowable impact to GDEs has been based on rates and quantum of groundwater drawdown as defined by the Government, and a definition that there can be impact of up to 30% of GDEs . What parameters were included in the model to determine the level of impact? Was the model based on a historic climate data series or a future scenario that considers likely climate change impacts on GDEs (both in terms of rainfall, heat and the resultant impacts to recharge). Without development and only looking at climate change impacts, are the GDEs that we would expect to see at full development (say 30 years in the future) be the same as what we see now, or should the impact on GDEs have been modelled from a different base? What requirement is there for government to consider climate change impacts in assessing water extraction

licences – especially in the arid zone where there is meant to be an assessment covering at least 100 years into the future.

14. The NTG has a climate change response policy that states 'The Territory Government will use water monitoring data, real time weather observations and seasonal data, and projected climate change impacts to manage the sustainable use of water in the Territory.' Does the modelling adequately considers 'projected climate change impacts' for Central Australia, in accordance with NTG policy (northern-territory-climate-change-response-towards-2050.pdf).
15. Are the assumptions underpinning the GDE component of the modelling based on the same information as was used to inform the recharge.

<u>ATTACHMENT B:</u>

SUBMISSION SEEKING MINISTERIAL REVIEW OF WATER CONTROLLER'S DECISION TO GRANT THE NEW WATER EXTRACTION LICENCE WDPCC10000 TO FORTUNE AGRIBUSINESS

Made by the Central Land Council on 7 May 2021

Submission seeking ministerial review of Water Controller's decision to grant the new water extraction licence WDPCC10000 to Fortune Agribusiness

A. INTRODUCTION

1. On 8 April 2021, the Controller of Water Resources (**Water Controller**) made the decision to grant the following water extraction licence WDPCC10000 (**Singleton Water Licence**) under section 60 of the *Water Act 1992* (NT) (**Water Act**):

Applicant	Volume of water (ML/year) and Beneficial Use	Land from which water may be taken and used
Fortune Agribusiness Funds Management Pty Ltd (**Fortune Agribusiness)**	A maximum entitlement of 40 000 to service the Singleton Horticultural Project which includes: • 39 800 for agriculture • 100 for public water supply and • 100 for industry	Singleton Station NTP 653 (**Singleton Station**)

2. The Central Land Council (**CLC**) is a statutory authority established under section 21 of the *Aboriginal Land Rights (Northern Territory) Act 1976* (Cth) (**Land Rights Act**) and has functions and duties under Land Rights Act. These functions include:
   a) ascertaining and expressing the wishes and opinion of Aboriginals living in the area of the CLC as to the management of Aboriginal land in the area[1];
   b) protecting the interests of traditional Aboriginal owners of, and other Aboriginals interested in, Aboriginal land in the area of the CLC[2]; and
   c) assisting Aboriginals in the taking of measures likely to assist in the protection of sacred sites on land (whether or not on Aboriginal land) in the area of CLC[3].
3. Singleton Station is subject to a native title determination, *Rex on behalf of the Akwerlpe-Waake, Iliyarne, Lyentyawel Ileparranem and Arrawatyen People v Northern Territory of Australia* [2010] FCA 91 (**Singleton Determination**). Mpwerempwer Aboriginal Corporation (ICN: 7316) (**MAC**) is the prescribed body corporate for the purposes of section 57(2) of the *Native Title Act 1993* (Cth) (**Native Title Act**) and the registered native title body corporate for the purpose of performing the functions in section 57(3) of the Native Title Act in relation to the Singleton Determination.
4. The CLC is the recognised Aboriginal/Torres Strait Islander body for the southern region of the Northern Territory pursuant to section 203AD of the Native Title Act which includes Singleton Station.
5. The function of a native title representative body includes the performance of the assistance and facilitation functions set out in section 203BB of the Native Title Act. The carrying out of such functions is governed by a service agreement between CLC and MAC.
6. The CLC represents affected native title holders for Singleton Station, traditional Aboriginal owners of neighbouring Aboriginal land trusts including Warrabri Aboriginal Land Trust (**Warrabri ALT**) and Iliyarne Aboriginal Land Trust (**Iliyarne ALT**) and

[1] Section 23(1)(a) of the Land Rights Act
[2] Section 23(1)(b) of the Land Rights Act
[3] Section 23(1)(ba) of the Land Rights Act

residents of the affected Aboriginal community of Alekerange (together, the **affected Aboriginal constituents**).

7. The affected Aboriginal constituents are persons who are aggrieved by the decision of the Water Controller to grant the Singleton Water Licence for the purposes of section 30(1) of the Water Act:

a) **Native title holders have rights and interests over lands and waters in Singleton Station**

The Singleton Determination covers the *lands and waters* over Singleton Station. The native title holders' rights and interests include[4]:

(i) the right to hunt, gather, take and use the natural resources of the land and waters, including the right to access, take and use natural water resources on or in the land;

(ii) the right to access, maintain and protect places and areas of importance on or in the land and waters;

(iii) the right to engage in cultural activities and teach the physical and spiritual attributes of places and areas of importance; and

(iv) the right to share and exchange natural resources obtained on or from the land and waters, including traditional items made from the natural resources.

With the projected groundwater drawdown of up to 50 metres in the Singleton Station[5] and the potential impact on groundwater dependent ecosystems (**GDEs**)[6], the Singleton Water Licence affects the exercise of native title rights and interests by native title holders.

b) **Aboriginal persons have rights to enter, use or occupy Aboriginal land in accordance with Aboriginal tradition.**

Aboriginal land trusts hold Aboriginal land for the benefit of Aboriginals entitled by Aboriginal tradition to use or occupy the land concerned[7].

The Water Controller notes that a report prepared for Fortune Agribusiness by GHD titled "Singleton Horticulture Project Groundwater Dependent Ecosystem Mapping and Borefield Design" (**Fortune Report**) indicates that "*groundwater drawdown will extend beneath the Iliyarne ALT and may result impacts in GDEs on that land trust*[8]*".*

Given the groundwater drawdown and the potential negative impact on GDEs on Warrabri ALT and Iliyarne ALT, the rights of Aboriginals, including traditional Aboriginal owners, to use and occupy Aboriginal land will also be affected.

8. On behalf of affected Aboriginal constituents, MAC, Warrabri ALT and Iliyarne ALT, the CLC applies to the Minister to review the decision by the Water Controller to grant the Singleton Water Licence (**Water Controller Decision**).

[4] Paragraph 4 of the Singleton Determination
[5] Paragraph 66 of the Statement of Decision by the Water Controller for the Singleton Water Licence dated 8 April 2021 (**Statement of Decision**)
[6] See paragraphs 101 and 102 of the Statement of Decision
[7] Section 4(1) of the Land Rights Act
[8] Paragraph 48 of the Statement of Decision

9. We seek a review of the Water Controller Decision on the following grounds:

a) The estimated sustainable yield used by the Water Controller and derived from the *Western Davenport Water Allocation Plan* 2018 – 2021 (**WDWAP**) is not an *"estimated sustainable yield*" within the meaning of sections 22B(5)(a) and 71B(3)(d) of the Water Act because it results in depletion of the aquifer underlying the Central Plain Management Zone and unacceptable impacts on the environment.

b) The Water Controller and the WDWAP fail to take into account the level and extent of uncertainty underlying the groundwater model for WDWAP (**Groundwater Model**) and the conditions imposed by the Water Controller in the Singleton Water Licence cannot address such deficiency (because the level of uncertainty has not been quantified and insufficient investigation has been undertaken).

c) The Water Controller Decision fails to take into account the impact that the Singleton Water Licence will have on Aboriginal cultural values.

d) The "*Guideline: Limits of acceptable change of groundwater dependent vegetation in the Western Davenport Water Control District"* (**Guideline**) is inconsistent with the WDWAP and the Water Controller should not have relied on the Guideline.

e) The thresholds in the Guideline are arbitrary and the Water Controller fails to address the arbitrary nature of these thresholds in in the way that she made the Water Controller Decision.

f) The authors of the WDWAP fail to assess the risks to aquatic GDEs in the Western Davenport District. The risks to the aquatic GDEs have not been considered in the Guideline, the Fortune Report and the Water Controller Decision.

g) The WDWAP and Guideline demonstrate a lack of understanding of region-specific vegetation GDEs and the use of criteria are not consistent with those used in other jurisdictions in Australia.

h) The Water Controller should not have granted the Singleton Water Licence for a term more than 10 years given the uncertainty underlying the Groundwater Model and the potential impacts arising from granting the Singleton Water Licence.

i) The Water Controller fails to address concerns raised by CLC about biodiversity surveys undertaken by the Northern Territory Government which may impact on the assessment of lack of threatened species.

j) Condition CP6 in the Singleton Water Licence does not sufficiently address the elevated soil salinity risks recognised in the Statement of Decision.

B. GROUND 1 – ESTIMATED SUSTAINABLE YIELD IN WDWAP NOT WITHIN THE MEANING OF "ESTIMATED SUSTAINABLE YIELD' IN THE WATER ACT

Ground 1: The estimated sustainable yield used by the Water Controller and derived from the WDWAP is not an "estimated sustainable yield" within the meaning of sections 22B(5)(a) and 71B(3)(d) of the Water Act because it results in depletion of the aquifer underlying the Central Plain Management Zone and unacceptable impacts on the environment.

10. In 2018, the Minister declared the WDWAP. Under the WDWAP, the estimated sustainable yield for the Central Plains Management Zone for the Western Davenport

Water Control District (**Western Davenport District**) was modelled at 112,720 ML/year (or 112 GL/year) with the consumptive pool being 87,720 ML/year (or 87 GL/year)[9].

11. Estimated sustainable yield was considered "*to be equal to the sum of modelled evapotranspiration, plus 100% allocation of modelled recharge using the longest available rainfall record, plus the staged depletion of water stored in the regolith above 15 metres below ground level over 100 years"*[10]. Under this scenario, modelling of aquifer storage in the Central Plains Management Zone predicts a reduction in the volume of aquifer storage of 3.9% in 100 years (i.e. an average aquifer drawdown of 18.9 m assuming available aquifer storativity of 0.04) based upon full abstraction of the consumptive pool[11].

12. Section 22B(5)(a) of the Water Act provides that "*a water allocation plan is to ensure in the water control district that (a) water is allocated within the estimated sustainable yield to beneficial uses*[12]*"*. In making her decision, the Water Controller relied on the estimated sustainable yield stated in the WDWAP to assess the availability of water in the Western Davenport District for use by Fortune Agribusiness for Singleton Station.

13. The term "*estimated sustainable yield*" is not defined in the Water Act. A definition of "*estimated sustainable yield*" is used in *Arnold v Minister Administering the Water Management Act 2000* [2014] NSWCA 386, the New South Wales Court of Appeal said (at [4]):

> "*in this context and relevant to the issues in the appeal, the estimated sustainable yield of a groundwater system is determined by reference to the long-term average annual recharge of the system. The latter is capable of determination by groundwater numerical modelling using known or assumed physical parameters.* ***The sustainable yield is then that proportion of the long-term annual recharge of the system which may be extracted without causing unacceptable impacts on the environment or other groundwater users****. Unlike the determination of the relevant recharge of the system, the assessment of the sustainable yield involves matters of policy. Depending on the environmental circumstances, the sustainable yield may be 100% of the recharge or a lesser percentage."*

14. "*Sustainable yield"* is defined in the *Oxford Dictionary of Environment and Conservation* (3rd edition) (emphasis added):

> *"The rate at which a renewable resource may be used in a sustainable way. Traditional ways of harvesting natural renewable resources, such as fish from the oceans, wood from the forests, and plants and products from natural ecosystems, have usually been sustainable,* ***so long as the quantities extracted were not greater than natural processes were able to replace****."*

15. A similar definition appears in *Merriam-Webster* dictionary:

> *"Production of a biological resource (such as timber or fish) under management procedures which ensure replacement of the part harvested by regrowth or reproduction before another harvest occurs."*

[9] Table 2 in Section 1.1.2 of WDWAP, page 9.
[10] Section 6.2 of WDWAP, page 33.
[11] Section 6.2 of WDWAP, page 33.
[12] Beneficial uses are defined in section 4(3) of the Water Act.

16. The key concept is a sustainable yield which is equal to or less than the long-term annual recharge of the system and so cannot result in depletion of the resource.

17. However, the *"estimated sustainable yield"* in the Water Controller Decision and the WDWAP contemplates and results in aquifer depletion[13].

18. The grant of the Singleton Water Licence, using the estimated sustainable yield stated in the WDWAP, results in:

    a) groundwater drawdown up to 50 metres after 30 years[14]; and

    b) where the baseline depth to groundwater (**DGW**) is less than 15 metres:

        (i) 26% of alluvial GDEs and 13% of sandplain GDEs on the Singleton Station may be impacted; and

        (ii) 25% of alluvial GDEs and 15% of sandplain GDEs on the Central Plains Management Zone may be impacted after 40 years[15].

    CLC considers that such impacts on GDEs would result in unacceptable impacts on environment. This is particularly the case given that the relative importance (biodiversity and/or cultural values) of the GDEs is not known, i.e. those GDEs impacted may be the most important in terms of biodiversity and cultural values.

19. The CLC submits that allocation of water which result in:

    a) the depletion of aquifers; and

    b) unacceptable impacts on the environment,

    is not within the definition of "*estimated sustainable yield"* as contemplated in the Water Act.

C. <u>GROUND 2 – UNCERTAINTY IN GROUNDWATER MODEL</u>

Ground 2: The Water Controller and the WDWAP fail to take into account the level and extent of uncertainty underlying the Groundwater Model and the conditions imposed by the Water Controller in the Singleton Water Licence cannot address such deficiency (because the level of uncertainty has not been quantified and insufficient investigation have been undertaken).

20. The WDWAP recognises key issues underlying the Groundwater Model. These issues include:

    a) the volumes presented in Table 3 (Management Zones – hydrogeological attributes) being largely theoretical based upon modelled thickness of the aquifers;[16]

    b) groundwater recharge being highly episodic[17] and recharge periods are rare and difficult to predict;[18] and

    c) water storage in regolith not being defined with the same precision as the modelled aquifer recharge.[19] In fact, the water storage in the regolith is not referred to in the

[13] Section 6.2 of WDWAP, page 33.
[14] Paragraph 66 of the Statement of Decision
[15] Paragraph 101 of the Statement of Decision.
[16] Section 4.3 of WDWAP, page 21.
[17] Section 4.3.1 of WDWAP, page 21.
[18] Section 4.4.2 of WDWAP, page 23.
[19] Section 7.4.6 of WDWAP, page 38.

report prepared by Anthony Knapton for the Department of Environment and Natural Resources in 2017 (**Knapton Report**). Section 7.4.6 of the WDWAP recommended that additional work be done to better define the regolith resource. Further work could result in the exclusion of this resource from the allocation for consumptive beneficial uses[20].

21. The Groundwater Model presented in WDWAP is simplistic and based on inadequate investigations and very little site-specific data. This is recognised in the WDWAP itself which states that "*The model is based upon the available data and has been calibrated to reflect the observed aquifer response. However, there are limitations to the available data, notably, the small number of bores, regolith resource is not included in the model and the aquifer and GDE response to pumping is largely inferred*"[21]. The key issues for the Groundwater Model are:

    a) **Lack of drilling and aquifer testing in the Singleton Station:** Most of the previous groundwater investigations have been undertaken in the central and eastern parts of the Central Plain Management Zone. Drilling in the area shows that the north and middle blocks of the proposed development in the Singleton Station are underlain by more than 160 metres of the Hooker Creek Formation which is a likely low yielding aquifer (as it is silt and mudstone dominated)[22].

       The Hanson River beds and Hooker Creek formation in the Wiso Basin (composed of silts and mudstones and with poor aquifer potential) have been classified as Hydrostratigraphic Unit 3 (HSU3) in the Knapton Report. This erroneously equates them with the more prospective carbonate and sandstone aquifers identified in the Georgina Basin which is to the east of the Singleton Station. This could introduce significant errors in terms of yields and water in storage and result in an underestimation of drawdown and pumping impact predictions.

       This is a key example of why extrapolating groundwater investigation results from the other parts of the Central Plains Management Zone to the Singleton Station could be incorrectly interpreted which result in incorrect predictions. The assumption that Wiso basin sediments have the same aquifer characteristics as Georgina Basin sediments is simplistic and not consistent with known lithological differences between the two basins as described in the Fourth Annual and Final Surrender Report for EL 28211, EL 28213 and EL 28214.

    b) **Storage estimates based on modelling:** Storage estimates are based on modelling alone (with no direct measurements of the aquifer's properties and ability to produce water at the Singleton Station). If these estimates are too high then storage will be reduced substantially and impacts will be greater than predicted.

    c) **Regolith aquifer based on little or no data:** The regolith, which accounts for 30.7 GL/year of the total of 112.7 GL/year[23] of estimated sustainable yield, is based on little to no data as this has not been investigated directly. There is no justification for incorporating this in the available water resources for allocation.

22. Water allocation planning and the development of the Groundwater Model for the Western Davenport District has been hindered (in terms of rigour) by a lack of spatially

[20] Section 7.4.6 of the WDWAP, page 38.
[21] Section 9.1 of WDWAP, page 55.
[22] See the Fourth and Final Surrender Project for Davenport Project (EL 28211, EL 28213 and EL 28214 held by Areva Resources Australian Pty Ltd) dated 13 February 2015 and authored by Rachael Wilson
[23] Table 5 (Natural Water balance (ML/year), section 4.4.2 of WDWAP, page 24.

distributed data on aquifer geometry, lithology, hydraulic properties (particularly storage properties), water levels and water quality. Water level data with any useful time series (in the context of long-term predictive modelling) is lacking in the development of the Groundwater Model, particularly in the regolith.

23. Aquifer testing data is sparse and is typically restricted to short duration and single borehole tests which cannot determine storage properties. Storage properties are a key control on the relationship between abstraction and groundwater level drawdown change which is the key focus of the modelling and allocation planning.

24. The Water Controller and the authors of the WDWAP have not attempted to quantify the level of uncertainty and how it affects basic assumptions of the WDWAP such as storage. If the level of uncertainty concerning storage and estimated sustainable yield is high, say 50%, then a decision to allocate 40,000 ML/yr from an estimated sustainable yield of 112,720 ML/year for the Central Plains Management Zone (but where 50% uncertainty would take that level significantly lower) is unreasonable. Under the 2011 plan, the estimated sustainable yield for the Central Plains Management Zone (taken as 80% of estimated annualised recharge) was 27,224 ML/year[24]. There has been insufficient work undertaken to warrant the substantial increase in the estimated sustainable yield of 85,496 ML/year, from 27,224 ML/year to 112,720 ML/year

25. There is substantial work still required to be done under the WDWAP. The WDWAP sets out the work required to be done to address the uncertainties in the Groundwater Model (see section 7.4.5 of the WDWAP) and the regolith (see section 7.4.6 of the WDWAP). Additional work is set out in section 8.4.1 (Framework setting out WDAP implementation activities)[25] and section 9.1 (Table of risk management treatments)).[26]

26. CLC has previously submitted, in its submission in response to the Notice of Intention for the Singleton Water Licence, that the Water Controller should not consider any application for a groundwater licence in the Western Davenport District until such work has been completed. In the Statement of Decision, the Water Controller fails to address CLC's concerns and fails to identify the work in the WDWAP completed (if any) to refine and enhance the Groundwater Model.

27. The Water Controller claims that uncertainty in the Groundwater Model can be addressed by imposing the following conditions in the Singleton Water Licence:

    a) field validation and mapping of the type and extent of GDEs on the Singleton Station;

    b) development of a monitoring plan to detect potential impacts of groundwater extraction; and

    c) an adaptive management plan to respond to triggers of potential impact on groundwater levels, quality and GDEs.[27]

28. We submit that the conditions in the Singleton Water Licence are vague and deficient in addressing the uncertainty in the Groundwater Model. They key problem is that until the level and extent of uncertainty is known and the area better understood in a hydrogeological, biodiversity and cultural context, the effectiveness of these conditions is speculative. The conditions in the Singleton Water Licence require the preparation of

[24] Section 7 of the 2011 Western Davenport Water Allocation Plan, page 20.
[25] Section 8.4.1 of WDWAP, page 49.
[26] Section 9.1 of WDWAP, page 55.
[27] Paragraph 53 of the Statement of Decision.

a map and spatial data of groundwater dependent ecosystems[28] and development of a monitoring program[29]. However, such conditions do not specify what data is required to be collected, in which location and what frequency, to improve confidence in the Groundwater Model.

29. An adaptive management framework is an ineffective framework when there is insufficient understanding of the risks that a water licence poses and insufficient understanding of the uncertainty in the modelling. To be effective, an adaptive management framework needs a strong understanding of the water resource, biodiversity and cultural values of the GDEs and potential environmental impacts on GDEs. This understanding does not currently exist for the Singleton Water Licence and it is unclear if investigations proposed as part of the Conditions Precedent in the Singleton Water Licence will provide an appropriate level of understanding. Baseline monitoring of GDEs (GDE condition verses local water levels and quality) should be required for 5 to 10 years to understand the environmental and cultural linkages with GDEs in sufficient detail to develop strong management criteria and separate drawdown impacts from natural variability.

30. Given the acknowledged uncertainty underlying the Groundwater Model, the grant of a water licence which comprises nearly 50% of the estimated sustainable yield of the Central Plains Management Zone which was allocated for consumptive uses, renders this a high risk decision by the Water Controller.

31. The Water Controller has a duty under section 34 of the Water Act to ensure as far as possible that a continuous program for the assessment of water resources of the Territory is carried out, including the investigation, collection, collation and analysis of data concerning the occurrence, volume, flow, characteristics, quality, flood potential and use of water resources. The WDWAP identified further work to be done and much of it should have been done by now. If it has not been done, the Water Controller has failed to carry out her duty in section 34 of the Water Act. If it has been done, it should have been disclosed in advance of any decision being made and the failure to do so is a denial of procedural fairness.

D. GROUND 3 – LACK OF PROTECTION OF CULTURAL VALUES IN WESTERN DAVENPORT DISTRICT

Ground 3: The Water Controller Decision fails to take into account the impact that the Singleton Water Licence will have on Aboriginal cultural values.

32. One of the objectives of the WDWAP is to protect Aboriginal cultural values associated with water[30].

33. Water is fundamentally important to traditional Aboriginal owners and native title holders of the Western Davenport District and Aboriginal people who live in the Western Davenport District. Aboriginal people have a strong connection to country and a dynamic relationship with water which includes social, cultural and environmental components.

34. All water sources such as soakages, waterholes, rock holes, springs and rivers play a major role in the social, cultural, spiritual and customary values of traditional Aboriginal owners and native title holders of the Western Davenport District. The significance of water is not limited to surface water and GDEs as it is found throughout the country and

[28] Condition CP5 in Singleton Water Licence
[29] Condition CP8 in Singleton Water Licence
[30] Section 1 of WDWAP, page 6.

in all living things.[31] Water availability also affects many activities like hunting and harvesting for bush tucker, bush medicine, tool and craft making.[32]

35. Section 8.2.2 of the WDWAP states that:

> *"Groundwater modelling (based on the cumulative consideration of all approved extraction) should be undertaken to determine if proposed groundwater extraction will unacceptably impact on groundwater dependent Aboriginal cultural values. The proposed extraction should not result in a change to groundwater conditions that would result in the loss or decline of cultural values, as demonstrated through modelling."*

36. Section 8.4.1 specifies work required to be completed to ensure the protection of Aboriginal cultural values in the Western Davenport District. This includes mapping and documenting water dependent cultural values[33].

37. The Water Controller is required to consider whether Fortune Agribusiness has demonstrated a commitment to protect cultural values from the impacts of groundwater extraction applications[34].

38. In her statement of decision, the Water Controller did not address:

    a) how the Singleton Water Licence would not result in a change of groundwater conditions that would result in the loss or decline of cultural values in the Western Davenport District; and

    b) the commitments (if any) given by Fortune Agribusiness to protect cultural values in the Western Davenport District.

39. The Water Controller again claims that the conditions that she imposed[35] would suffice to address "*the full extent of cultural values and practices and their water requirements and responses to increased extraction[36]."*

40. Fortune Agribusiness is required to "*produce a map (and spatial data), verified through suitable on-ground surveys of groundwater dependent ecosystems in each landform on Singleton Station in the Aeolian sandplain and alluvial plain areas shown in Figure 7.2 provided in Attachment A."[37]* However, the Water Controller does not require Fortune Agribusiness to consider the cultural values of GDEs in preparing such a map and ensuring that measures are in place to protect such cultural values.

41. The drawdown area for the Singleton Water Station extends well beyond the Singleton Station[38] and the Fortune Report also recognises that the Singleton Water Licence may impact on GDES in the Central Plain Management Zone[39]. Yet, the Water Controller does not require Fortune Agribusiness to produce a map of the GDEs of the drawdown area and assess the cultural values of the GDEs in the drawdown area. This must be required of Fortune Agribusiness, *before* any licence is granted.

42. CLC has not been provided a copy of the authority certificate which Fortune Agribusiness obtained from Aboriginal Areas Protection Authority. However, as

[31] Section 5.2.2 of WDWAP, page 28.
[32] Section 5.2.2 of WDWAP, page 28.
[33] Section 8.4.1 of WDWAP, page 50.
[34] Section 8.2.2 of WDWAP, page 43.
[35] See paragraph 53 of the Statement of Decision
[36] Paragraph 51 of the Statement of Decision
[37] CP5(a) of the Singleton Water Licence
[38] See pages 23 to 31 of the Summary Report
[39] Paragraph 101 of the Statement of Decision.

indicated in the Summary Report for the Singleton Horticulture Project prepared by Fortune Agribusiness dated August 2020 (**Summary Report**), the subject land in the authority certificate does not cover the drawdown area of the Singleton Water Licence[40]. It does not even cover the drawdown area of the Singleton Water Licence which is in Singleton Station. Given the limited subject land of the authority certificate, the authority certificate will be unable to protect cultural values as required under the WDWAP and there could be a substantial risk of damage to sacred sites in the drawdown area which is within the vicinity of the subject land.

E. GROUND 4 – GUIDELINE INCONSISTENT WITH THE WDWAP

Ground 4: The Guideline is inconsistent with the objectives of the WDWAP and the Water Controller should not have relied on the Guideline.

43. In making her decision, the Water Controller considered and relied on the Guideline[41]. The Guideline was not subject to public consultation including consultation with the Western Davenport Water Advisory Committee.

44. The Guideline specifies that 70% of the current extent of the GDEs in the Western Davenport District should be protected from negative impact[42] (**70% Threshold**). This means that 30% of the current extent of GDEs ***do not need to be protected from negative impact***.

45. One of the objectives of the WDWAP is to meet the environmental water requirements (**EWRs**) of water dependent ecosystems and detrimental impacts to water dependent ecosystems as a consequence of consumptive water use will be avoided as far as possible. [43]

46. Section 22B(4) of the Water Act provides that "*water resource management in a water control district is to be in accordance with the water allocation plan declared in respect of the district".*

47. The Guideline, which allows a potential 30% negative impact on GDEs, is inconsistent with the objective of the WDWAP to avoid detrimental impacts on water dependent ecosystems as far as possible. Given such inconsistency and the requirement under section 22B(4) of the Water Act that water resource management is in accordance with the declared water allocation plan, the Water Controller should not have relied on the Guideline in making the Water Controller Decision. Although the Water Controller claims that she is able to rely on the Guideline as it "*constitutes new scientific knowledge"*[44] (and this is disputed by CLC in Ground 5 below), the Water Controller fails to explain how her decision that foresees a potential 30% negative impact on GDEs meets the objective of the WDWAP to avoid detrimental impact to water dependent ecosystems *as far as possible*.

F. GROUND 5 - THRESHOLDS IN GUIDELINE ARBITRARY

Ground 5: The thresholds in the Guideline are arbitrary and the Water Controller fails to address the arbitrary nature of these thresholds in in the way that she made the Water Controller Decision.

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[40] See pages 23 to 26 and 28 to 31 of the Summary Report
[41] Paragraphs 46 and 95 of the Statement of Decision
[42] Page 8 of the Guideline
[43] Section 3 of the WDWAP, page 16
[44] Paragraphs 46 and 95 of the Statement of Decision

48. The Guideline recognises that there is limited scientific evidence to confidently set this threshold for Australian Arid zones specifically[45] and fails to specify the basis for the 70% Threshold. Without providing any basis, the authors of the Guideline, which was approved by the Chief Executive Officer of the Department of Environment and Natural Resources, who is also the Water Controller, has arbitrarily set this threshold without any reasonable grounds.

49. Furthermore, until more work is done to rank the biodiversity and cultural values of the various GDEs in the Western Davenport District, and particularly GDEs impacted by the Singleton Water Licence, there is a possibility that amongst the 30% of GDEs which are impacted, there are important cultural sites or sites of high biodiversity value. The Guideline also provides that "*additional consideration may need to be given to minimising the impact of groundwater extraction on sites or areas specifically identified as having important cultural values."*[46]

50. The Water Controller has failed to address the lack of scientific basis underlying the 70% Threshold and has mechanically applied the 70% Threshold. By mechanically applying the 70% Threshold without undertaking the necessary work to rank the biodiversity and cultural values of various GDEs, the Water Controller has failed properly to consider if the Singleton Water Licence will minimise the impact of that licence on sites with important cultural and biodiversity values.

G. GROUND 6 – NO CONSIDERATION OF AQUATIC GDES

Ground 6: The authors of the WDWAP fail to assess the risks to aquatic GDEs in the Western Davenport District. The risks to the aquatic GDEs have not been considered in the Guideline, the Fortune Report and the Water Controller Decision.

51. There is a major gap in the allocation planning and impact assessment in the WDWAP as aquatic GDEs have not been included.

52. According to the attached maps in Annexure A, which are extracted from the Bureau of Metrology GDE atlas, there are numerous sites with potential to contain aquatic GDEs. Given the proximity of these sites to Singleton Station, there is a possibility of the sites being impacted by the Singleton Water Licence.

53. Aquatic GDEs, particularly wetlands, springs and soakages, are typically those with the greatest sensitivity to drawdown. These are often the sites of greatest biodiversity and highest cultural value. The Fortune Report, which is a report considered by the Water Controller[47], fails to assess the impact of Singleton Water Licence on aquatic GDEs. The Guideline fails to contain any criteria for aquatic GDEs. The Water Controller also fails to consider the impact of the Singleton Water Licence on aquatic GDEs in the Western Davenport District in making the Water Controller Decision.

54. Aquatic GDEs are much more sensitive to drawdown than terrestrial vegetation GDEs, and the drawdown criteria proposed for the GDEs do not incorporate the more stringent drawdown criteria appropriate for aquatic GDEs. In some cases, any change in groundwater levels can "detach" the water table from these aquatic GDEs which will have serious impacts to aquatic fauna in particular. This could cause species to become locally or even regionally extinct. Rare and endangered species may be utilising these systems for resources and/or habitat but this has not been assessed.

[45] Page 8 of the Guideline
[46] Page 9 of the Guideline
[47] Paragraph 46 of the Statement of Decision.

H. GROUND 7 - LACK OF UNDERSTANDING OF REGION-SPECIFIC VEGETATION GDEs DRAWDOWN IMPACT CRITERIA

Ground 7: The WDWAP and Guideline demonstrate a lack of understanding of region-specific vegetation GDEs and the use of criteria are not consistent with those used in other jurisdictions in Australia.

55. The WDWAP and Guideline demonstrate a lack of understanding of region-specific vegetation GDEs and the use of criteria are not consistent with those used in other jurisdictions in Australia.

56. In the WDWAP and Guideline, all GDE areas with a DGW of 10 metres or less are considered together with the same drawdown magnitude and rate impact criteria. Areas with considerably shallower DGW than 10 metres, especially those areas with DGW of less than 5 metres, will be more highly groundwater dependant and will require more stringent rate impact criteria.

57. The WDWAP and the Guideline refer to a report by P.G Cook and D. Eamus titled "*The Potential for Groundwater use by Vegetation in the Australian arid zone"* (2018a). Cook and Eamus referred to a study done on banksias in Western Australia for a period over 20 years (**Banksia WA study)**. EWRs for terrestrial GDEs are presented based on the Banksia WA Study.

58. It is concerning that the Banksia WA study is referred to given that the Banksia WA study focussed on banksia woodlands on sandy soils (Gnangara Mound). The vegetation communities in the Western Davenport District do not contain these species and there are no similar soil types in Western Davenport District (with possibly the exception of the alluvial landform areas).

59. Given the limited application of the Banksia WA Study in determining the EWRs for the Western Davenport District, there are high levels of uncertainty about the criteria (namely rate and magnitude of drawdown criteria) and the impacts on the terrestrial vegetation GDEs in the WDWAP and the Guideline. EWRs specific to the vegetation community and soil type for the Western Davenport District need to be determined.

60. The banksia woodland criteria in the Banksia WA Study were developed based on 20 years of vegetation condition and groundwater level change information. This gives an indication of the research effort required to determine these criteria with any degree of rigor.

61. The Banksia WA study is seen as best practice with different drawdown rate and magnitude criteria for the following levels of DGW areas: 10 to 6 metres, 6 to 3 metres and less than 3 metres. The drawdown and rate of drawdown criteria become more stringent as the DGW decreases. There is no justification presented in the WDWAP and the Guideline for all GDEs with a depth to groundwater of 10 metres or less having the same drawdown impact criteria.

I. GROUND 8- SINGLETON WATER LICENCE SHOULD NOT BE LONGER THAN 10 YEARS.

Ground 8: The Water Controller should not have granted the Singleton Water Licence for a term more than 10 years given the uncertainty underlying the Groundwater Model and the potential impacts of granting the Singleton Water Licence.

62. Section 60(3) of the Water Act 1992 provides that a licence to take groundwater shall be granted for a period not exceeding 10 years. Section 60(4) provides:

> *"The Controller may, where in the opinion of the Minister there are special circumstances that justify so granting the licence, grant a licence for such period exceeding 10 years as is specified in the licence document."*

63. In her reasons, the Controller referred to the Minster of Environment having affirmed that in the Minister's opinion there are special circumstances for granting a licence in excess of 10 years[48].

64. The Guideline: Special circumstances for water extraction licence terms up to 30 years (**30 Years Guideline**) notes a case for special circumstances may exist where *"there is sound scientific knowledge of the water resource from which the licence takes water"*[49] and *"the impacts of extraction have been or can be assessed with a high degree of certainty."*[50] For the reasons given above under Grounds 2 to 7, particularly with the uncertainty underlying the Groundwater Model and the impact on cultural values in the Western Davenport District, these do not exist for the water extracted from the Western Davenport District.

J. GROUND 9- BIODIVERSITY SURVEYS UNDERTAKEN BY THE NORTHERN TERRITORY GOVERNMENT AND THREATENED SPECIES

Ground 9: The Water Controller fails to address the concerns raised by the CLC about the biodiversity surveys conducted by the Northern Territory Government which could have impacted on the assessment about the threatened species in the Western Davenport region.

65. In CLC's previous submission in response to the Notice of Intention for the Singleton Water Licence, the CLC requested that the Northern Territory Government undertake further biodiversity surveys as the Northern Territory Government conducted baseline flora and fauna survey work during a prolonged very dry period which meant that the results from such surveys were likely to be incomplete and unrepresentative. CLC also requested that the Northern Territory Government conduct surveys that included Warrabri, Mungkarta and Karlantijpa South Aboriginal Land Trusts in the Western Davenport District to establish a more thorough baseline with greater coverage.

66. Such concerns were not addressed by the Water Controller in her Statement of Decision and the Water Controller also did not set out the basis of the advice that she received that "*there are no known threatened species in the Western Davenport region that are dependent on GDEs.*[51]*"* The Water Controller's assertion of there being no threatened species should not rest on surveys conducted in the context described in paragraph 65.

67. This is significant as CLC considers that all GDEs known to support significant populations of threatened species (including both flora and fauna species) should be protected from negative impact.

K. GROUND 10 – CONDITION CP6 DOES NOT PROTECT FROM SALINITY IMPACTS.

48 Paragraph 120 of the Statement of Decision
49 Paragraph 5.2.1 of the 30 Years Guideline, page 6.
50 Paragraph 5.2.1 of the 30 Years Guideline, page 6.
51 Paragraph 105 of the Statement of Decision

Ground 10 - Condition CP6 in the Singleton Water Licence does not sufficiently address the elevated soil salinity risks recognised in the Statement of Decision.

68. The Water Controller notes that she has been advised that there is an elevated soil salinity risk associated with the Singleton Water Licence [52] and given that the salts are likely to flush beyond the root zone, there is uncertainty as to how this could impact the underlying groundwater resource[53].

69. CLC submits that the condition CP6 in the Singleton Water Licence does not adequately address such risks. The assessment and report to be provided to the Water Controller must include "*a discussion about the likelihood and extent of salinity impacts on the Land and Water Resource".* This is unnecessarily vague. A "discussion" does not suffice and that the Water Controller should require Fortune Agribusiness to conduct a detailed impact assessment if the study shows potential for elevated salt leaching from soils under irrigation. The assessment needs to consider irrigation return to the aquifer and potential for groundwater salinity increases and flushing during intense recharge events.

70. CLC also submits that such an assessment should be subject to independent peer review

L. DECISION SOUGHT FROM THE MINISTER

71. Based on the grounds set out above, the Water Controller should not have made the decision to grant the Singleton Water Licence.

72. CLC submits that the decision which should have been made by the Water Controller, in the first instance, is to ensure that the work set out in the WDWAP, including work to refine the Groundwater Model and to address the uncertainty in the Western Davenport District generally (see, for example, sections 7.4.5, 7.4.6 and 8.4.1) is completed before considering any application for a groundwater licence in the Western Davenport District, especially an application for a licence of such a significant volume comprising a substantial portion of the estimated sustainable yield. It is only once the work set out in the WDWAP and the additional work identified in paragraph 73 below are completed, that there will be certainty of sufficient understanding to manage the groundwater resource and environment in the Western Davenport District.

73. In addition to the work set out in the WDWAP, the following work should also be undertaken before any licence is granted to ensure that the objectives underlying the WDWAP are met:

    a) Ranking of relative importance of terrestrial vegetation GDEs based on biodiversity and cultural values. These studies need to cover:

        (i) flora and fauna surveys; and

        (ii) a relative biodiversity value ranking assessment.

        The assessment and the surveys need to be linked to cultural value studies. Groundwater monitoring is also required at these sites, particularly sites with the highest biodiversity value and/or cultural value.

    b) Assessment of the location, biodiversity and cultural value and EWRs of aquatic GDEs. As submitted in Ground 6 above, the risks to aquatic GDEs have not been

[52] Paragraph 81 of the Statement of Decision
[53] Paragraph 83 of the Statement of Decision

considered in the WDWAP, the Guideline, Fortune Report and the Water Controller Decision.

The sites identified in the maps in Annexure A should be selected at a minimum for biological, hydrological and hydrogeological investigation and other aquatic sites, particularly culturally significant aquatic sites, should also be included. Aquatic GDEs need to be surveyed for:

(i) aquatic flora and fauna; and

(ii) terrestrial flora and fauna;

These surveys need to be linked to cultural value studies. Once completed, a relative biodiversity and cultural value ranking assessment can be carried out and hydro-ecological linkages and degree of groundwater dependence determined. This will provide the requisite understanding of the ecological thresholds and EWRs required to manage these important sites.

c) Hydrogeological investigations of GDEs at a local scale need to be integrated with the regional groundwater and geophysics investigation and the monitoring regime covering water levels and quality. This will require additional drilling. Monitoring and investigation of hydrology, hydrogeology and biology must be done at the same sites, at the same frequency and timing to ensure consistent overlap of these datasets. To determine the degree of groundwater dependence and impact risk to aquatic GDEs will also require individual aquatic GDE water and solute balances to be derived from monitoring data.

d) The completion of work under paragraphs 73(a) and (c) will allow determination of appropriate vegetation community specific EWRs while work completed under paragraphs 73(b) and (c) will allow determination of appropriate aquatic GDE EWRs the latter of which will likely vary on site specific basis.

e) Development of an improved groundwater model to assess impact on new and robust EWRs. Only once this is completed can development of a long-term integrated monitoring plan, with periodic review of GDE condition and EWRs, be appropriately robust and precautionary.

74. As indicated in Ground 9 above, the CLC also requires the Northern Territory Government to undertake further biodiversity surveys as the Northern Territory Government conducted baseline flora and fauna survey work during a prolonged very dry period which meant that the results from such surveys were likely to be incomplete and unrepresentative.

75. Accordingly, the CLC submits that the Minister should substitute the Water Controller Decision with the decision set out in paragraphs 72, 73 and 74 above.

76. If the Minister appoints a review panel to advise her under section 30(3)(b) of the Water Act, it is important that someone with hydrogeological expertise is appointed on the review panel given the grounds raised in the submissions above are required to be considered by someone with such expertise.

77. CLC also submits that while the ministerial review process is underway under the Water Act, all other remaining approval process relating to the Singleton Horticultural Project (and as set out in the Singleton Horticulture Project approvals map which is available online) be halted to ensure that this ministerial review process is not undermined in an way. No works should be undertaken, including vegetation clearing, until the ministerial review process is completed.

ANNEXURE A - MAPS

Groundwater Dependent Ecosystems Atlas

Local WCD_rivers

Aquatic GDE

- Known GDE (regional study)
- High potential GDE (regional study)
- Moderate potential GDE (regional study)
- Low potential GDE (regional study)
- Unclassified potential GI (regional study)
- High potential GDE (national assessment)
- Moderate potential GDE (national assessment)
- Low potential GDE (national assessment)
- Unclassified potential GI (national assessment)

N

1:1,413,455

Kilometres 20 40 60

Data Source: Bureau of Meteorology, Geoscience Australia and State/Territory lead water agencies. Refer to metadata for further information: Click here

Australian Albers GDA94

Date: 24 February, 2021

Australian Government
Bureau of Meteorology

Groundwater Dependent Ecosystems Atlas

Local WCD_norivers

Aquatic GDE

- Known GDE (regional study)
- High potential GDE (regional study)
- Moderate potential GDE (regional study)
- Low potential GDE (regional study)
- Unclassified potential GI (regional study)
- High potential GDE (national assessment)
- Moderate potential GDE (national assessment)
- Low potential GDE (national assessment)
- Unclassified potential GI (national assessment)

N

1:1,413,455

Kilometres 20 40 60

Data Source: Bureau of Meteorology, Geoscience Australia and State/Territory lead water agencies. Refer to metadata for further information: Click here

Australian Albers GDA94

Date: 24 February, 2021

<u>ATTACHMENT C:</u>

WESTERN DAVENPORT GROUNDWATER MODEL – SENSITIVITY ANALYSIS AND INDICATIONS OF PREDICTIVE UNCERTAINTY

Prepared by Dr Ryan Vogwill of Hydro Geo Enviro Pty Ltd and
Dr Eduard De Sousa of Intera Geosciences

10 February 2023

WESTERN DAVENPORT GROUNDWATER MODEL - SENSITIVITY ANALYSIS AND INDICATIONS OF PREDICTIVE UNCERTAINTY

PREPARED FOR | Central Land Council - Northern Territory

PREPARED BY | Intera Geosciences and Hydro Geo Enviro Pty Ltd

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DATE | 10/02/2023

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Document Information

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Client distribution:		**Date:**

Contents

Executive Summary

As part of assessing the likely variability in the CloudGMS model predictions in the Western Davenport area CLC has requested INTERA Geosciences Pty Ltd to conduct a predictive spatial sensitivity analysis of the CloudGMS groundwater model. The methodology consisted of generating model (sensitivity) runs using a range of hydraulic parameters in order to demonstrate that the model could still be calibrated (i.e. recreate the available groundwater level data) under said range and the implications of this range of hydraulic parameters in terms of model predictions. Particularly in terms of those parameter combinations which result in greater drawdown. A total of 14 scenarios were constructed to test different parameter configurations. These scenarios are divided into groups aimed at demonstrating different predictive outcomes while maintaining a similar level of calibration.

Visual inspection of the simulated predictive hydrographs shows that the groundwater level differences between scenarios and base model is considerably larger than those obtained for the calibration period. This indicates that 1 – the ability of the calibration dataset to constrain model predictions is limited and 2 – as the calibration period experienced modest groundwater use compared to the predictive period, historical groundwater levels provide little information regarding aquifer response to the large increase in groundwater abstraction proposed at Singleton Station.

The targeted sensitivity analysis presented in this study demonstrate that the non-uniqueness of model parameters, with respect to calibration, will have large implications to predictive uncertainty. Non-uniqueness is the concept that many different possible sets of model inputs (hydraulic parameters for example) can produce nearly identical computed aquifer head distributions (hence near identical model calibration) for any given model (Middlemis, 2019). The fact that differences between groundwater levels produced by the predictive results in the sensitivity scenarios are significantly larger than differences in calibration results clearly show this. While this analysis demonstrates some of the uncertainty regarding drawdown predictions, it has by no means explored the entire uncertainty range as relatively subtle changes in hydraulic parameters were used in most scenarios as compared to a full sensitivity range. Uncertainty quantification techniques such as the ones mentioned in Section 1.1 are widely used in the modelling community, but require large computational efforts to do so and are difficult to undertake in this case due to the choice of modelling platform. The results of the sensitivity scenarios we have provided give some indication of uncertainty in the model's predictions but to actually give a range for each prediction would require a predictive uncertainty analysis that wasn't possible with the resources provided, due to the proponent's choice of model platform (MikeSHE). Predictive uncertainty analysis would have entailed probabilistically defining a plausible range of hydraulic parameters and running 100's to 1000's of model scenarios across this range to produce the uncertainty in drawdown predictions according to the model.

In the context of how our scenarios meet or breach GDE impact criteria, given that the landform class data was not made available to CLC across the model domain we were not able to explicitly assess the various model scenarios against these criteria. However, it is clear that the area breaching these criteria increases significantly under a number of the sensitivity scenarios. The calibration and predictive modelled drawdowns are typically near the most optimistic (least drawdown) range of predictions shown in this modelling exercise.

It must also be noted firstly that conceptual uncertainty, another source of uncertainty associated with incorrect assumptions about the various aquifers' distribution and hydraulic connectivity, is not addressed in this assessment. There is considerable conceptual uncertainty due to the lack of drilling and aquifer testing available at the point in time that the model was constructed and calibrated. Secondly although this is not an exhaustive set or range of scenarios, the results clearly indicate how uncertain the model is. Modelling commensurate with our outputs should have, at a minimum, been provided to decision makers based on the

Australian Groundwater Modelling Guidelines, though a full predictive uncertainty analysis is recommended. For a full description of types of uncertainty in groundwater modelling the reader is directed to Middlemis (2019).

Given the uncertainty around the model in terms of conceptual and numerical uncertainty it is recommended that the areas which breach GDE criteria under any of these scenarios are reassessed by the proponent or DEPWS and are included as having impact potential until the modelling is refined substantially and has undergone a full uncertainty quantification. This would include the need for baseline data to be obtained on groundwater levels and biodiversity at the GDEs prior to any drawdown impacts manifesting. Our work reinforces that the use of model produced baselines and depth to groundwater relationships (a critical control on which areas are currently assessed as having impact potential) at GDEs is not justified with such an uncertain model. Relying on their single model's outputs to define baselines and depth to groundwater relationships will make it much more difficult to ascertain the causes of impacts when they manifest in the future, especially if they are areas outside the base model's currently estimated area of impact. Essentially if asked was it reasonable for decision-makers to rely on a single model's outputs to define baselines and depth to groundwater relationships? We would say, in our opinions, this is fraught with risk and not reasonable based on our scientific opinion, experience and the Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

Models are limited by the data which has been used to construct them and in areas of no data we don't have any distinct measurements to compare the model's predictions to. Therefore, if some time in the future impacts at a particular site manifest (vegetation deaths etc) and we don't have baseline measured data at the site, it can often be difficult to determine the cause of an observed impact (i.e. is it pumping related drawdown, climate, landuse or a combination thereof).

As a final point we would suggest that this model in its current form is not the best-suited platform by which to make a licence decision nor is it suitable in terms of defining which biodiversity and cultural assets can be impacted. The single scenario used by the proponent and DEPWS may not identify a number of cultural and biodiversity sites which could may be impacted, hence need investigation and baseline data obtained to facilitate adaptive management. In terms of modelling platform, given the current lack of data many of the key strengths of MikeSHE (coupled unsaturated zone flow, saturated flow and overland flow) are not being utilised. MikeSHE is a difficult modelling platform to undertake predictive uncertainty analysis in, unlike MODFLOW 6 in which we can do this analysis routinely.

1.0 INTRODUCTION AND MODELLING CONTEXT

Hydrogeoenviro Pty Ltd. (HGE) was commissioned by the Central Land Council (CLC) of the Northern Territory to undertake the review of a MIKE-SHE (CloudGMS) Western Davenport Water Allocation Plan groundwater model. This model was presented as part of a water extraction licence application by Fortune Agribusiness Funds Management Pty Ltd (Fortune) for the purposes of the Singleton Horticultural Project. Part of that review (HydroGeoEnviro, 2021) suggested (at paragraphs 24, 86 and 90) exploring alternative model outputs resulting from model non-uniqueness and subsequent variability in model predictions. CLC has requested INTERA Geosciences Pty Ltd to conduct a predictive and spatial sensitivity analysis in relation to the uncertainty in predictions from the CloudGMS groundwater model.

We prepared this report without any written instructions from CLC and have carried out predictive spatial sensitivity analysis in the way we consider most appropriate and feasible, given the time and resources we had available, as described in this report.

Ryan Vogwill is a Principal Hydrogeologist and Director for HydroGeoEnviro PTY LTD. Ryan has more than 20 years of technical expertise encompass groundwater modelling, water resource planning and recovery of hydrologically impacted ecosystems, with a focus on applying research to sustainable groundwater management and environmental impact/risk assessment. He has undergraduate, first class honours and doctorate degrees in Applied Geology from Curtin University. He graduated from his PhD in 2003. Ryan is also a Member of the Australian Institute of Geoscientists (specialisation hydrogeology). His CV is presented in Appendix 5.

Eduardo de Sousa is a Principal Groundwater Modeller and Managing Director at INTERA Australia. He has nearly two decades of experience working in South America, Africa and Australasia delivering modelling solutions in hydrogeological systems of high complexity, including modelling of geothermal systems, reactive transport modelling, design of dewatering and depressurization systems, environmental impact assessments, ecohydrology and groundwater remediation. Dr. De Sousa's work has included the development of DHI's tool for MODFLOW6 to FEFLOW conversions, dewatering optimization workflows for consulting projects and software product, tools to emulate steam pressures in the unsaturated zones in geothermal sites, software infra structure to allow the use of PEST with FEFLOW models, and high-complexity three-dimensional (3D) models in mining environments for operations (dewatering and depressurisation), environmental purposes and dynamic coupling of pit-lake and groundwater models in mine closure projects. Eduardo graduated from his PhD at the University of Western Australia in 2021. His CV is also presented in Appendix 5.

The MikeSHE groundwater modelling files were obtained via secure FTP from DEPWS in November 2021. These files consist of the Western Davenport's model's specific files that comprise a functioning groundwater model that can be altered and/or run within the MikeSHE modelling software platform.

1.1 Objectives of the Sensitivity Analysis

Given that one of the concerns that led to the review of the model was related to uncertainty underlying its predictive estimates, the original scope of work investigated the possibility of implementing a full predictive uncertainty analysis approach using the groundwater model. This is calibration-constrained uncertainty analysis utilising methods such as the Null Space Monte Carlo (Doherty, 2015) or the Iterative Ensemble Smoother (White, 2018). These approaches would enable the uncertainty quantification of the predictions of interest. Simplistically, uncertainty quantification in a prediction allows us to understand if a model's predicted drawdown of 5m at a particular feature, is +/- 10 cm, 0.5 m, 10m etc.

Further exploration has identified that the use of these techniques for the model in question was not feasible within the project timeframe due to:

- Inability of MIKE-SHE to run in a parallelised environment, which is a pre-condition given the large number of model runs required during the uncertainty analysis; and
- Potentially long model run times typical of fully-integrated surface-water models.

The scope of work presented herein intends to therefore demonstrate the non-uniqueness of model parameters and the approximate consequence in terms of predictions, rather than full uncertainty quantification, utilising sensitivity analysis and "what-if" parameter scenarios.

2.0 METHODOLOGY AND SENSITIVITY SCENARIOS

The model developed for the Singleton Station (Fortune Agribusiness) water extraction licence consists of an integrated surface-groundwater model using the MIKE-SHE platform. This model is described in detail in CloudGMS (2018) and has been reviewed in HydroGeoEnviro (2021).

The methodology consisted of generating target sensitivity runs in order to demonstrate the parameter non-uniqueness and the implications in terms of predictive estimates. Small parameter changes were introduced in the original model setup (named base model in this report), aiming at obtaining different predictive estimates while preserving model calibration (i.e., the match between historical groundwater level records and corresponding model outputs). Parameters included in the sensitivity runs include:

- Horizontal hydraulic conductivity (Kh),
- Vertical hydraulic conductivity (Kv),
- Specific storage (Ss), and
- Specific yield (Sy).

Since recharge rates in the model were simulated rather than prescribed, direct sensitivity runs on recharge could not be undertaken. As an alternative the soil saturated conductivity (Ksat) parameter of the soil infiltration model was utilised as a proxy for recharge sensitivity.

Small changes in the parameters were introduced using multipliers on the original values in the base model. Most of these changes in parameters were less than 25% increases or decreases (Table 3) with the exception of scenarios 3, 4, 7 and 8 where changes of up to 75% have been made. With the exception of specific yield (Sy) being decreased by 75% (from 0.04 to 0.01 in Scenario 8) these hydraulic parameters are more or less equally plausible as compared to the base model at a regional scale.

We would note that in a full sensitivity analysis or predictive uncertainty analysis, hydraulic parameters would have typically been varied through a greater range than we have used. Generally, in a sensitivity analysis we would vary (from the calibrated values) hydraulic conductivity by up to an order of magnitude (10X increase and 10X decreases). As for storage parameters, these would be varied by +/-50% in the case of specific yield and by an order of magnitude for specific storage. We did not run scenarios across this full range as the range we used was sufficient to demonstrate the considerable variability in groundwater level and drawdown predictions.

There is not enough hydrogeological work done in the Western Davenport area such that ranges in these parameters can be defined precisely based on rock types/aquifers. Regardless, rock type does not precisely determine hydraulic parameters because there are other factors at play such as degree of fracturing, weathering, diagenesis among others. The lack of aquifer testing, drilling and other data means the conceptual uncertainty is too high for anyone to define a precise range of hydraulic parameters based on field data.

These hydraulic parameter multipliers were applied simultaneously over all the model parameter zones (for aquifer properties) and soil types (for the infiltration model). The base parameters for aquifer and recharge soil properties are summarised in Tables 1 and 2.

Table 1 – Base parameters for aquifer properties.

Zone ID	Description	Kh (m/s)	Kv (m/s)	Sy (-)	Ss (1/m)
1	Cenozoic	2.11E-05	5.44E-06	0.04	0.0001
2	Soil	1.00E-06	1.00E-06	0.04	0.0001
3	Dulcie	9.52E-06	9.52E-07	0.04	1.00E-05
4	Arrinthrunga	8.65E-06	8.65E-07	0.04	1.00E-05
5	Chabalowe	2.15E-05	2.15E-06	0.04	5.00E-06
6	Fractured rock	1.00E-06	1.00E-06	0.01	1.00E-06
7	Basement	5.00E-07	5.00E-07	0.01	1.00E-06

Table 2 – Base parameters for recharge soil properties.

Zone ID	Description	Ksat (m/s)
1	Loam	7.20E-07
2	Loam Sand	7.00E-07
3	Outcrop	1.00E-07
4	Alluvium	1.00E-07
5	Colluvium	1.50E-07
6	Hard Pan	1.00E-08
7	Calcrete	8.00E-07
8	Silt	1.00E-07
9	Floodout	6.00E-07

A total of 14 scenarios were constructed to test different parameter configurations. These scenarios are divided in four groups aiming at demonstrating different predictive outcomes while maintaining calibration, namely:

- Possibility of larger drawdown magnitudes by lowering hydraulic conductivity;
- Possibility of larger drawdown magnitude and extent by lowering hydraulic conductivity and storage;
- Possibility of larger drawdown footprint by increasing hydraulic conductivity; and
- Possibility of larger drawdown footprint by increasing aquifer diffusivity (ratio between hydraulic conductivities and storage parameters)

All the scenarios were simulated for the calibrated (1970-2020) and predictive (2020 to 2080) periods, with exception of Scenario 1 (which was only simulated for the calibrated period as the results were very similar to the base model in prediction due only a 10% decrease in the hydraulic conductivity values). Parameter multipliers, scenario descriptions and objectives are summarised in Table 3.

Table 3 – Summary of sensitivity runs.

Scenario	Description	Objective	Parameter multipliers				
			Kh	Kv	Sy	Ss	Ksat
1	Apply lower hydraulic conductivity and maintain K / Recharge ratio	Demonstrate possibility of larger drawdown magnitude	0.9	0.9	1	1	0.9
2			0.75	0.75	1	1	0.75
3			0.5	0.5	1	1	0.5
4			0.25	0.25	1	1	0.25
5	Apply lower hydraulic conductivity and maintain K, Recharge and Storage ratios	Demonstrate possibility of larger magnitude and faster drawdowns	0.9	0.9	0.9	0.9	0.9
6			0.75	0.75	0.75	0.75	0.75
7			0.5	0.5	0.5	0.5	0.5
8			0.25	0.25	0.25	0.25	0.25
9	Apply higher hydraulic conductivity and maintain K / Recharge ratio	Demonstrate possibility of larger drawdown footprint	1.1	1.1	1	1	1.1
10			1.25	1.25	1	1	1.25
11			1.1	1.1	1.1	1.1	1.1
12			1.25	1.25	1.25	1.25	1.25
13	Apply higher hydraulic conductivity, maintain K / Recharge ratio, and decrease storage	Demonstrate possibility of larger drawdown footprint by using larger diffusivity (K/S)	1.1	1.1	0.9	0.9	1.1
14			1.25	1.25	0.75	0.75	1.25

3.0 SENSITIVITY ANALYSIS RESULTS

3.1 Effects on Calibration

Since the original calibration dataset used in the base model was not available for this scope, calibration performance was undertaken through the comparison of results from the scenario runs and the base model in 43 locations (equating to the monitoring bores used in the calibration of the base model). Hydrographs of all sensitivity runs and the base model over the calibration period are presented in Appendix 1.

The analysis of these hydrographs suggests that:

- The difference and groundwater levels (or heads) between sensitivity runs and base model is small (usually less than 1 m) in most hydrographs, with exception of Scenario 4 which applied the lowest multiplier to the Kh, Kv and Ksat parameters;
- While the sensitivity runs show larger differences in head in some locations (e.g., Scenarios 4 and 8 in the borehole RN015585), they also show very small differences in others (e.g., borehole RN006440), likely related to heterogeneity within the different hydrogeological units;
- In hydrographs that show large head variations/fluctuations (like RN006440) from the sensitivity runs during the calibration period tend to be similar to those from the base model, possibly associated to proximity of boundary conditions and the subsequent lower parameter sensitivity (in terms of calibrated water levels) in these areas; and
- The fact that different parameter multipliers and settings from the sensitivity runs yield similar results to the base case demonstrate the non-uniqueness of the model.

3.2 Effects on Modelling Predictions

Modelling results are presented in three forms:

- Predictive hydrographs at the calibration locations for the period 2020 to 2080 (Appendix 2);
- Simulated drawdowns across the model domain for each of the scenarios, in terms of groundwater level difference between 2020 and 2080 (Appendix 3) and;

- Groundwater level differences between the scenarios and base model for year 2080 (Appendix 4).

Visual inspection of the simulated hydrographs shows that the groundwater level differences between scenarios and base model is considerably larger than those obtained for the calibration period. Some brief interpretation of the results (as compared to the results of the base case model) are given below for each scenario. The reader should compare these descriptions to the figures in Appendix 4:

- Scenario 1 (decreased hydraulic conductivity by 10%) produces drawdowns at the end of the model's predictive results (at year 2080) that are very similar to the base case so these results have not been presented;
- Scenario 2 (decreased hydraulic conductivity by 25%) shows drawdown increases of up to 4m near Singleton Station. Some groundwater level increases occur away from Singleton Station;
- Scenario 3 (decreased hydraulic conductivity by 50%) shows a drawdown increase of up to 11m near Singleton Station and a larger area of drawdown. Some groundwater level increases occur away from Singleton Station;
- Scenario 4 (decreased hydraulic conductivity by 75%) shows a drawdown increase of up to 30m near Singleton Station and a larger area of drawdown). Some groundwater level increases occur away from Singleton Station;
- Scenario 5 (all parameters decreased by 10%) shows a drawdown increase of 1m near Singleton Station and small changes elsewhere;
- Scenario 6 (all parameters decreased by 25%) shows a drawdown increase of up to 4m near Singleton Station. Some groundwater level increases occur away from Singleton Station;
- Scenario 7 (all parameters decreased by 50%) shows a drawdown increase of up to 14m near Singleton Station. Some groundwater level increases occur away from Singleton Station;
- Scenario 8 (all parameters decreased by 75%) shows a drawdown increase of up to 16m near Singleton Station. Very little difference elsewhere apart from on the model's western and southern boundaries where additional drawdown is predicted);
- Scenario 9 (all parameters increased by 10% except for storage) shows only minor change except at the model's north eastern and south western boundaries;
- Scenario 10 (all parameters increased by 25% except for storage) shows a drawdown reduction of 1m at Singleton Station but increased drawdown south of the Station of up to 4m. Groundwater level rises are predicted at the model's north eastern and south western boundaries;
- Scenario 11 (all parameters increased by 10%) shows little changes throughout;
- Scenario 12 (all parameters increased by 25%) shows a drawdown reduction of up to 2m at Singleton Station but increased drawdown of up to 4m is predicted south of the Station. Groundwater level rises are predicted at the model's north eastern and south western boundaries;
- Scenario 13 (hydraulic conductivity increased by 10% storage decreased by 10%) shows very little change at Singleton Station and surrounds. Most changes in drawdown are predicted near the model boundaries; and
- Scenario 14 (hydraulic conductivity increased by 25% and storage decreased by 25%) shows an increase in drawdown near Singleton Station of up to 2m but a greater drawdown of up to 4m occurs to the south of the station. Groundwater level rises are predicted at the model's north eastern and south western boundaries.

The predictive hydrographs in Appendix 2 should also be viewed noting that the black dashed line (the prediction of drawdown at the particular calibration bore for the base case model) are typically near the smallest predictions of drawdown from the multiple sensitivity model runs at that site. The additional drawdown predicted at some sites can be considerable (often 10+m of additional drawdown as compared to the base case). Some reduced drawdowns also occur under some of the scenarios but more often additional drawdown is predicted as would be expected based on our choice of scenarios. 8 sensitivity scenarios (1-8) are focussed on reduced (or constant) hydraulic parameters, 4 (9-12) on increased (or constant) parameters and 2 (13-14) on a mixture of increased and decreased hydraulic parameters.

Our interpretation of these results indicates:

1. the ability of the calibration dataset to constrain uncertainty in predictions is limited based on our experience with other models. This is demonstrated herein by large variations in drawdown predictions (while simultaneously having an only minor effects on model calibration) under the range of scenarios we have tested; and
2. as the calibration period experienced much smaller pumping regimes compared to the predictive period, historical groundwater and pumping levels used in the calibration provide little information regarding aquifer response to the large pumping regimes proposed at Singleton Station. Essentially until the drawdown response of the aquifer to a greater pumping regime is tested, measured and included in the modelling, through long term aquifer testing, the response of the aquifer to a large-scale increase in pumping is highly uncertain.

Sensitivity runs with larger hydraulic conductivity and diffusivity (i.e. Kh/Sy ratio) showed in general smaller drawdowns when compared to the base case. Although it was expected that the drawdown footprint would be larger, smaller drawdowns can be partly related to the fact that these scenarios show the largest drawdown over the calibration period, resulting in lower baseline levels in 2020 from which the predictive drawdowns are calculated. Furthermore, it is likely that the increased hydraulic conductivity added a "buffering capacity" for the aquifers due to their greater groundwater flowthrough facilitating the equilibration of groundwater levels as new hydraulic stresses (i.e., pumping) were introduced.

4.0 DISCUSSION AND RECOMMENDATIONS

The targeted sensitivity analysis presented in this study demonstrates that the non-uniqueness of parameters with respect to calibration have large implications to predictions, hence the model has a large amount of predictive uncertainty. The fact that differences between predictive results in the sensitivity scenarios are significantly larger than calibration results clearly show that.

While our analysis demonstrates the uncertainty regarding drawdown predictions, it has by no means explored the entire uncertainty range as relatively subtle changes in hydraulic parameters were used in most cases as compared to a full sensitivity range. Uncertainty quantification techniques, such as the ones mentioned in Section 1.1, are widely used in the modelling community, but require large computational efforts to do so. These approaches work best with a simpler and more efficient modelling approach.

The licensing constraints from the MIKE-SHE platform and the longer running times makes adoption of uncertainty quantification techniques very difficult. To that end, the use of simpler and more efficient approaches using open-source (without licence constraints) software would facilitate application of these techniques. For instance, MODFLOW 6 (Hughes et al., 2017) is a free, open-source and highly-efficient modelling platform, that would be better suited to assess the environmental, cultural and other groundwater user impacts associated with the drawdown. The trade-off with MIKE-SHE would be that recharge rates would have to be prescribed and calibrated as opposed to simulated. This is a small price given that soil parameters from MIKE-SHE soil infiltration model are also obtained through calibration, so differences between calibrating recharge directly would probably be small. There is also currently very little field data by which to parameterise and calibrate the MIKE-SHE soil infiltration model. Also given the surface water modelling capacity of MIKE-SHE wasn't particularly utilised MODFLOW is a better platform to have used in our opinion. Lastly, MODFLOW6 could be used in conjunction with other open-source software for recharge estimation, such as LUMPREM (Doherty, 2021) and SWB.

Therefore, should predictive uncertainty need to be quantified to further investigate the impacts from the groundwater abstraction, it is recommended that the current model be converted to MODFLOW 6, with or without use of additional software for recharge estimation.

The considerable amount of uncertainty in the CloudGMS model has flow on effects through the subsequent GDE impact analysis. The choice of point in time which is used for drawdown and depth to groundwater calculations (to apply to GDE criteria) is also a concern given the significant groundwater level fluctuations and uncertainty apparent in the model. The areas of significant groundwater level fluctuation (2-5m in most years in for example the hydrographs for RN006443 in appendices A and B) typically occur in areas with shallow groundwater (depth to groundwater 10m or less) and more frequent recharge due to leakage from surface water systems. These areas are more likely to contain GDEs but if the groundwater level fluctuates by as much as 5m in most years what is the appropriate baseline for calculating impact potential based on drawdown criteria? In this context the choice of the end of the calibration period is arbitrary and given the uncertainty around the model predicted groundwater levels explored herein, further consideration of this is required. For example, should the depth to groundwater be based on wet season groundwater levels, dry season groundwater levels, the highest groundwater level, the lowest groundwater level or some type of weighted average?

It is recommended that actual measured groundwater level data is used at all relevant GDEs (including cultural assets). Our work reinforces that the use of model produced groundwater level baselines at GDEs are highly uncertain which will make it much more difficult to ascertain the causes of impacts if they manifest.

The area of predicted impact which exceeds the groundwater dependent ecosystem (GDE) impact criteria as defined by DENR (2020) will vary considerably under this range of predictive sensitivity scenarios. These 3 groups of criteria are repeated here for reference:

Page 8 DENR (2020).

"In order that the principle of incorporating environmental variability is adequately applied, and in the absence of more comprehensive spatial data, the 70% threshold [i.e. 70% of GDEs must be protected] applies:

- within each of the two major landform classes (aeolian sandplain and alluvial plain)
- within each property occurring in the Water Control District."

Page 9 DENR (2020).

"For GDEs occurring where the depth of groundwater is less than or equal to 10 m, potential for negative impact occurs if modelled extraction shows that one or more of the following may occur:

- the maximum depth to water table exceeds 10 m below ground level
- the maximum depth to water table declines by more than 50% below the levels that would be expected under a natural baseline (no pumping) scenario
- modelled extraction results in a rate of groundwater drawdown that exceeds 0.2 m/year."

Page 9 DENR (2020).

"For GDEs occurring where the depth of groundwater is between 10 and 15 m, potential for negative impact occurs if modelled extraction shows that one or more of the following may occur:

- the maximum depth to water table declines by more than 35% below the levels that would be expected under a natural baseline (no pumping) scenario
- modelled extraction results in a rate of groundwater drawdown that exceeds 0.2 m/year."

Given that the landform class data was not made available to CLC we were not able to explicitly assess the various model scenarios against these criteria.

However, what is clear is that the area breaching these criteria increases under a number of the sensitivity scenarios. It does decrease in some scenarios but the calibration and predictive modelled drawdowns are typically near the most optimistic (least drawdown) range of predictions produced by our modelling exercise. As a comparison of the relative effect on drawdown of increasing the model's hydraulic parameters and decreasing parameters by an identical amount, we can compare the output of Scenario 2 (hydraulic conductivity decreased by 25% storage kept constant) and Scenario 10 (hydraulic conductivity increased by 25% storage kept constant). In Appendix 4 (the scenario drawdown difference maps relative to the base case) Scenario 2 predictions near Singleton Station indicate increases of up to 4 m over a large area while in Scenario 10 decreases of 1m occur over a smaller area than the area of increase in Scenario 2.

Given the uncertainty around the model in terms of both conceptual and numerical uncertainty it is recommended that the areas which breach GDE criteria under any of these scenarios (with the possible exception of Scenario 8) are included as having impact potential until the modelling is refined substantially at a minimum. Scenario 8 is considered unlikely as a specific yield of 0.01 (a 75% decrease from the base case's value of 0.04) is low. This would include the need for baseline measured (not modelled) data to be obtained on groundwater levels and biodiversity prior to impacts manifesting.

For reference of what should have been delivered as part of the licence application a number of the guiding principles from the Australian Groundwater Modelling Guidelines (Barnett et al., 2012) are repeated in this context.

- Guiding Principle 5.5: Sensitivity analysis should be performed to compare model outputs with different sets of reasonable parameter estimates, both during the period of calibration (the past) and during predictions (in the future).
- Guiding Principle 6.1: All model predictions are uncertain. The modelling process should acknowledge and address uncertainty through an appropriate uncertainty analysis (refer to Chapter 7).
- Guiding Principle 7.1: Because a single 'true' model cannot be constructed, modelling results presented to decision-makers should include estimates of uncertainty.
- Guiding Principle 7.6: Uncertainty should be presented to decision-makers with visual depictions that closely conform to the decision of interest.

The only uncertainty analysis presented in any reports provided to the CLC for drawdown predictions is on a pumping well which is not considered to relate to a "decision of interest". In this context the "decision of interest" is drawdown at GDEs, cultural sites and other groundwater users.

As a final point we would suggest that this model in its current form (MikeSHE) is not the best suited platform by which to make a licence decision nor is it suitable in terms of defining which biodiversity and cultural assets will be impacted and hence monitored. The use of a MODFLOW model would have made the application of predictive uncertainty analysis much easier as discussed in the executive summary and at the start of Section 4.

5.0 REFERENCES

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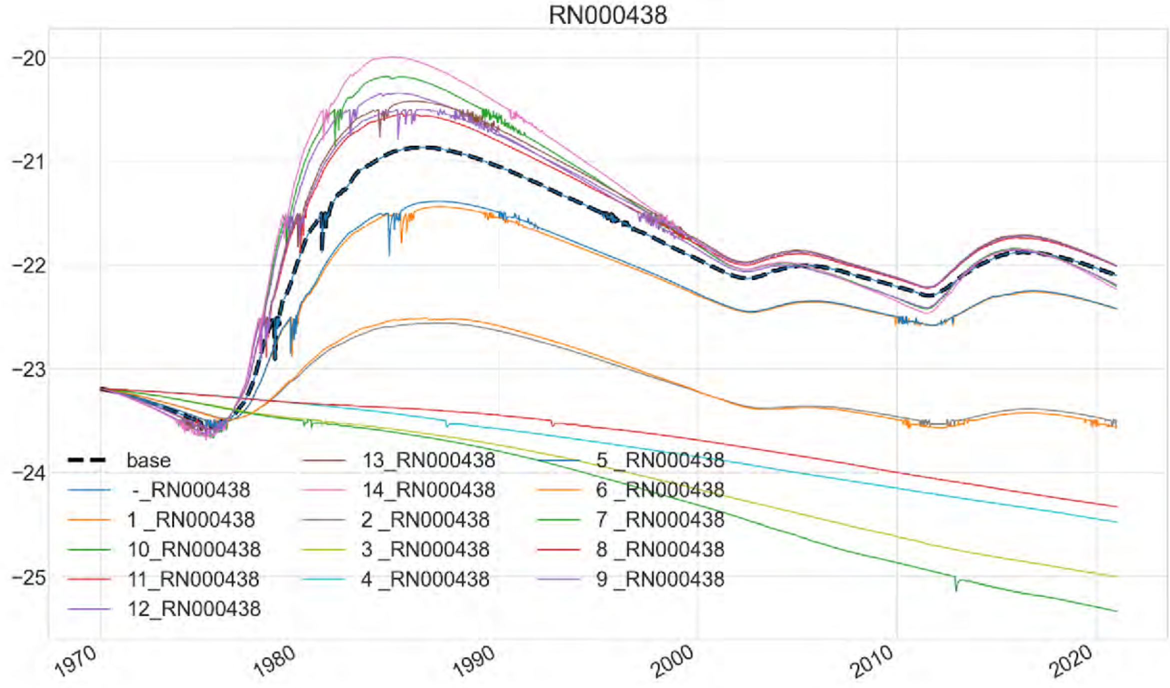
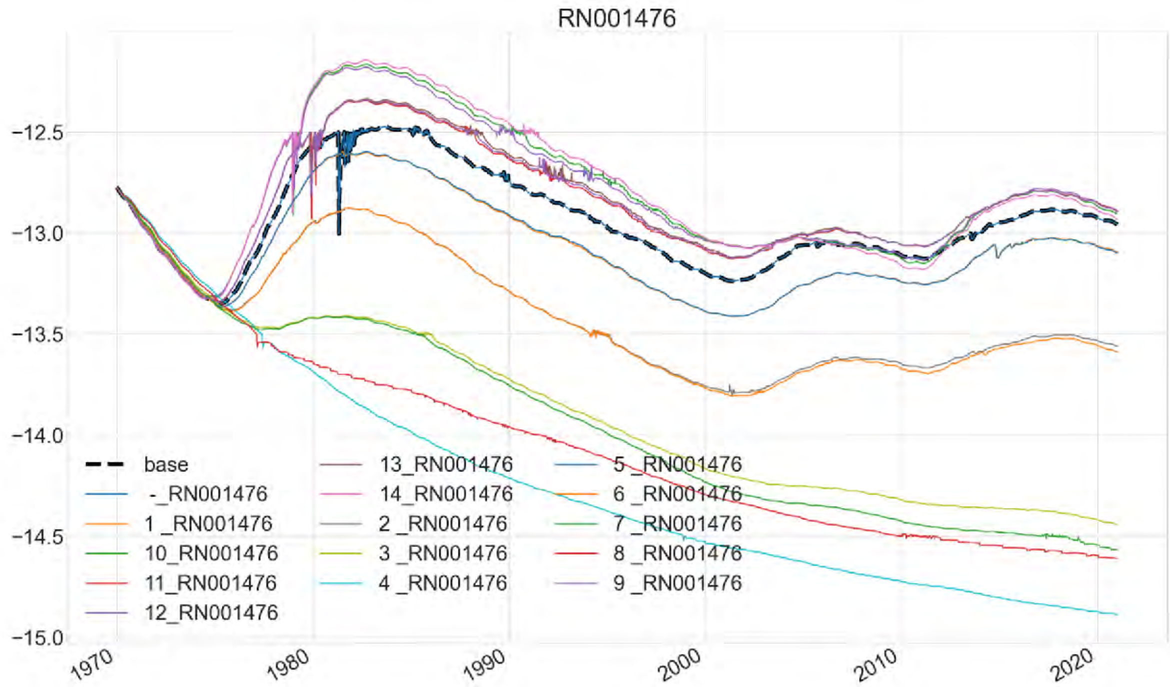
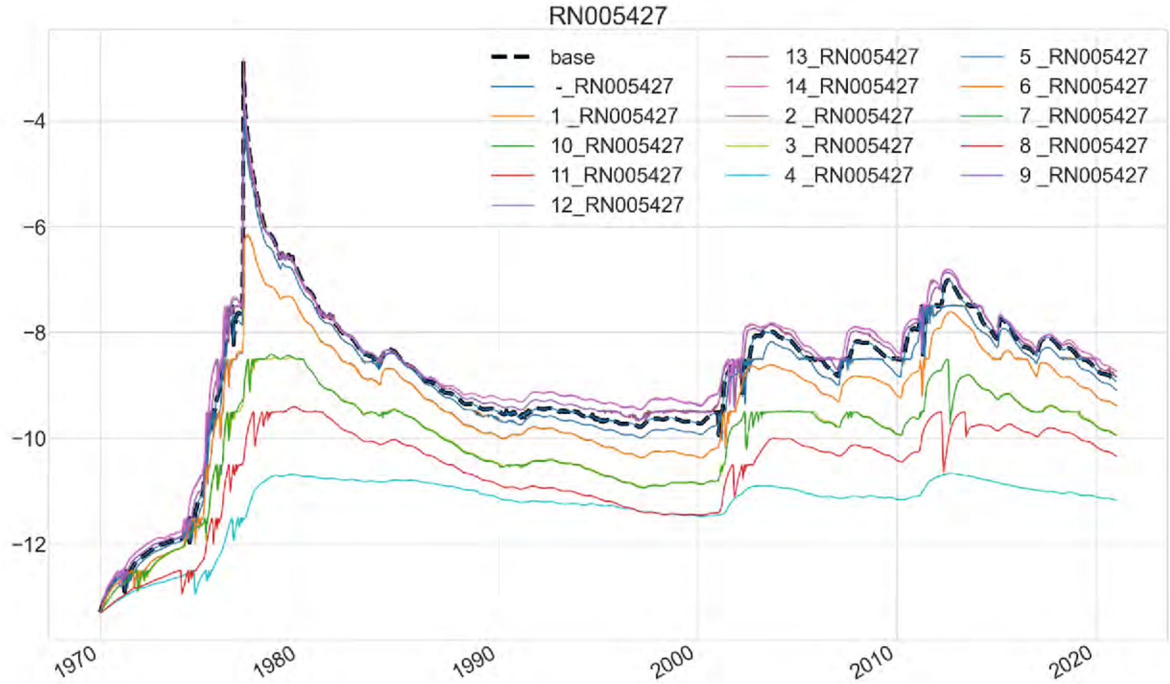
Appendix 1 - CALIBRATION HYDROGRAPHS



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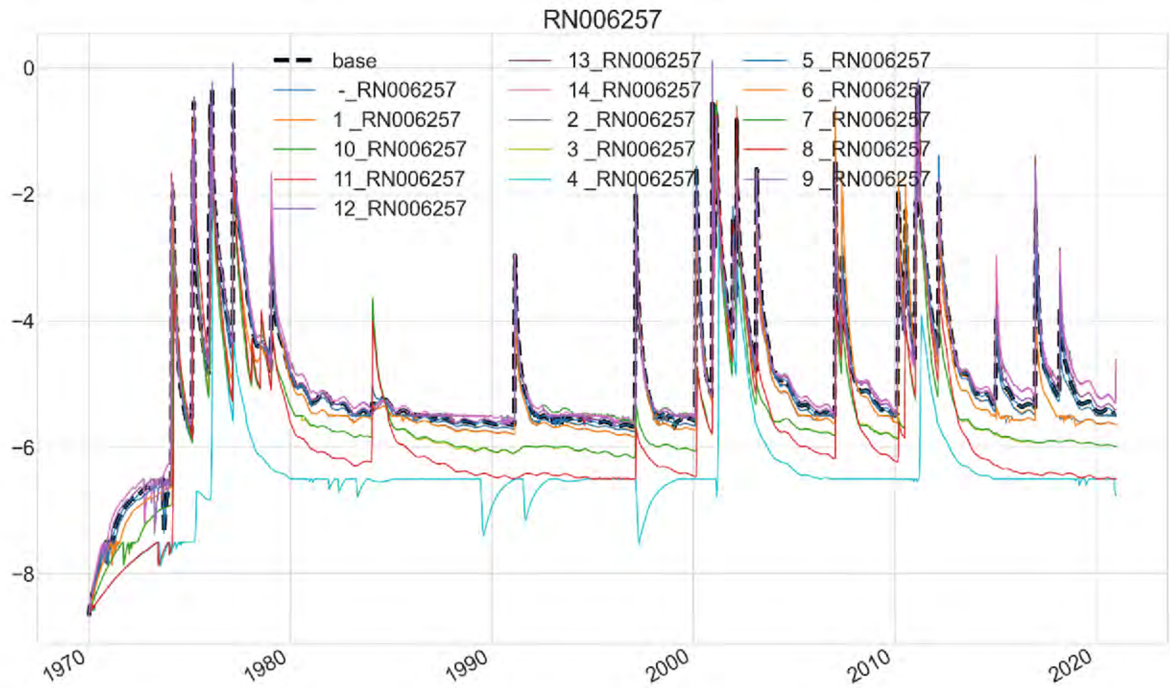
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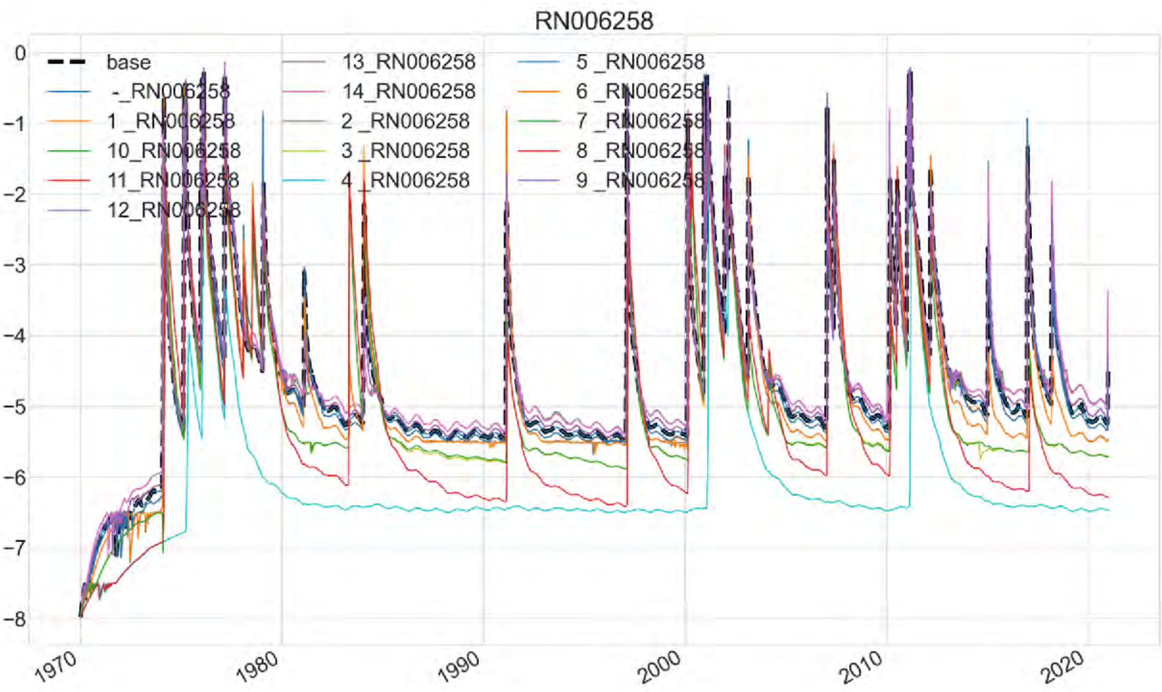
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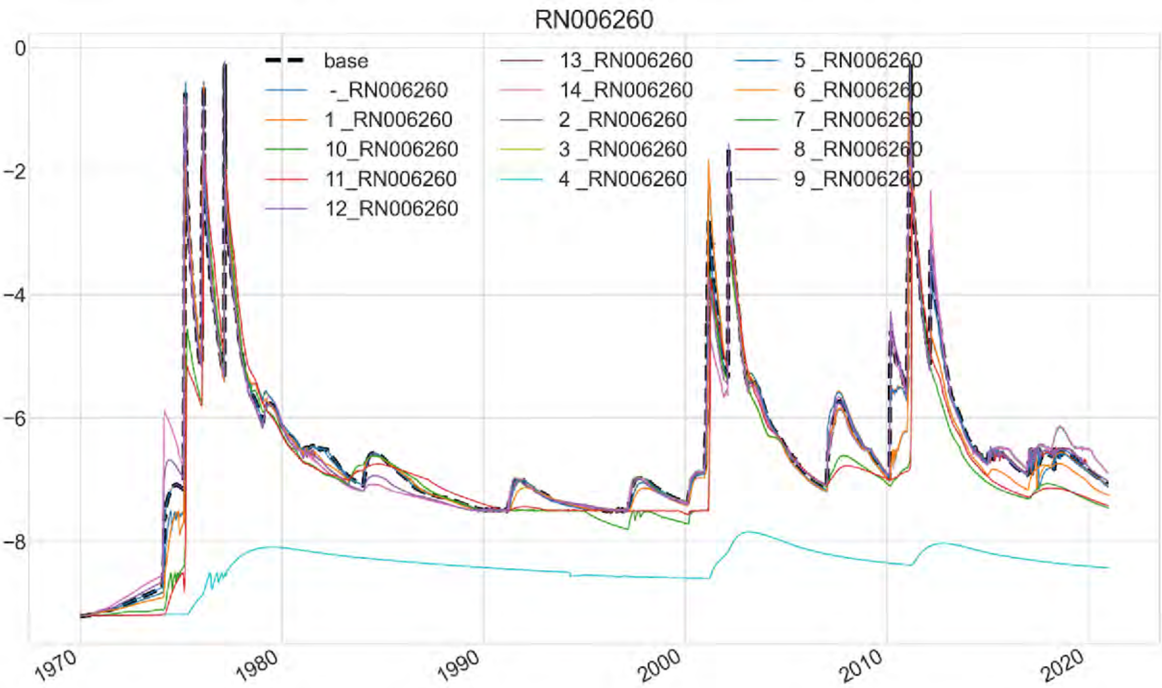
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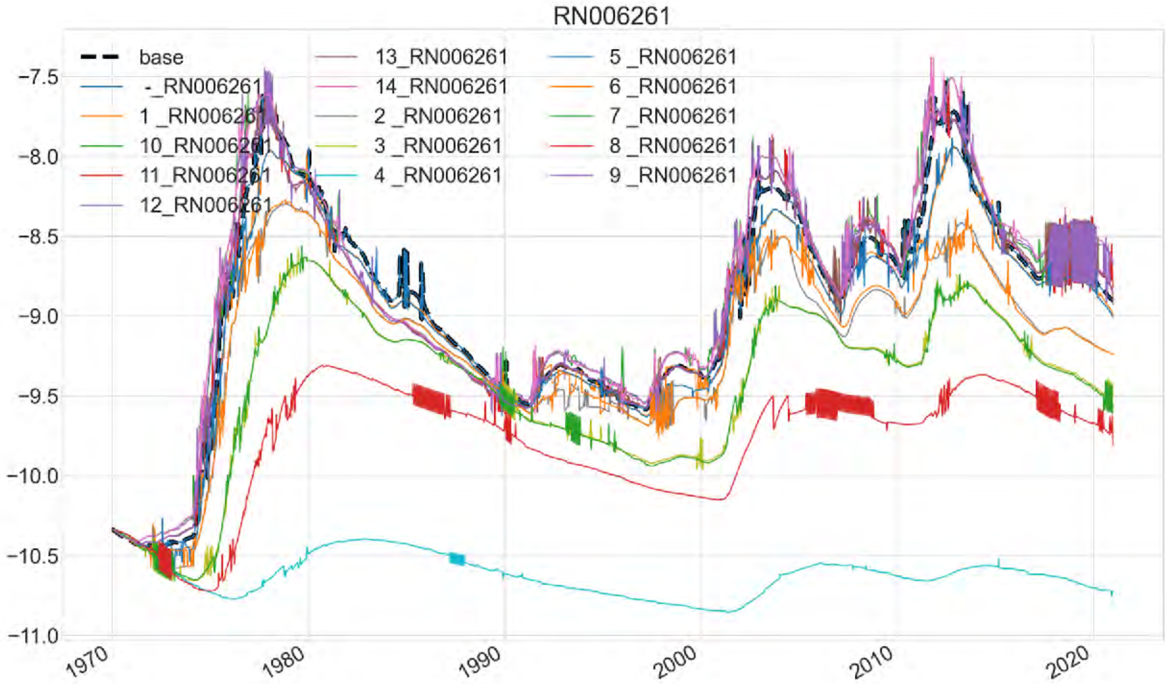
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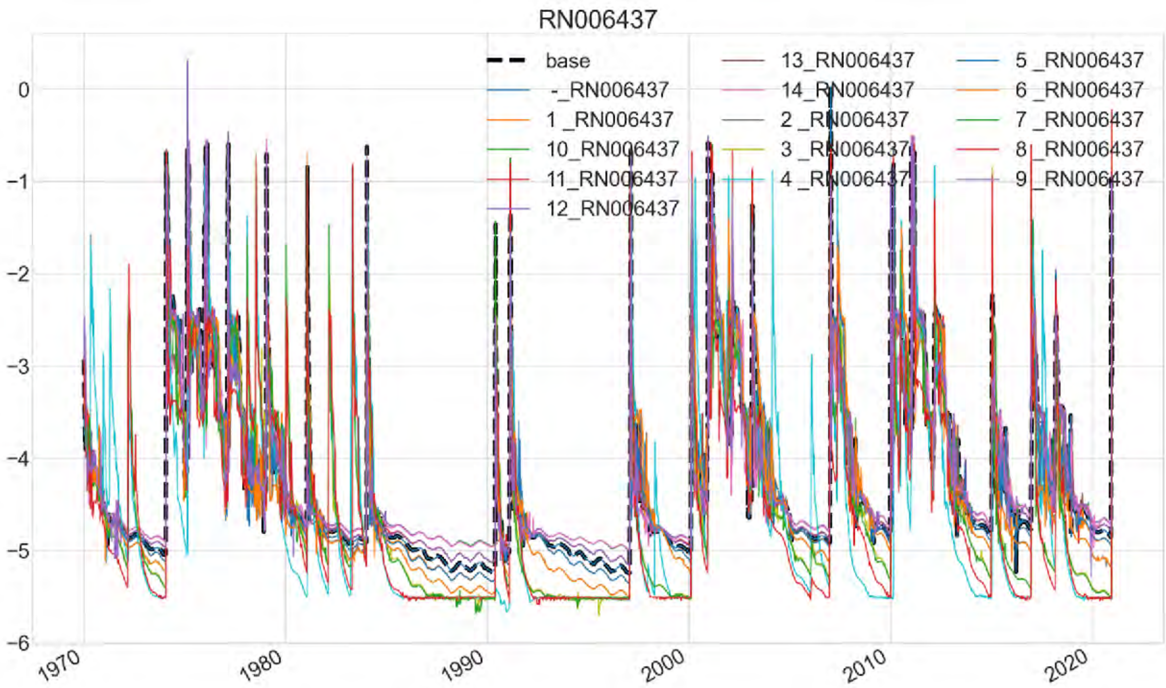
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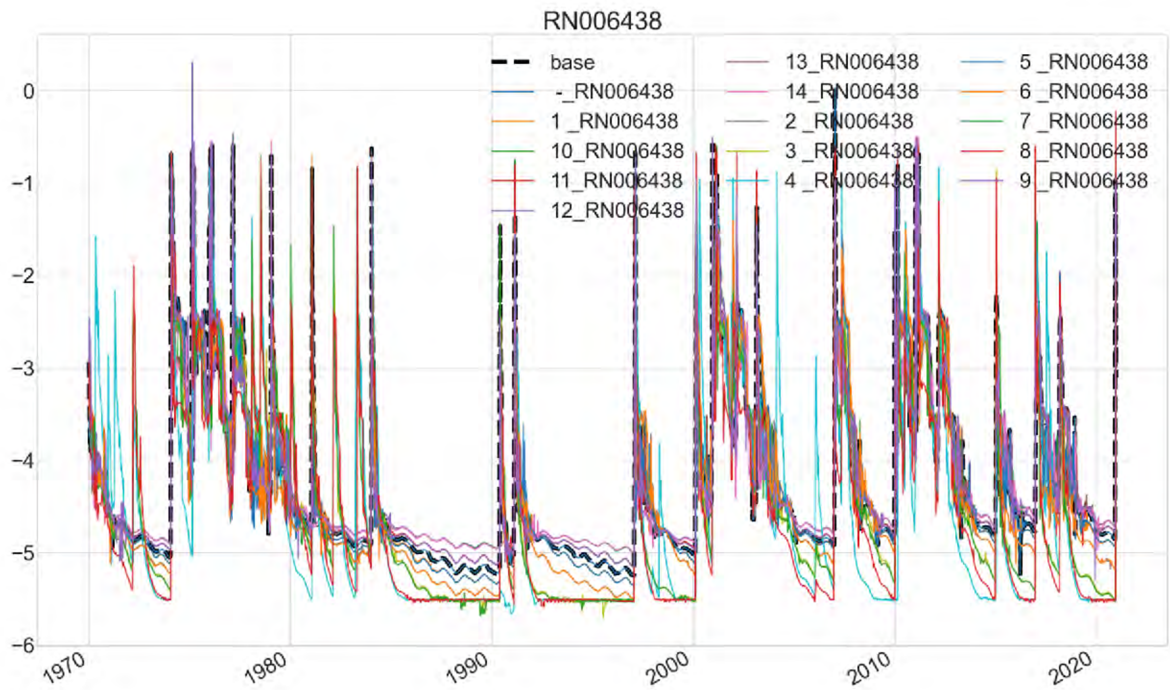
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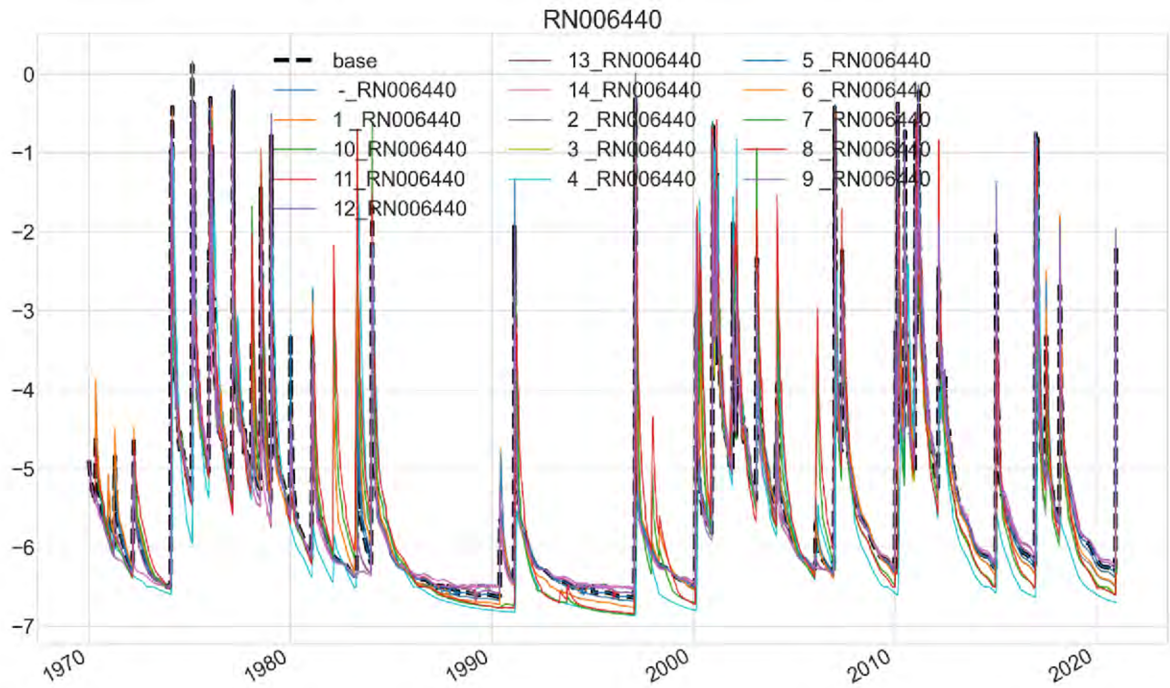
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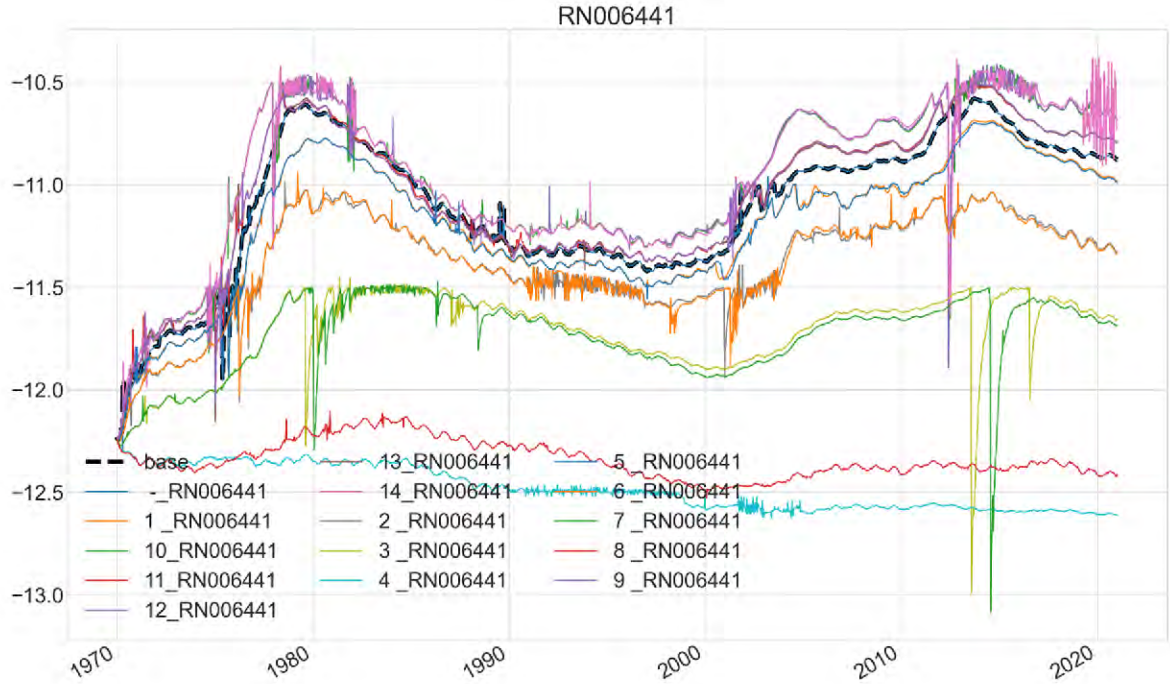
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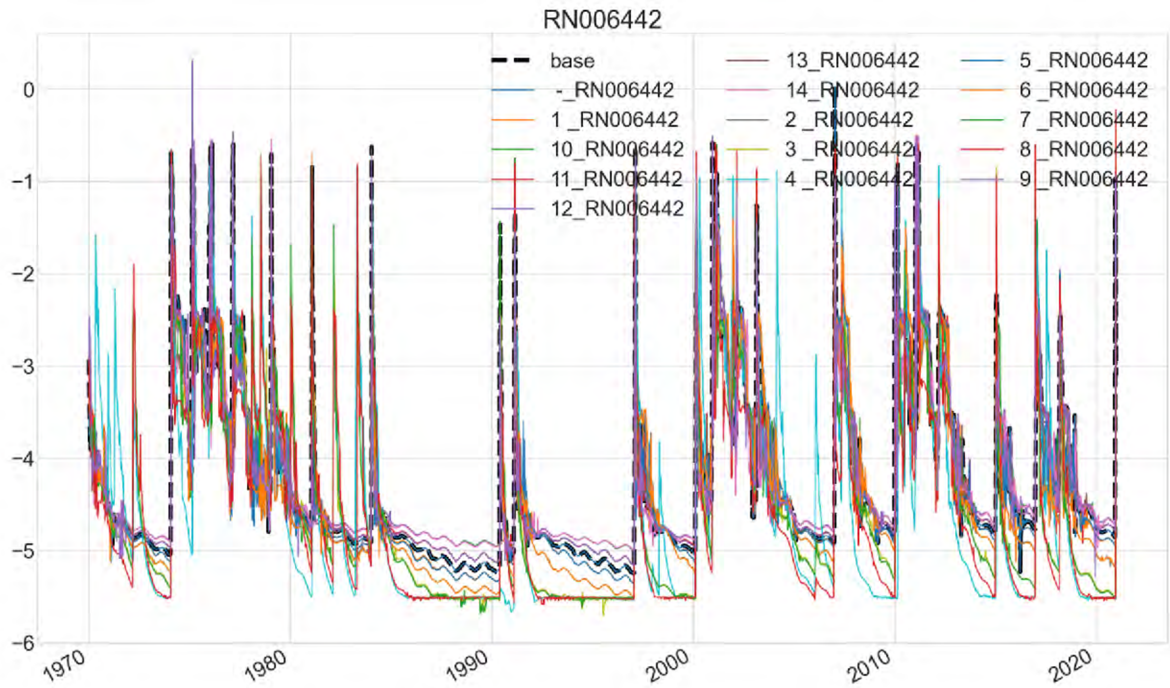
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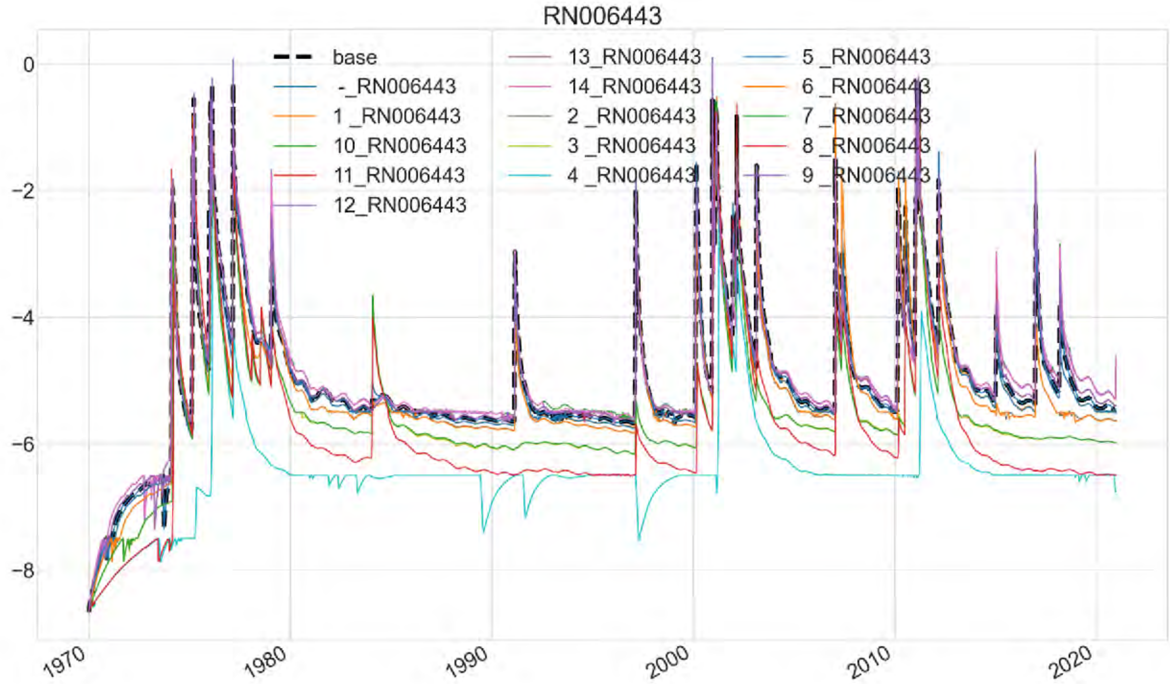
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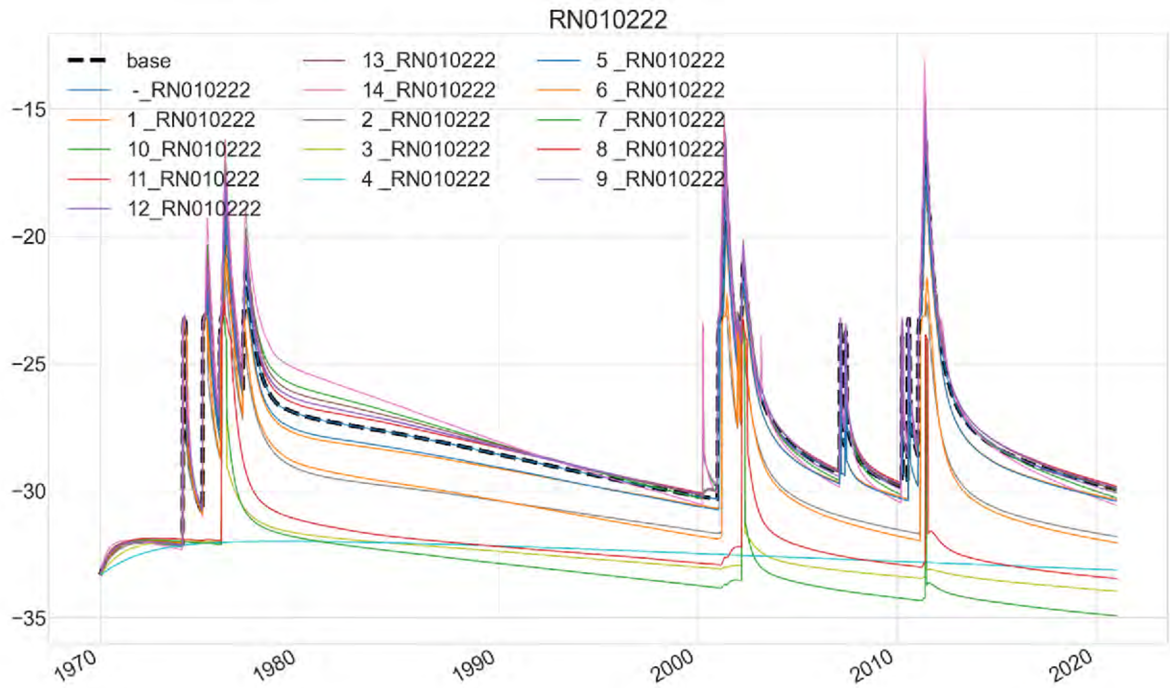
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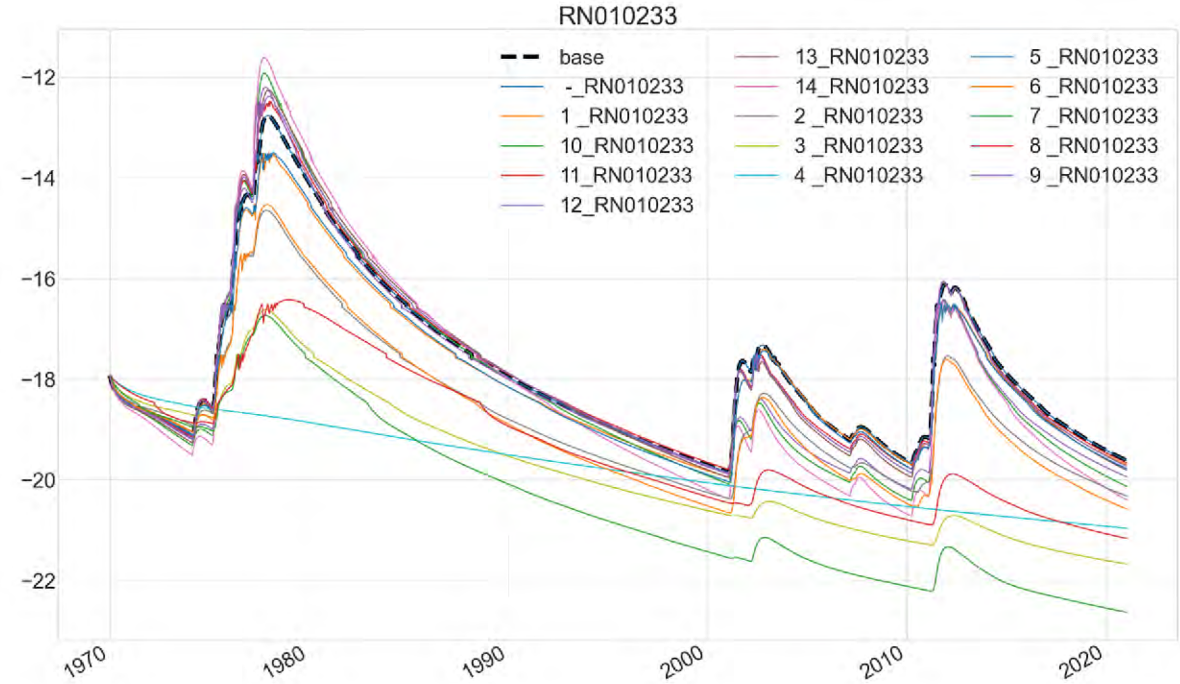
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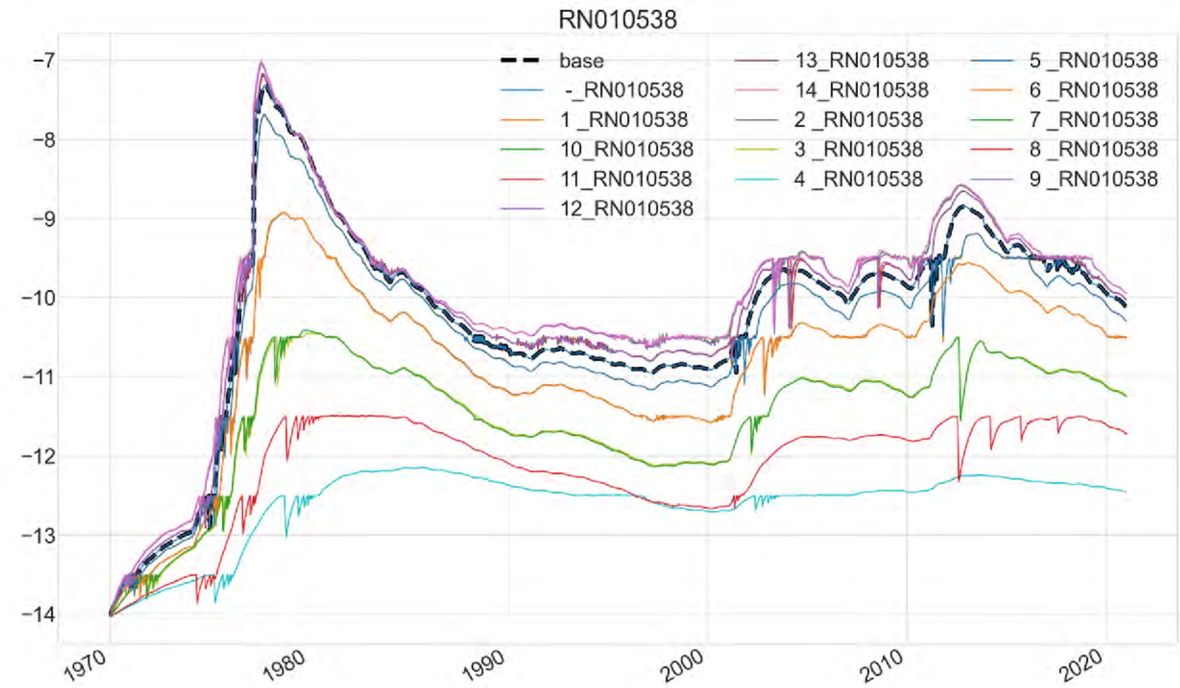
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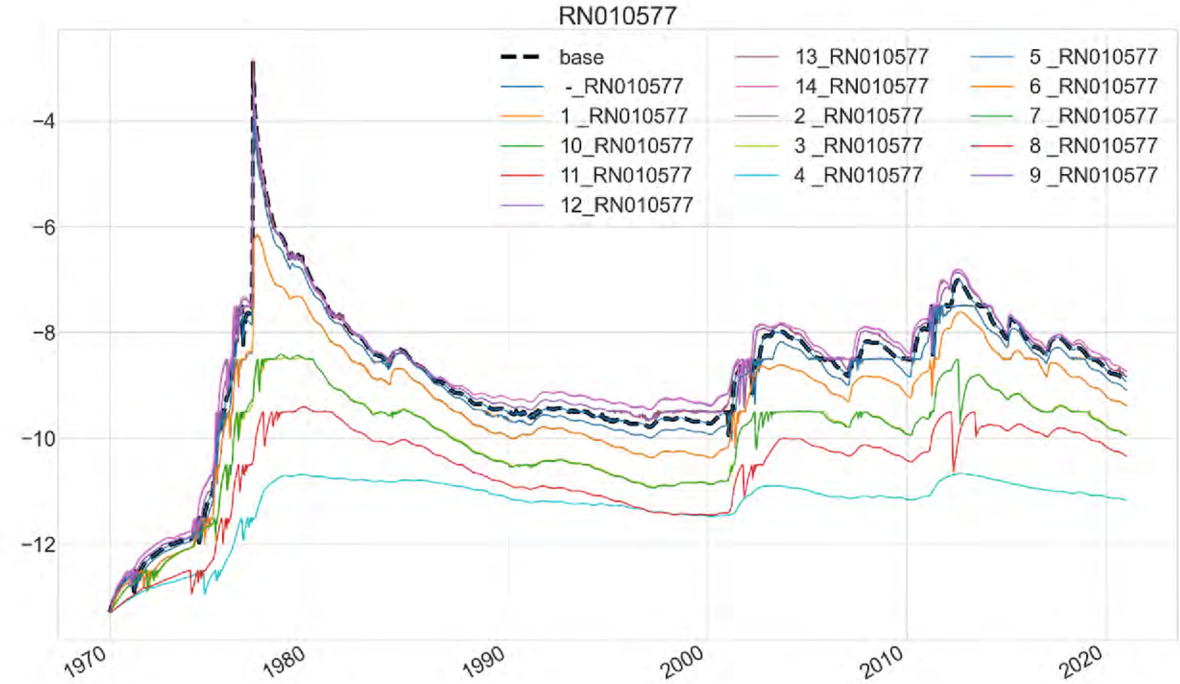
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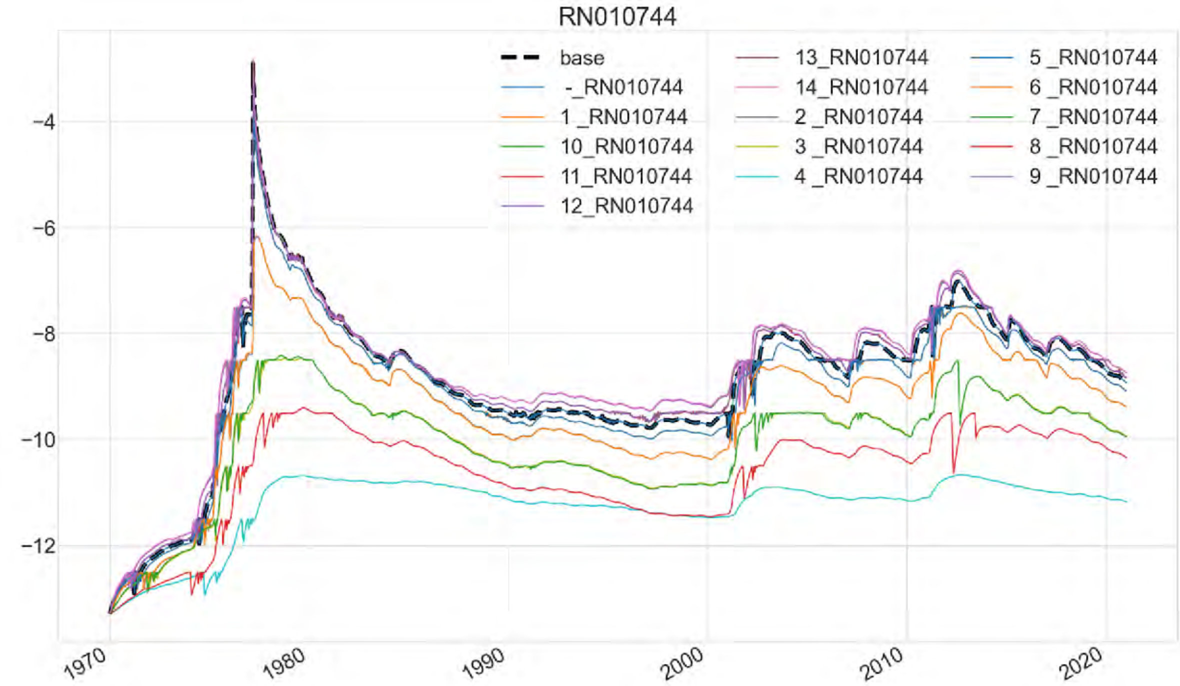
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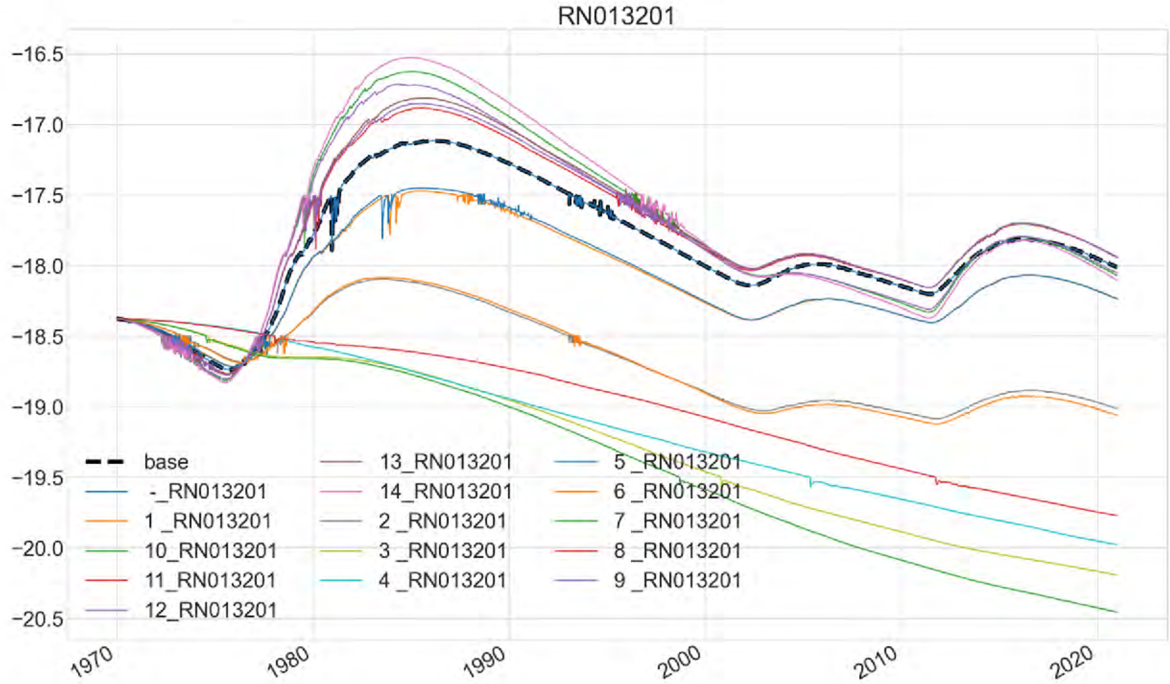
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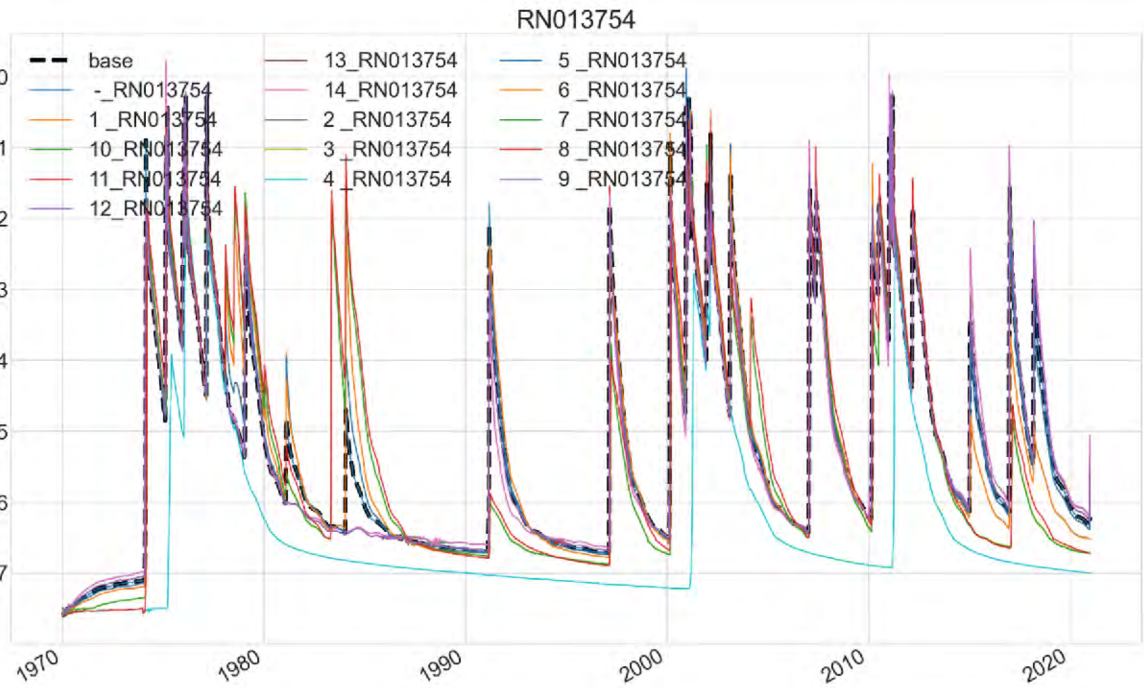
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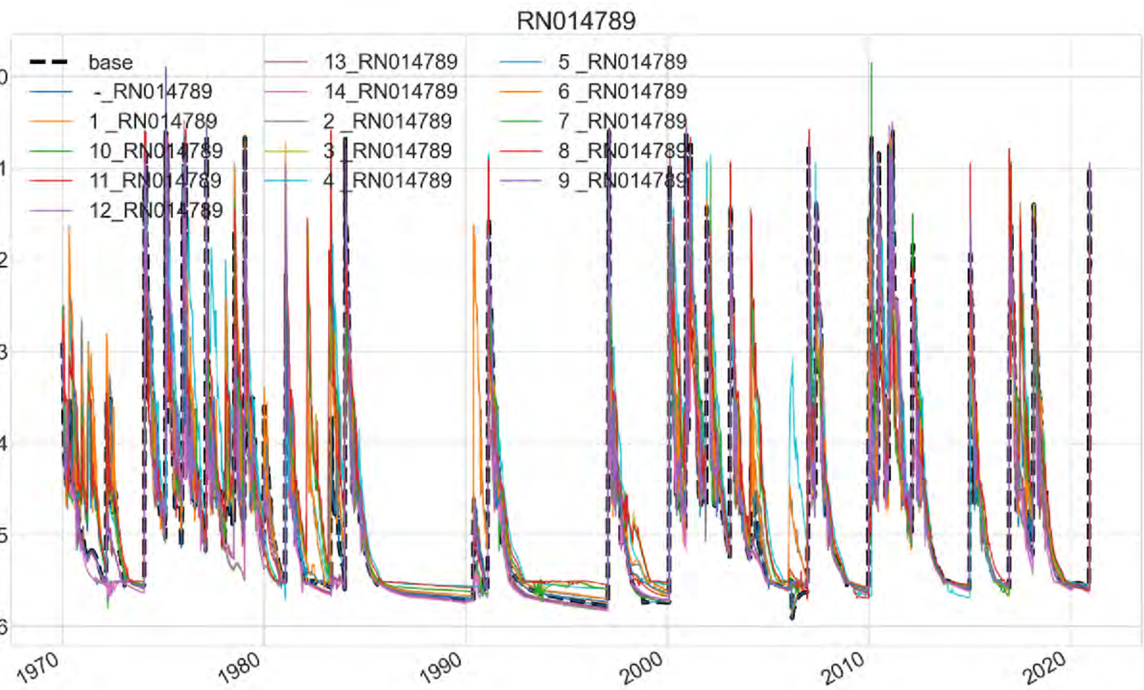
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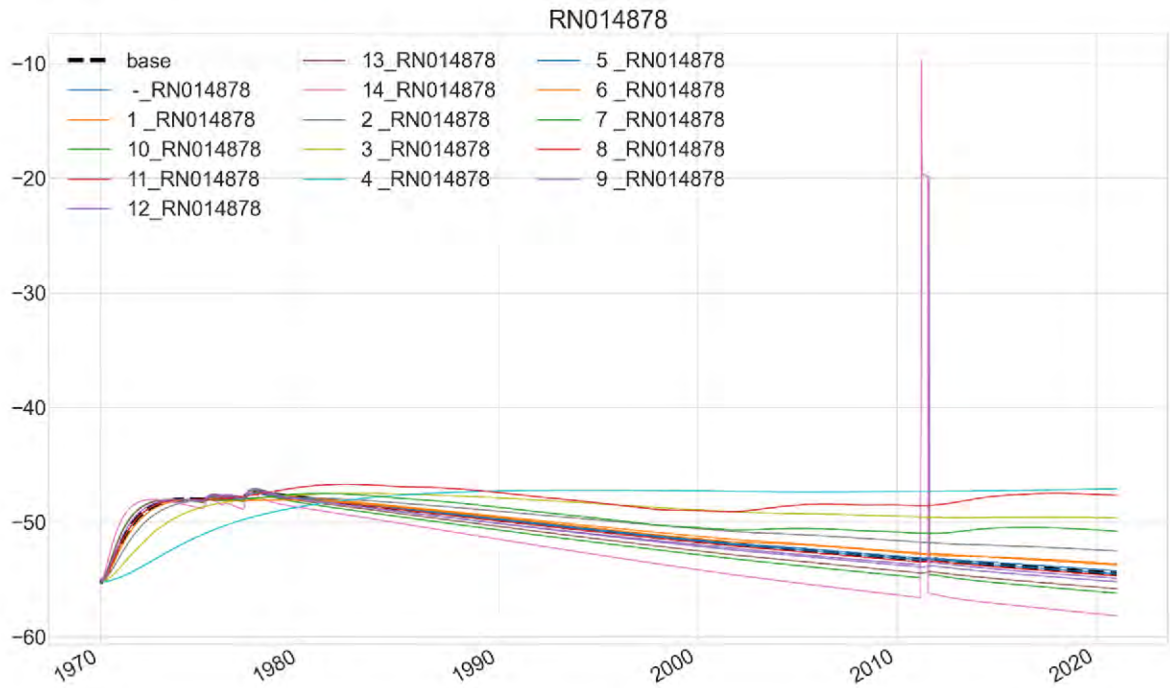
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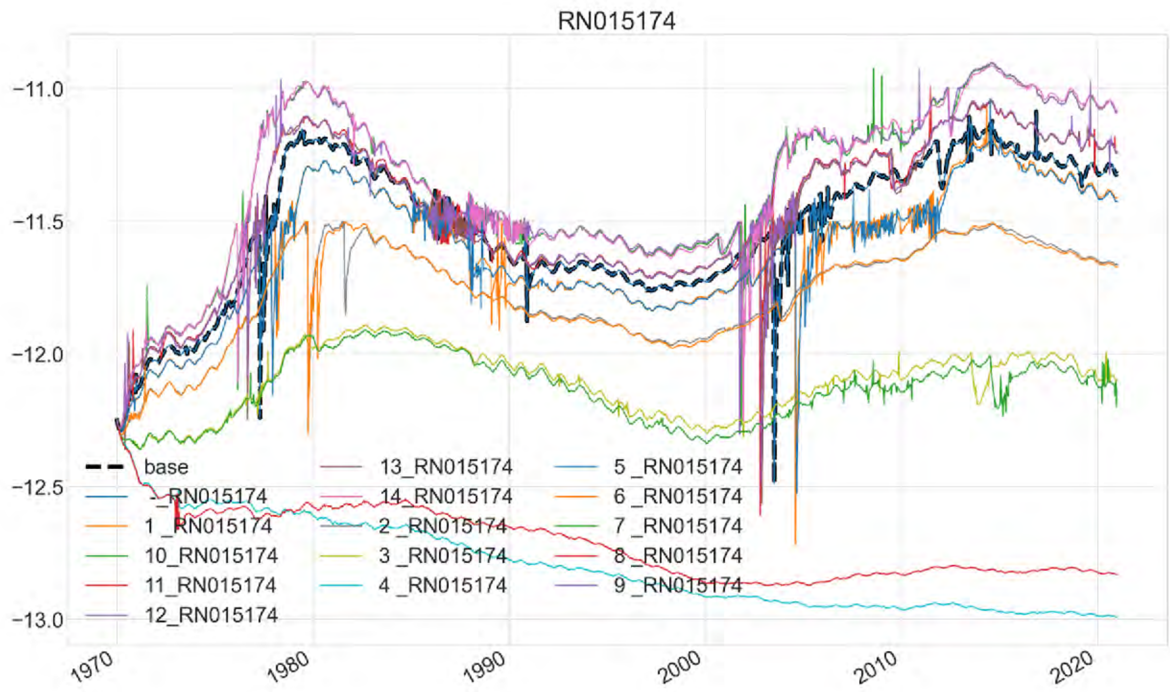
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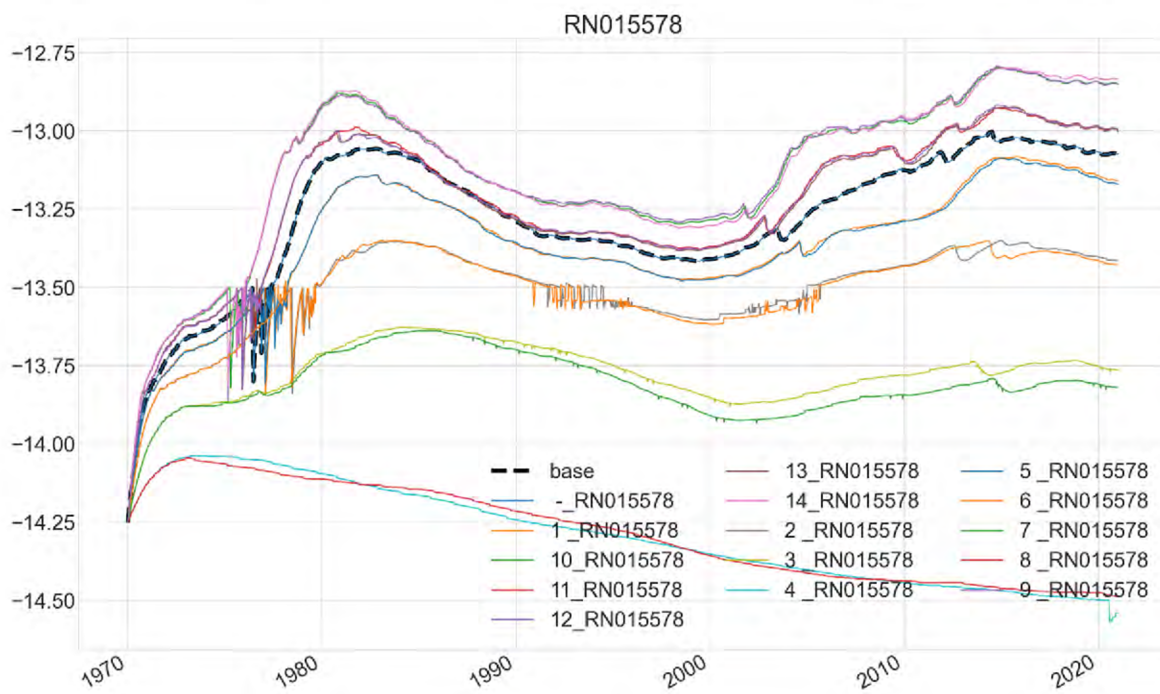
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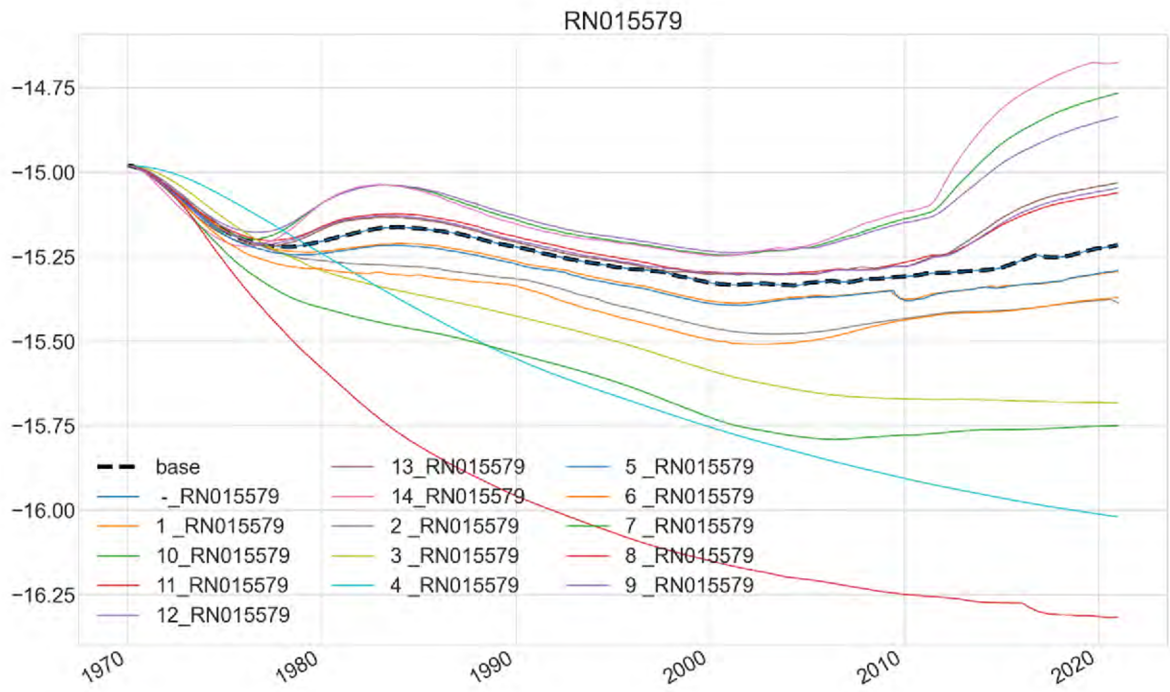

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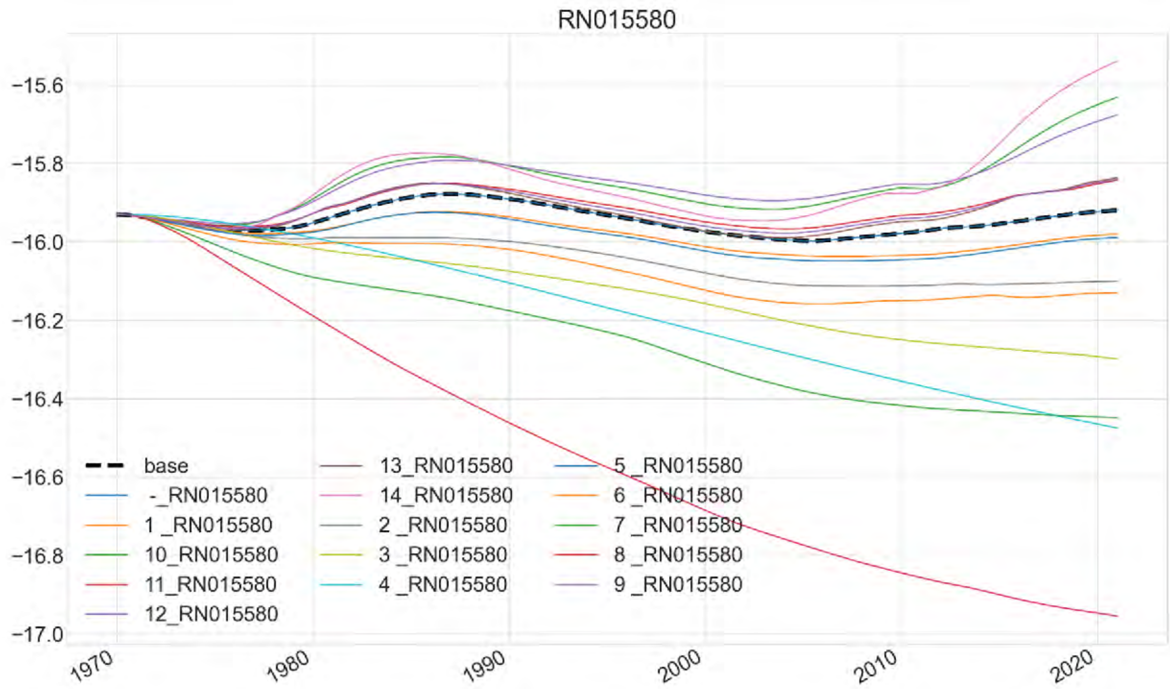

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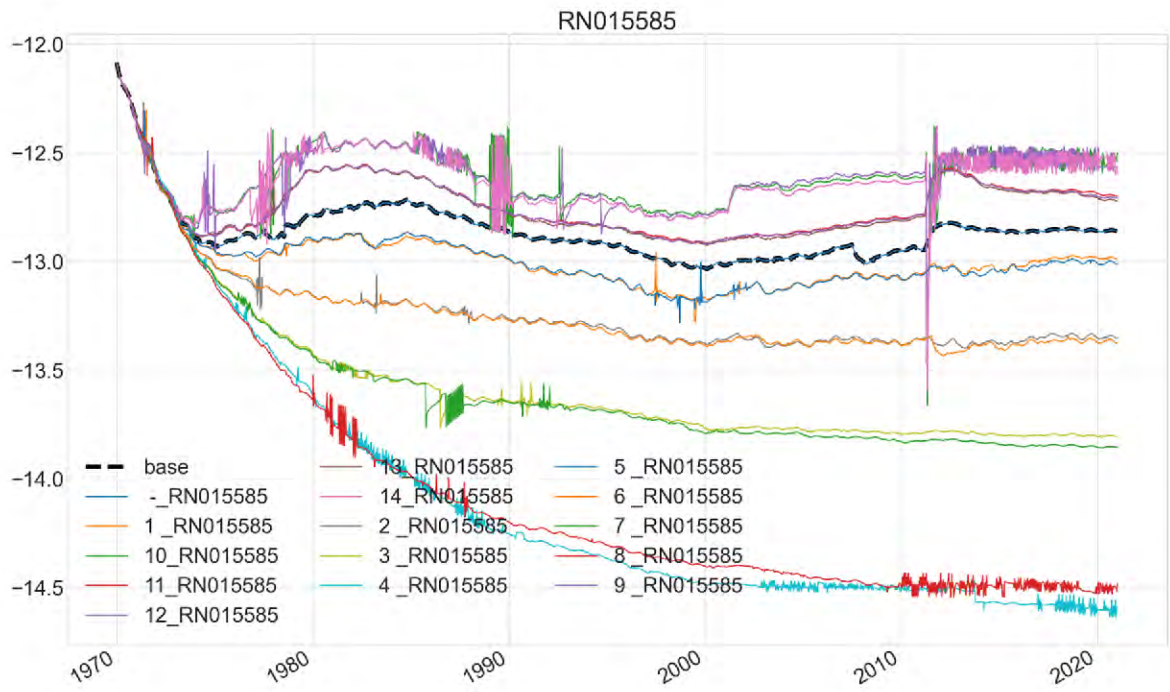
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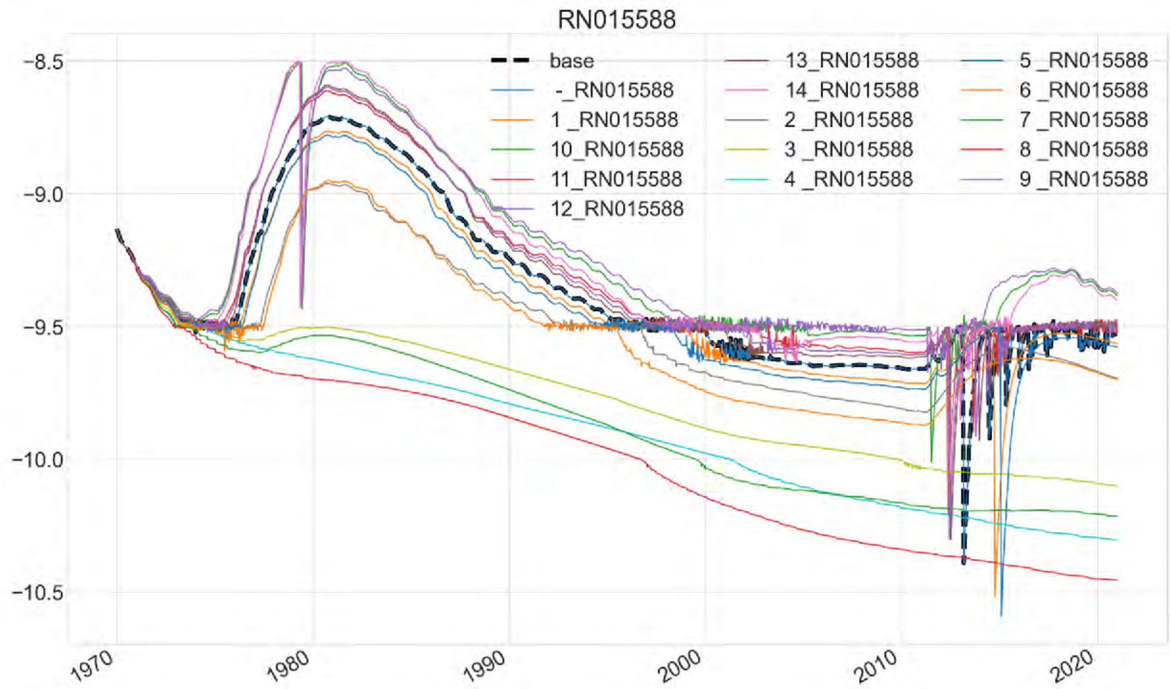
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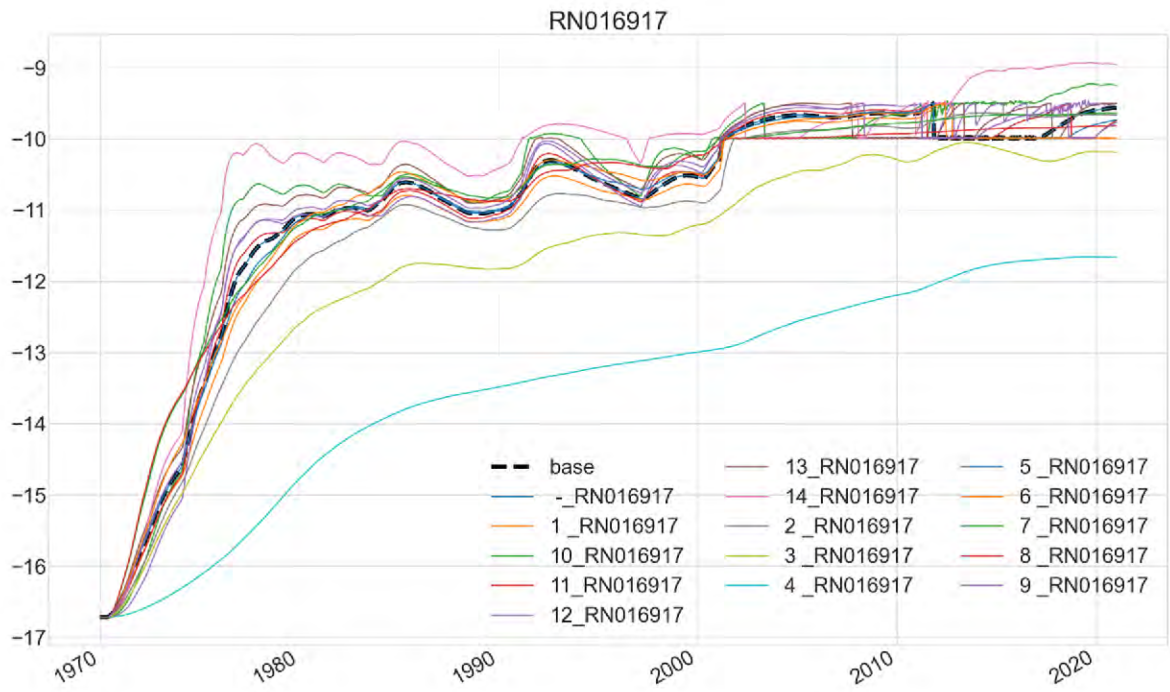
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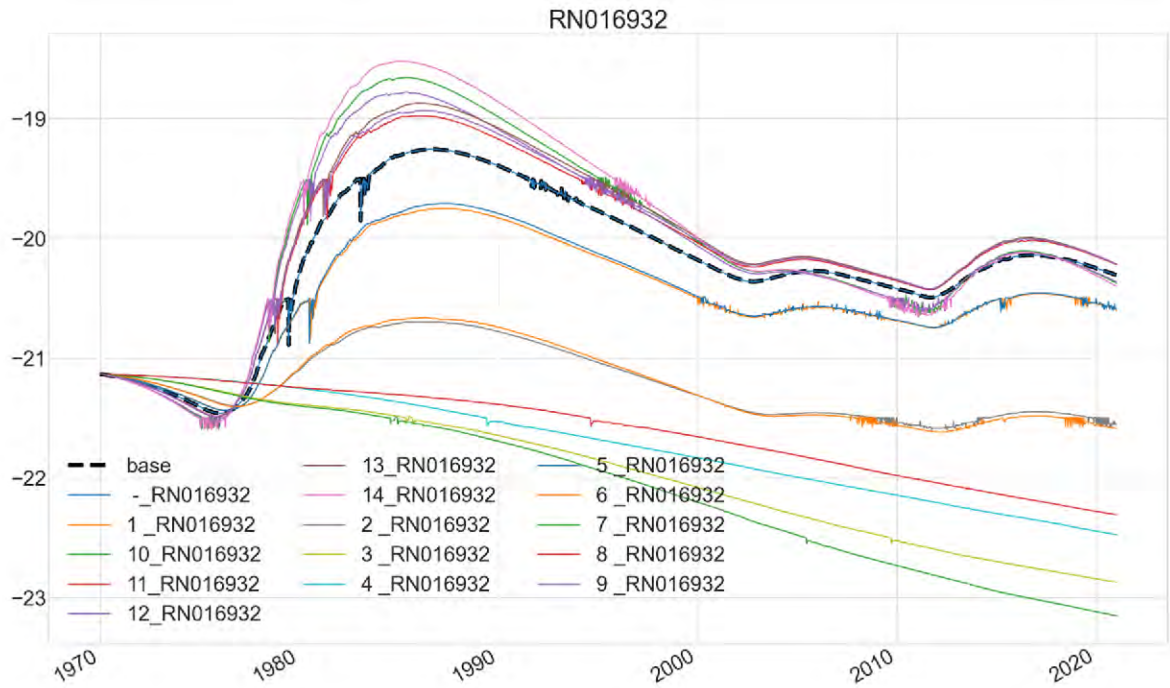
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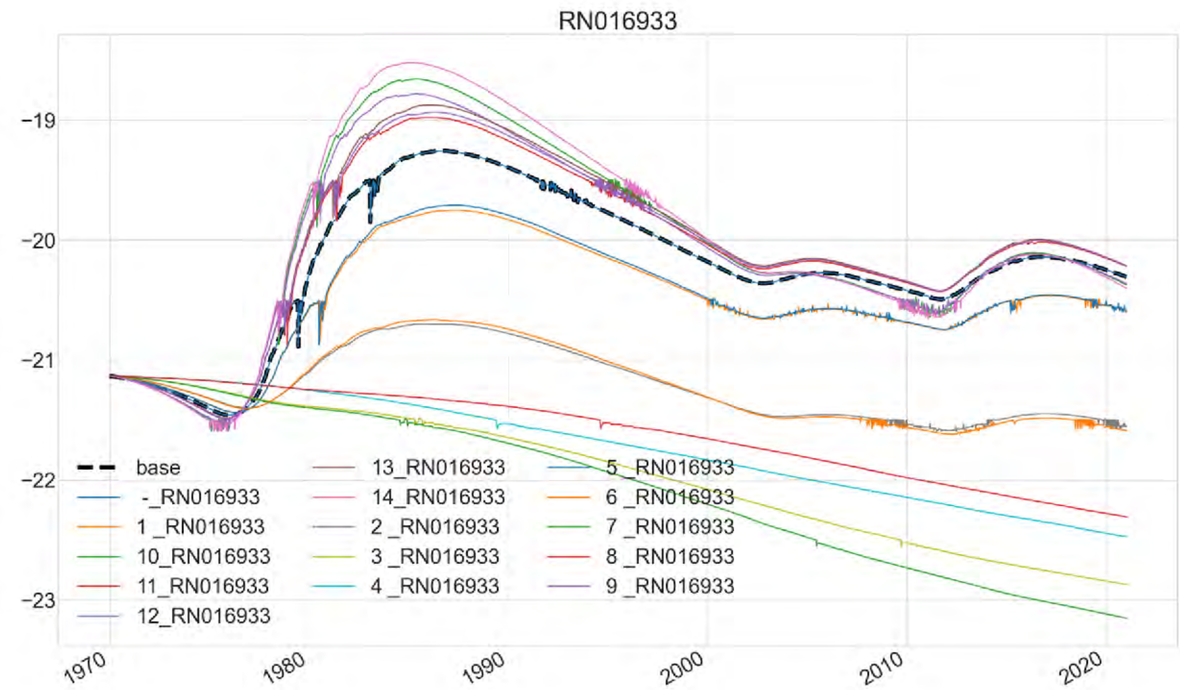
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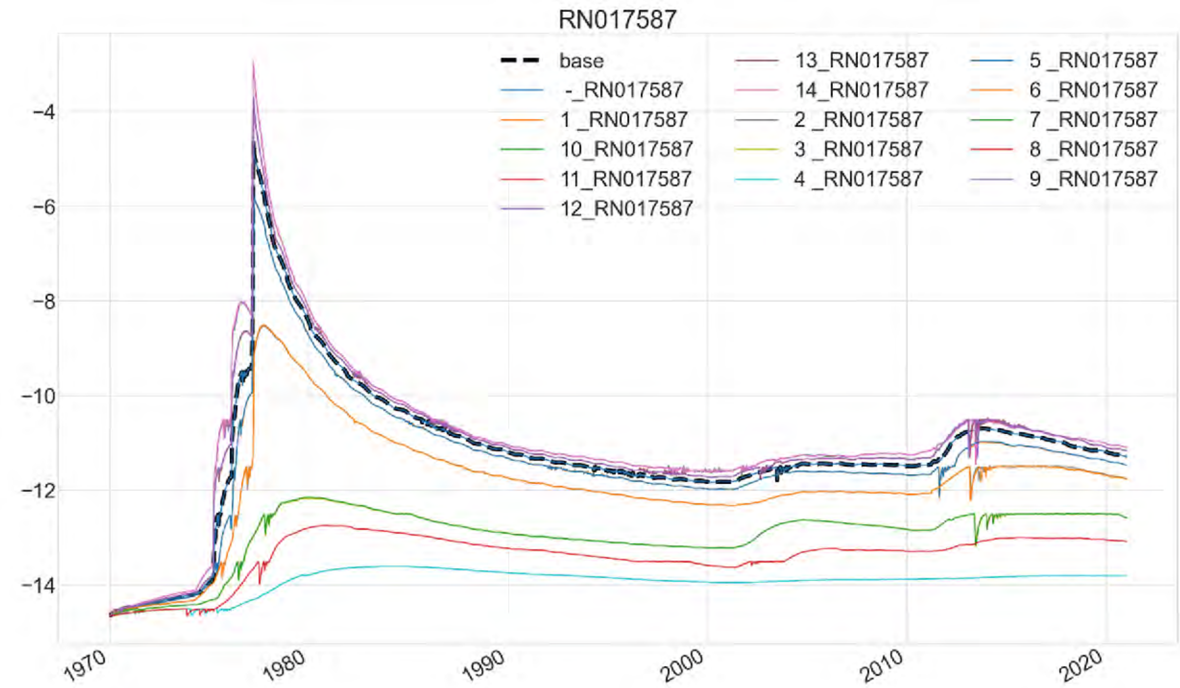
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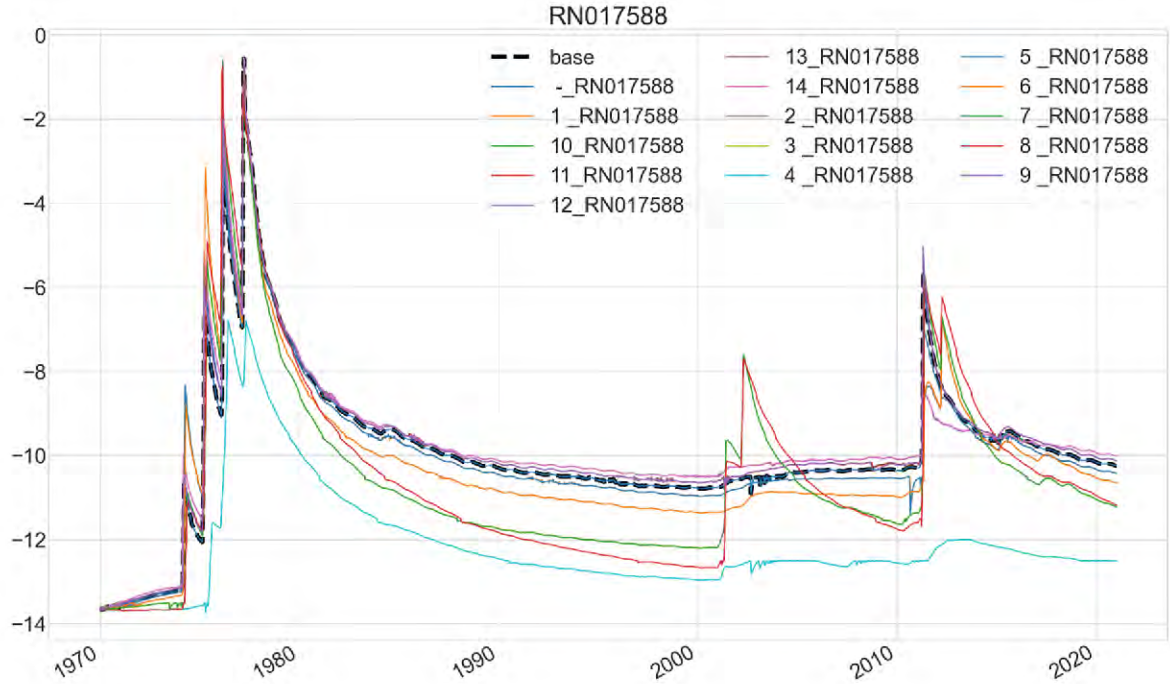
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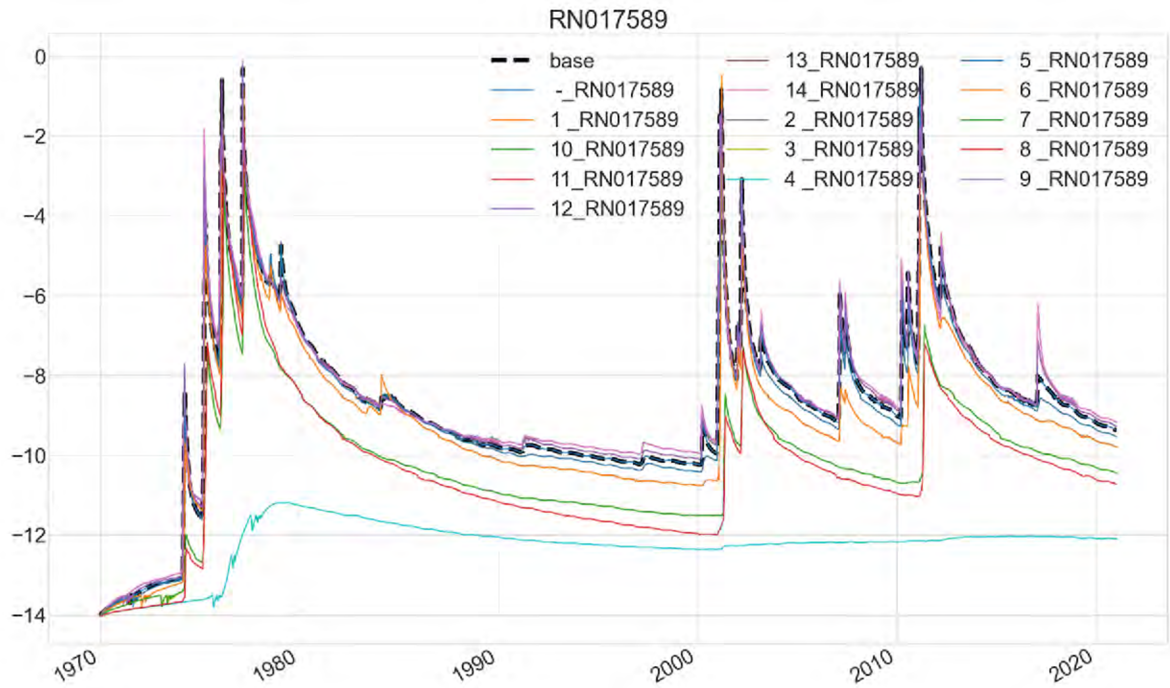
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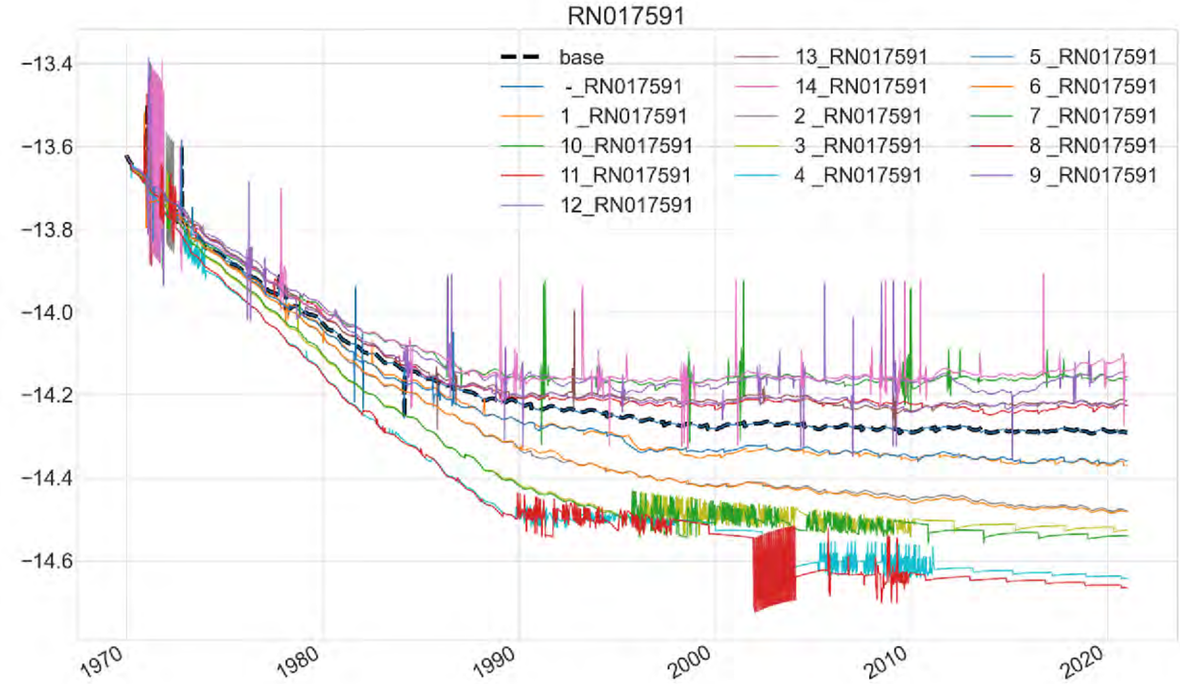
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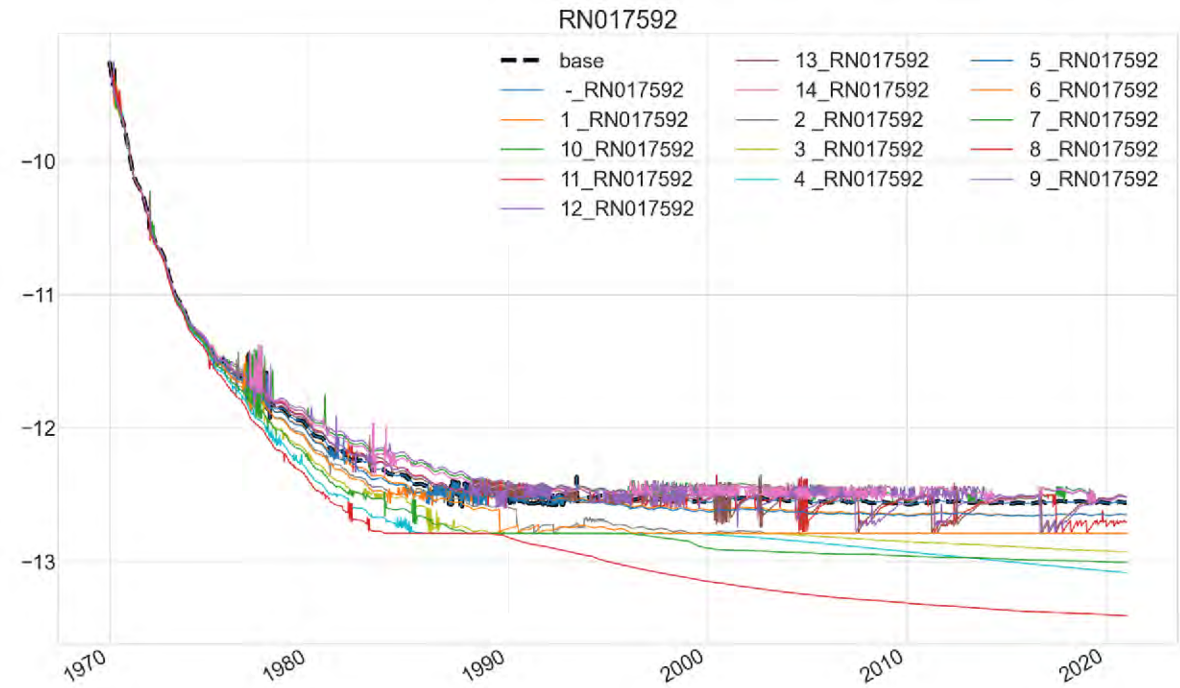
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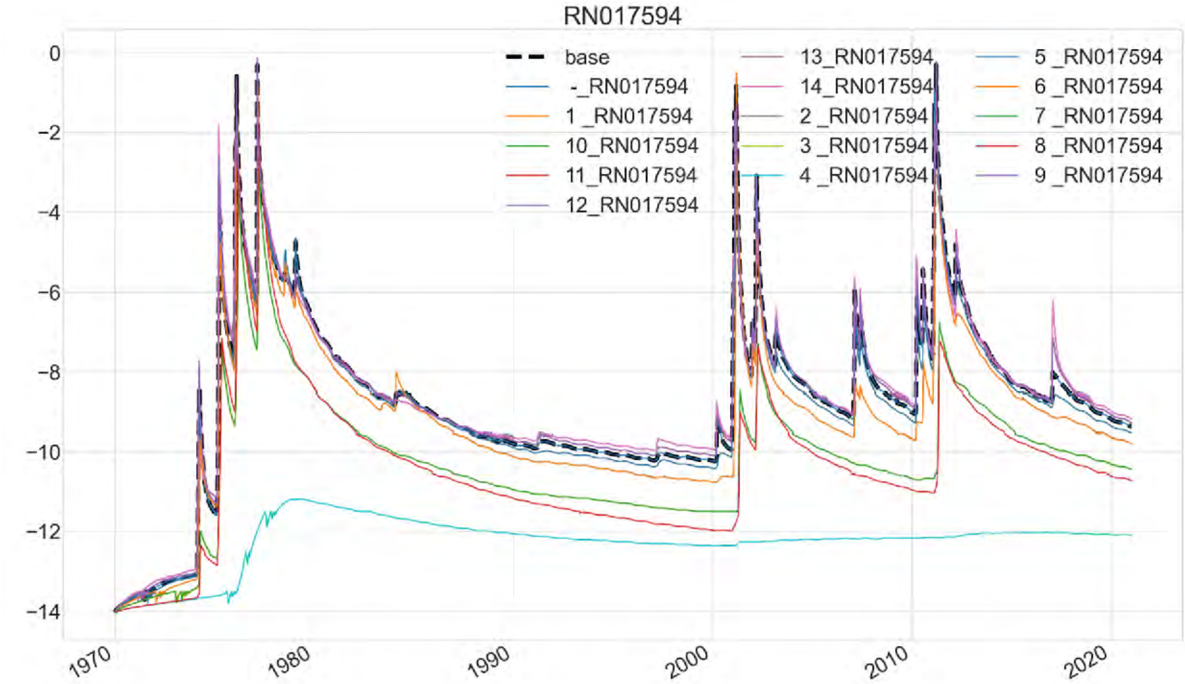
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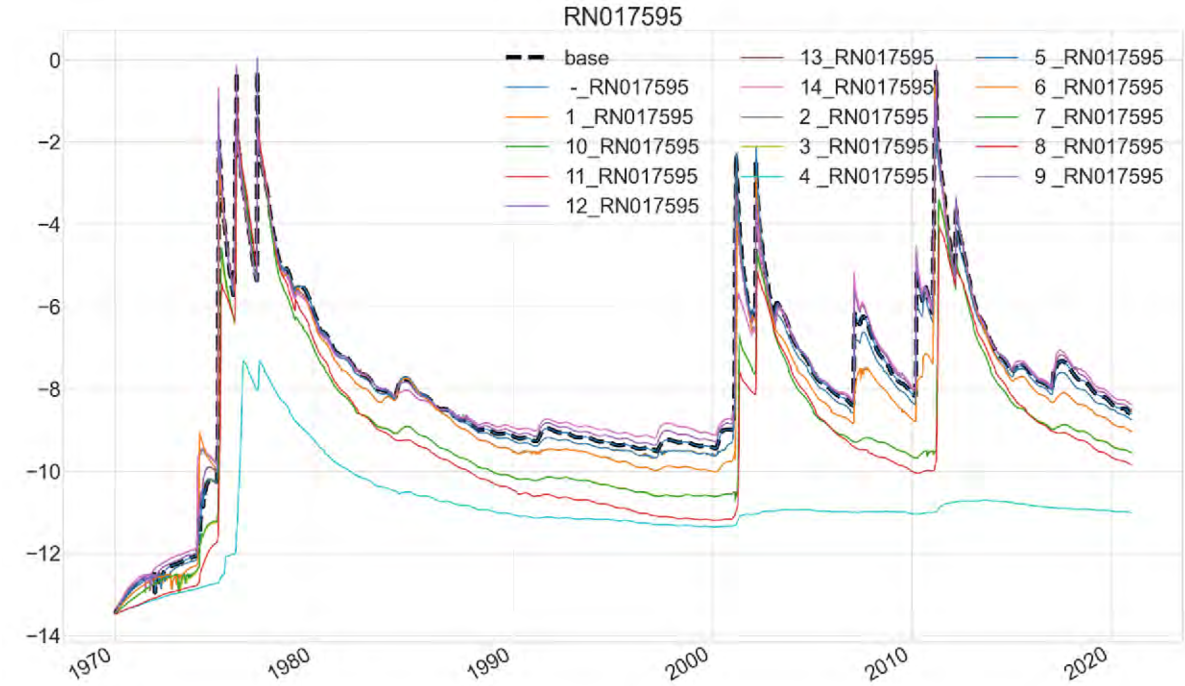
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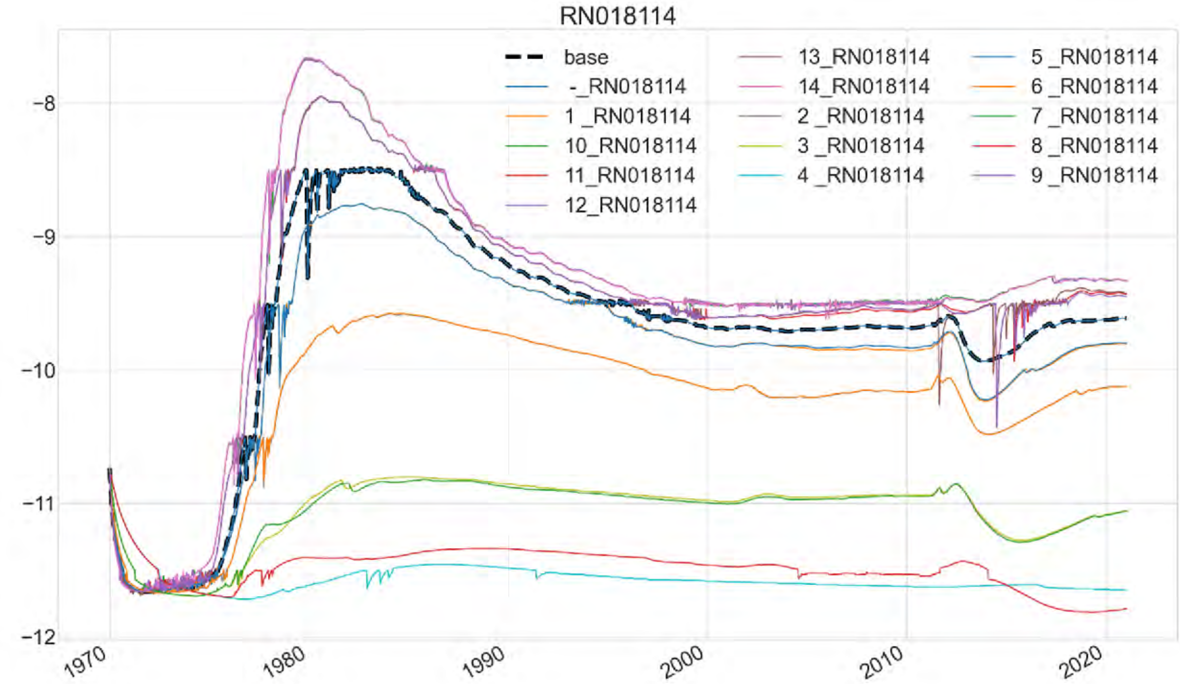
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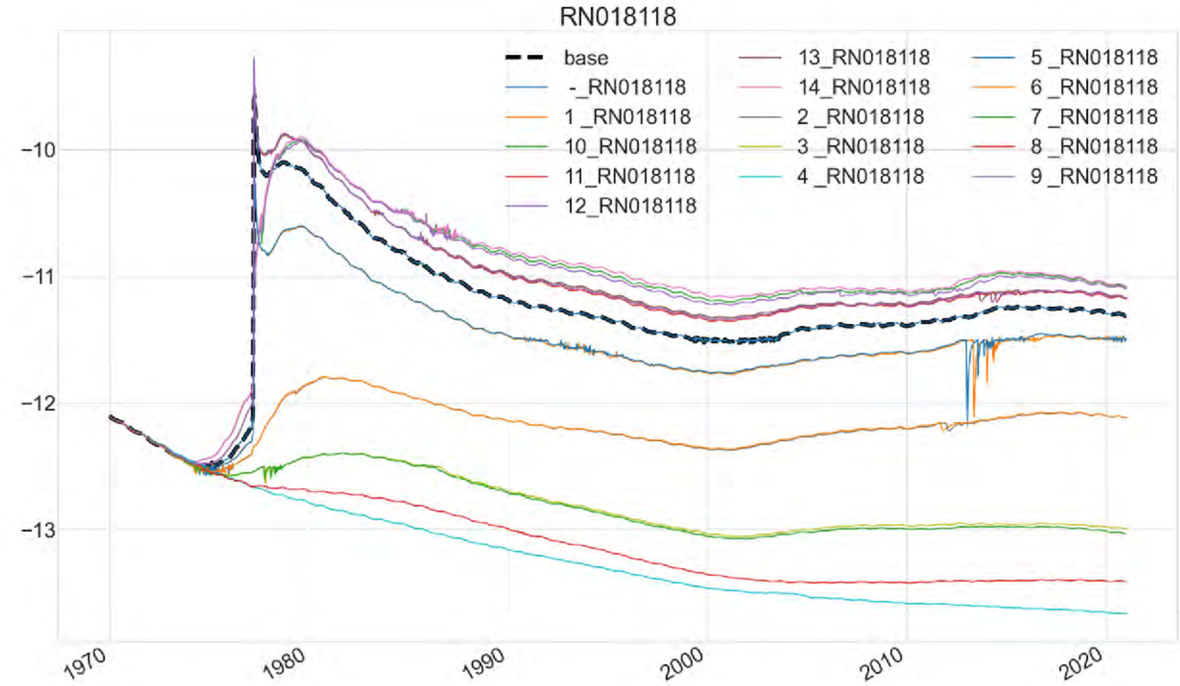
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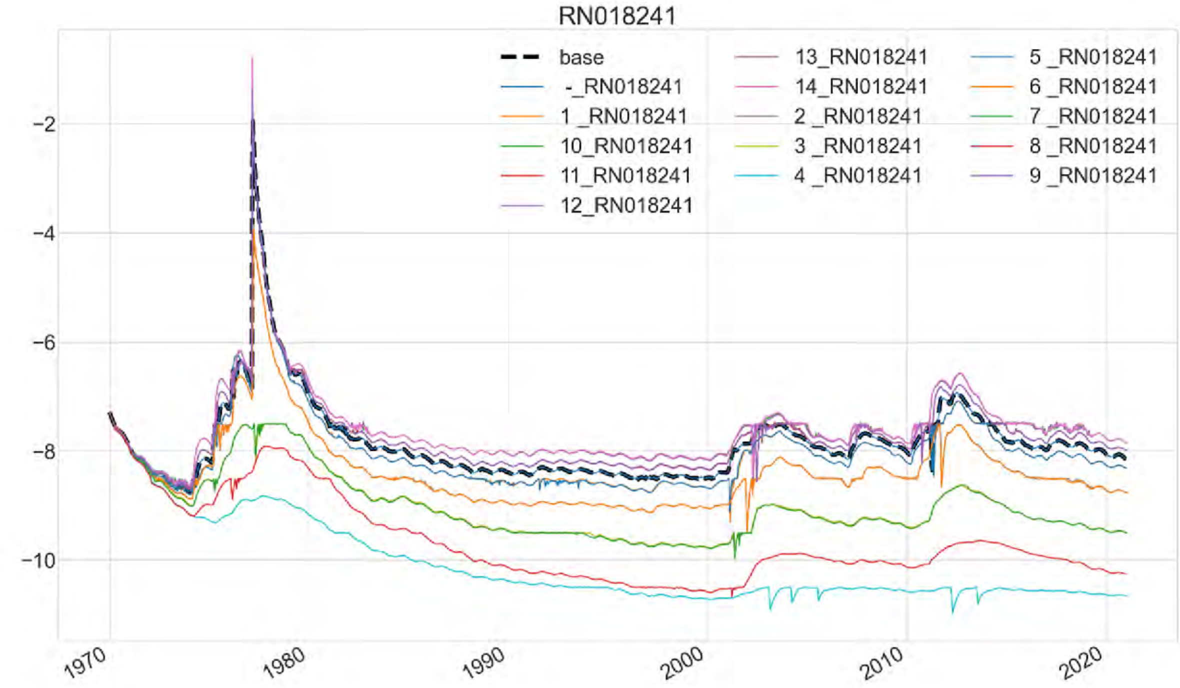
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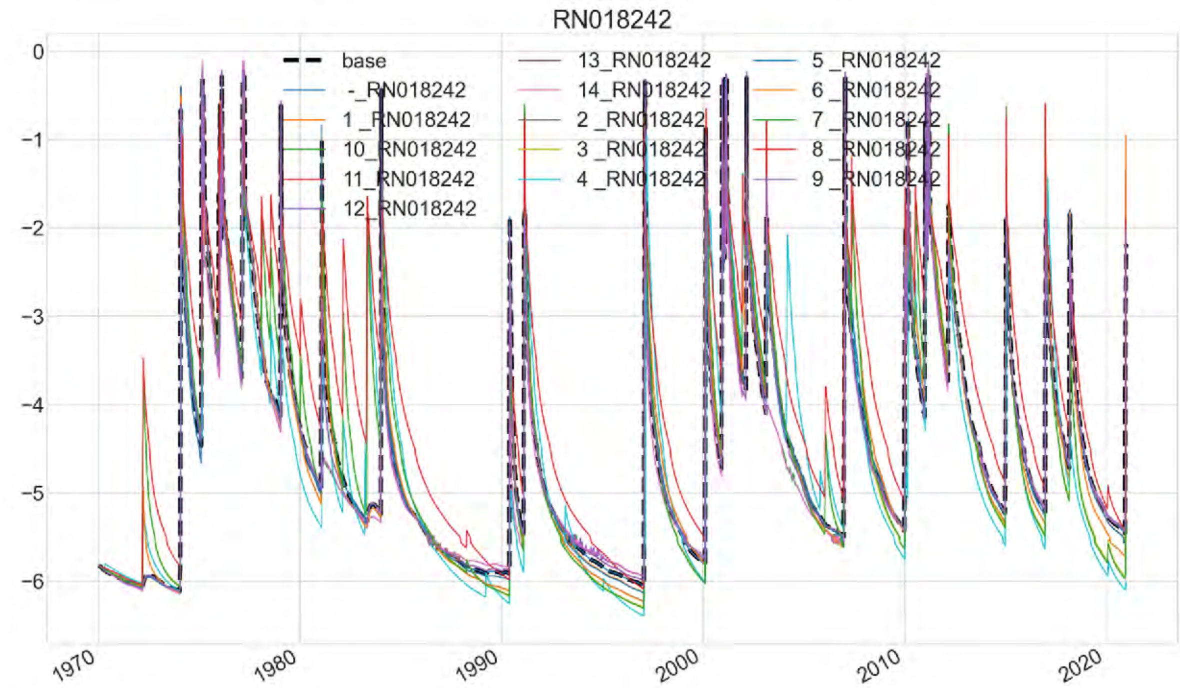
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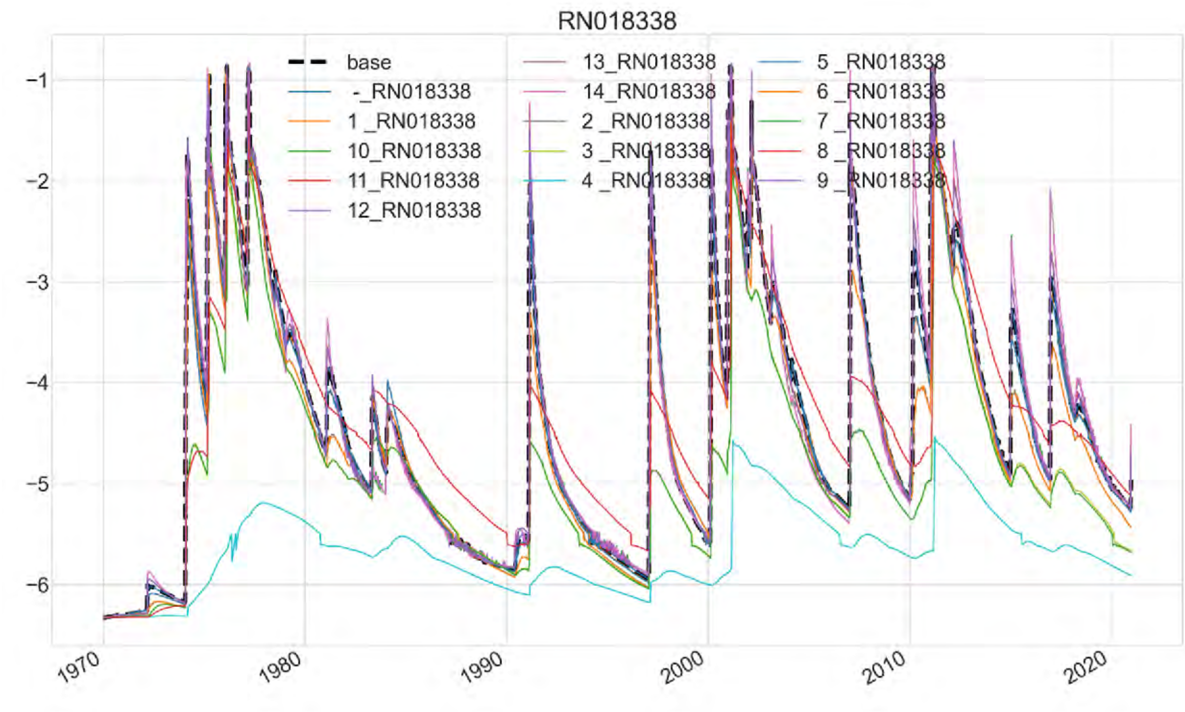
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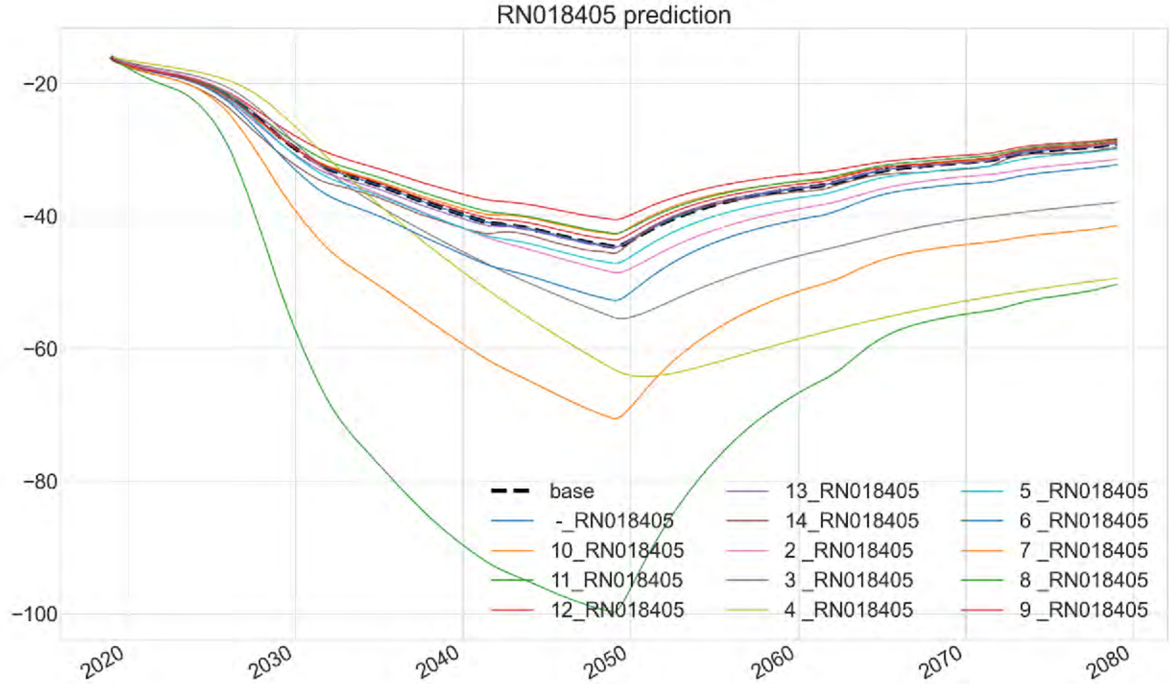
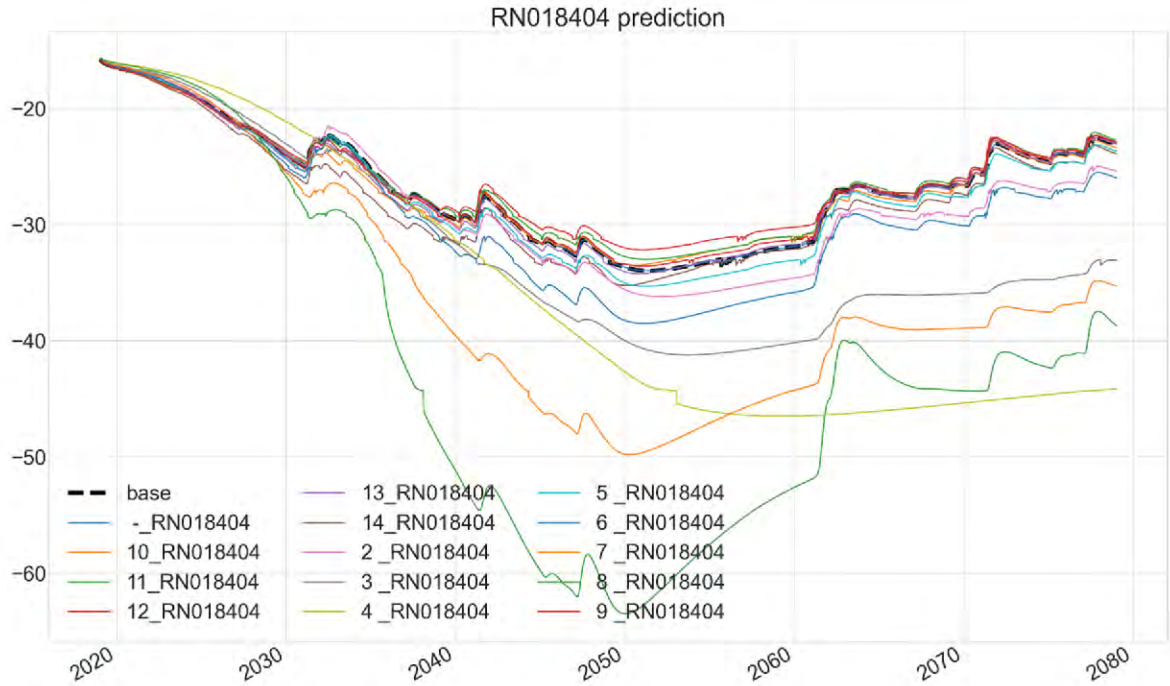
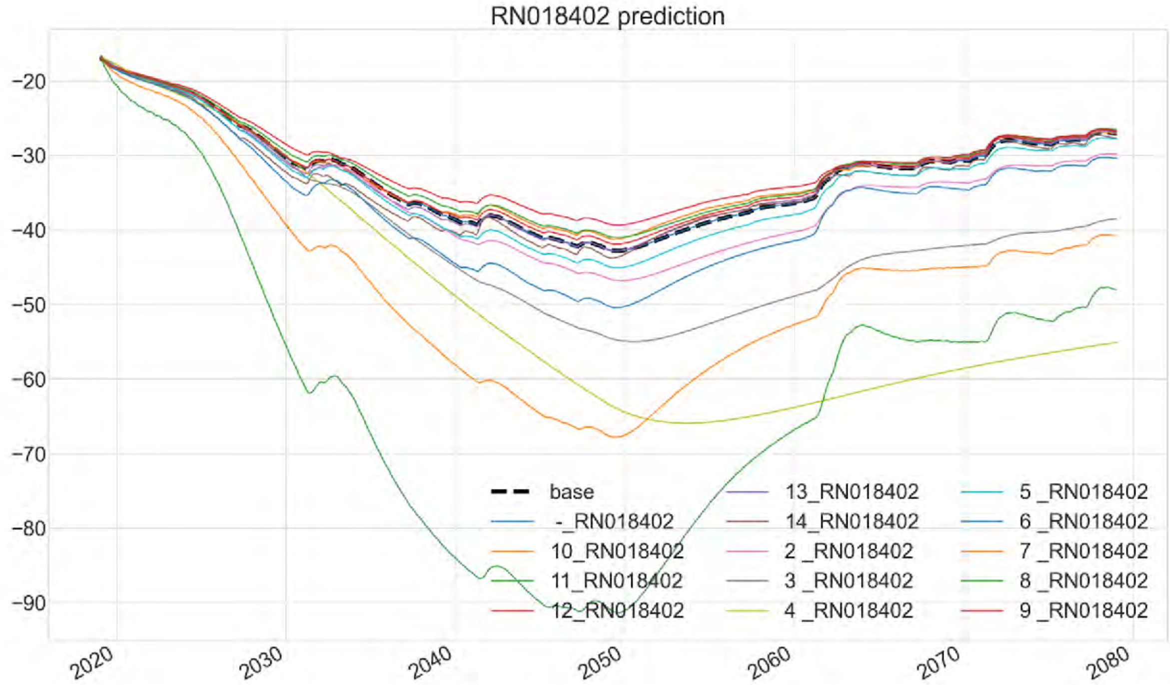
Appendix 2 - PREDICTIVE HYDROGRAPHS



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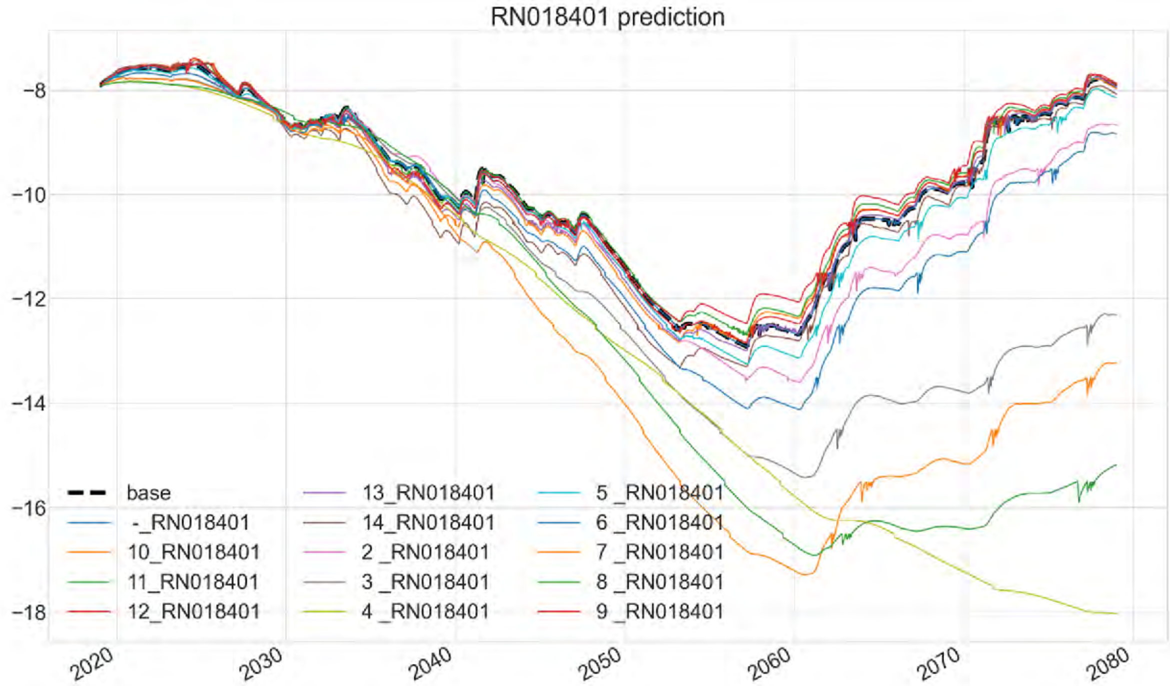
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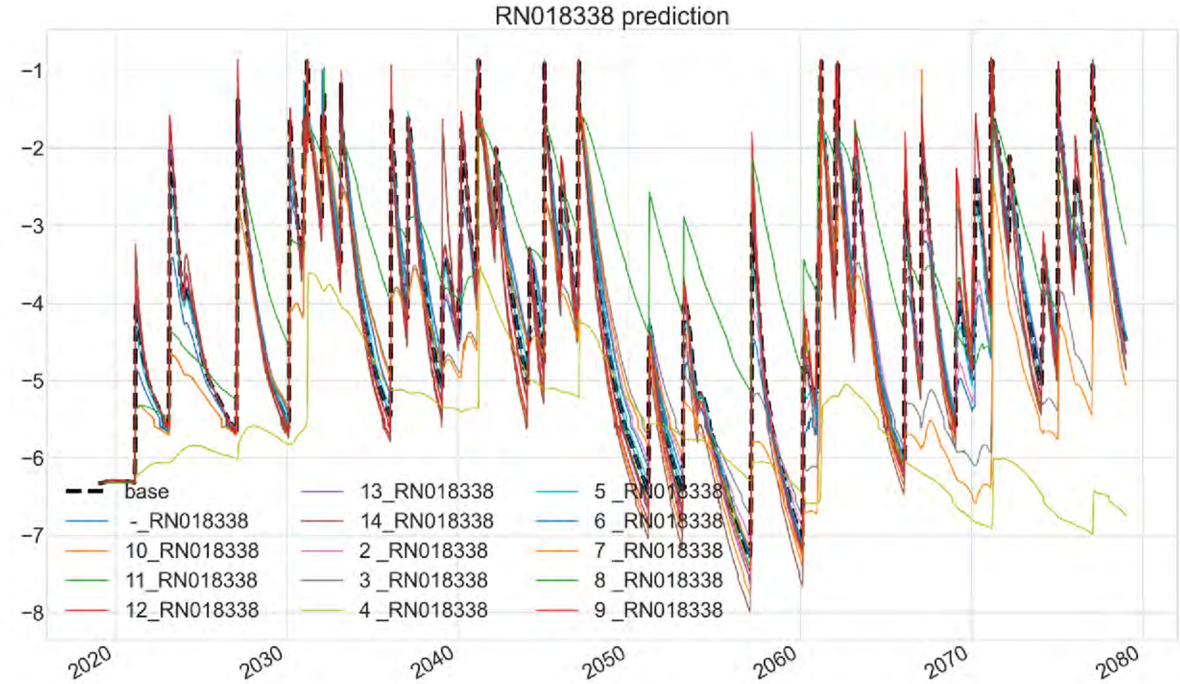
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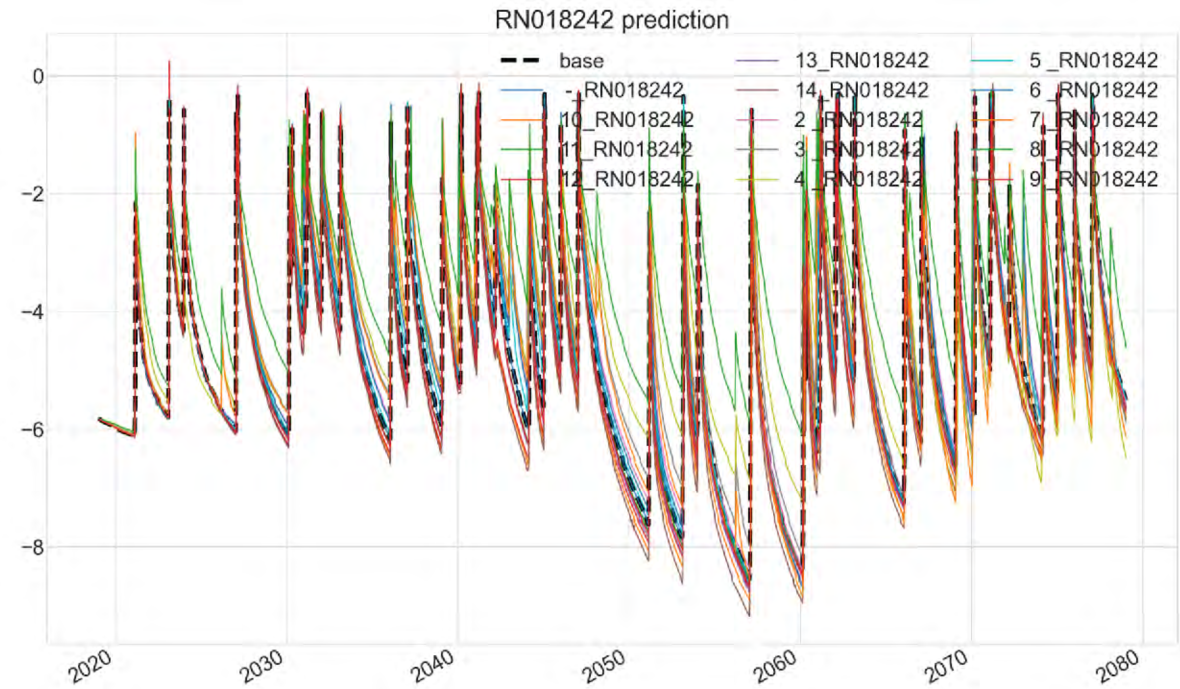
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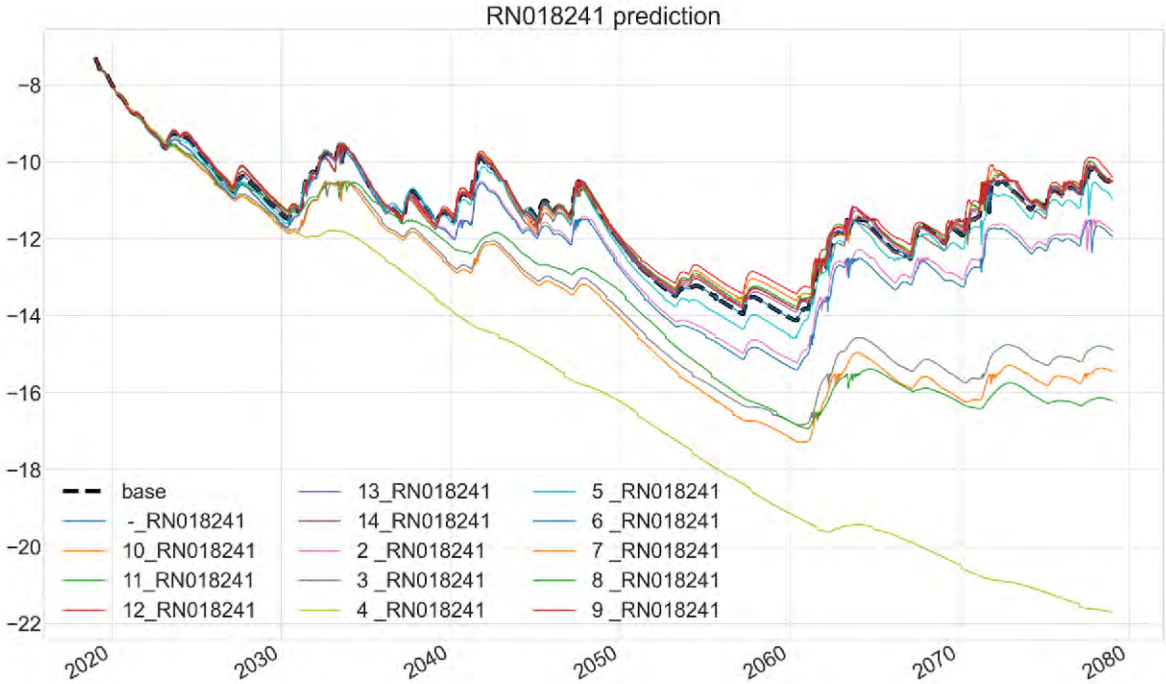

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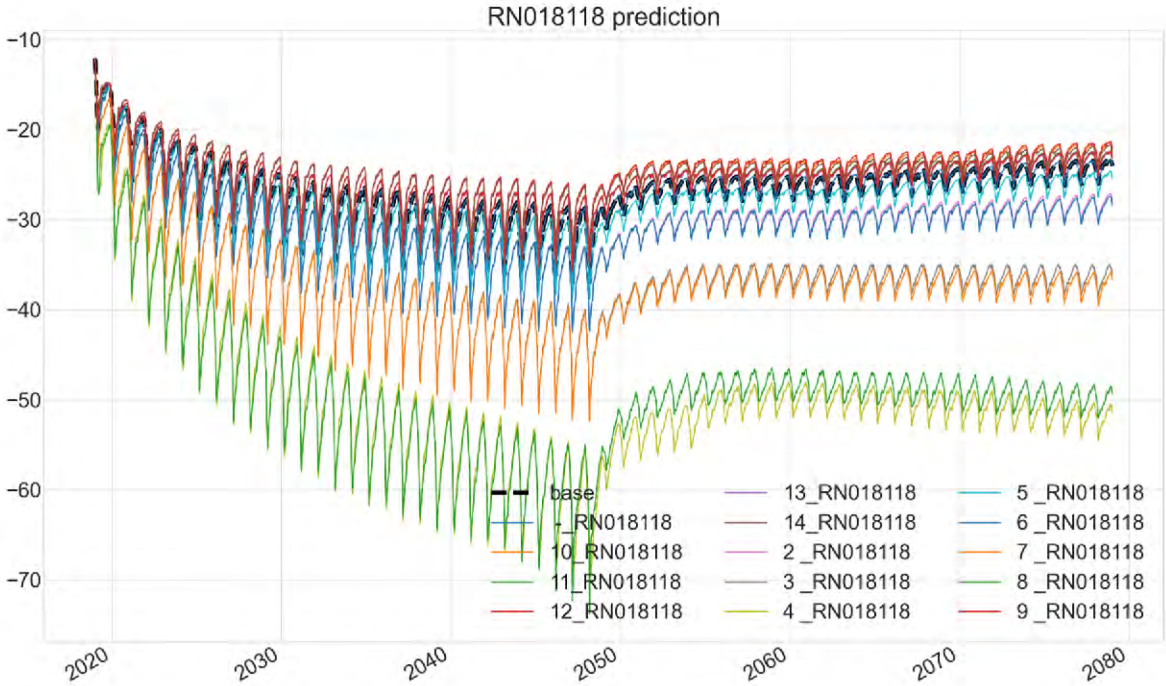

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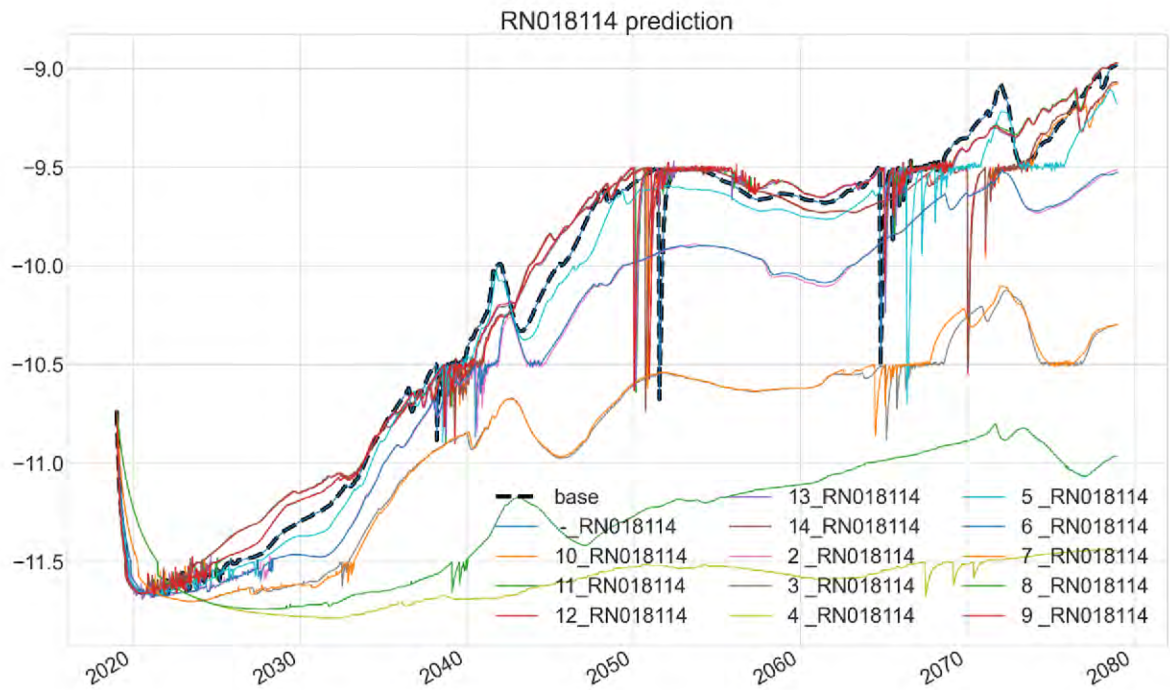
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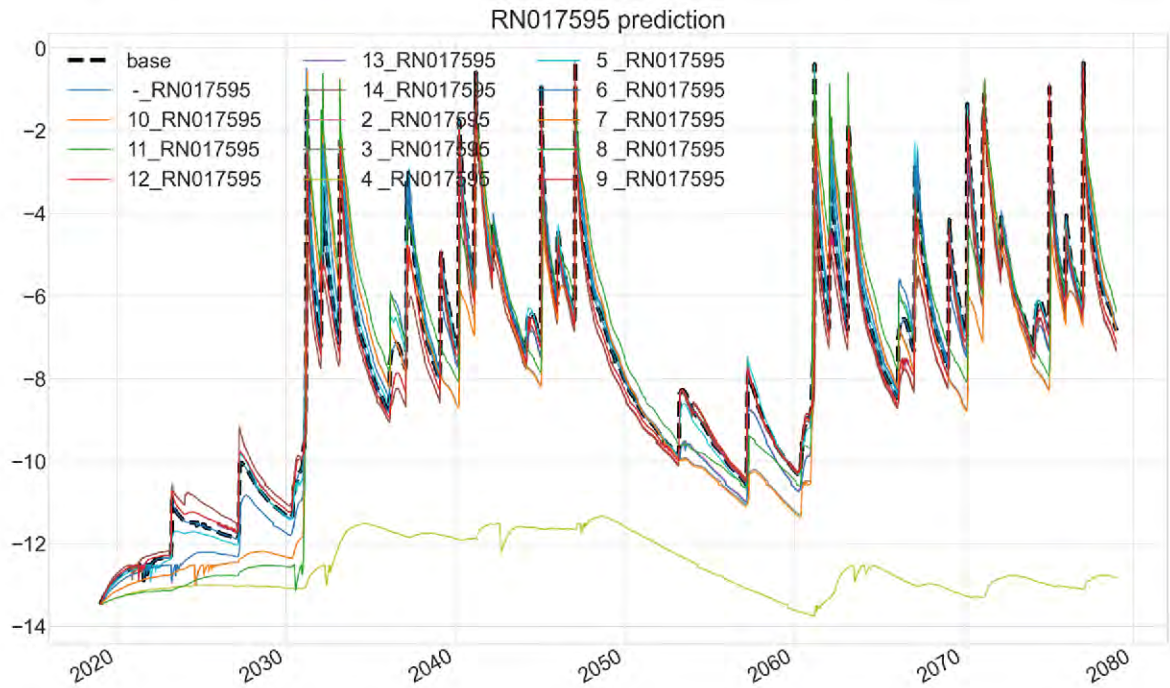
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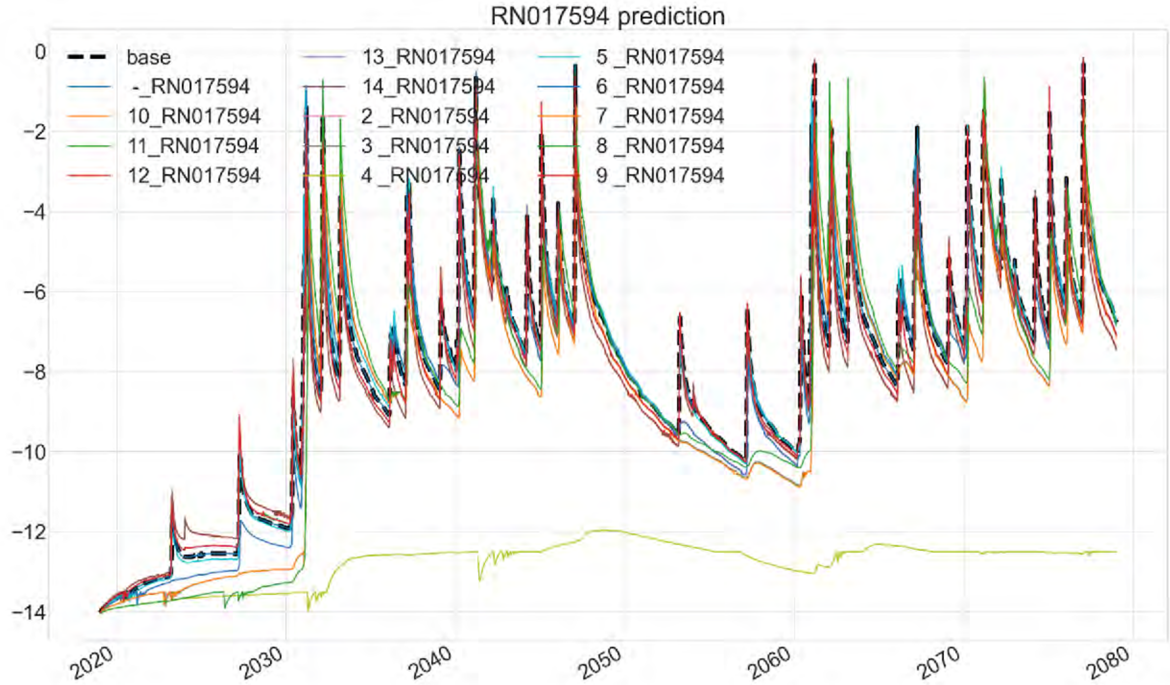
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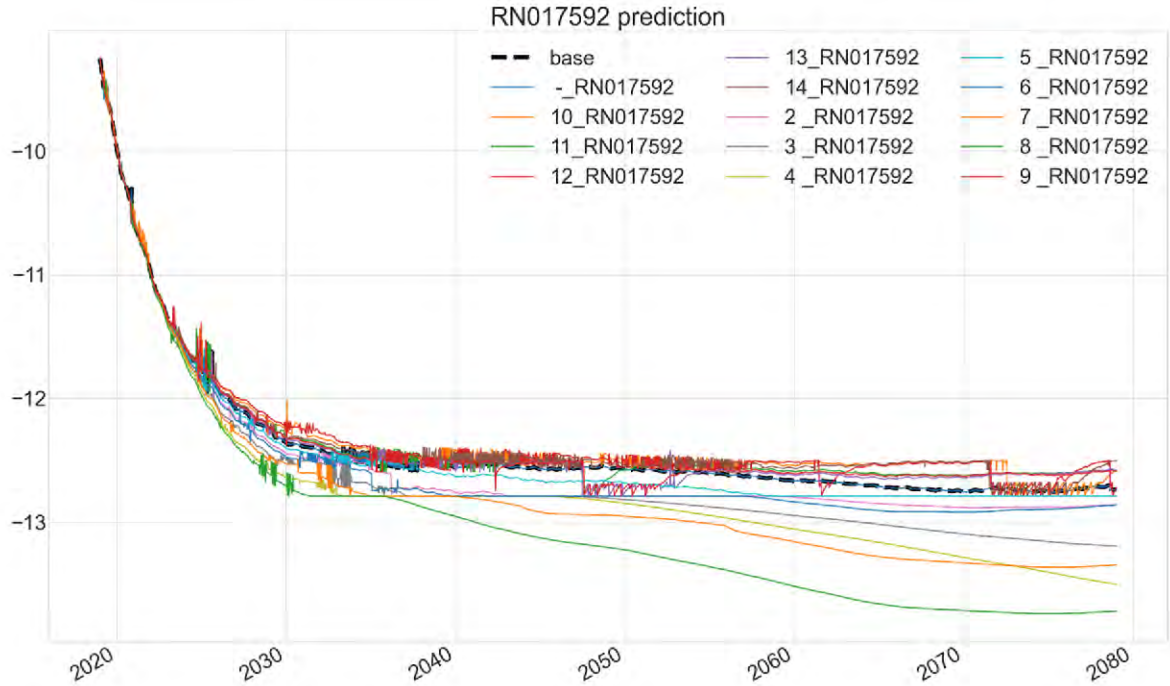
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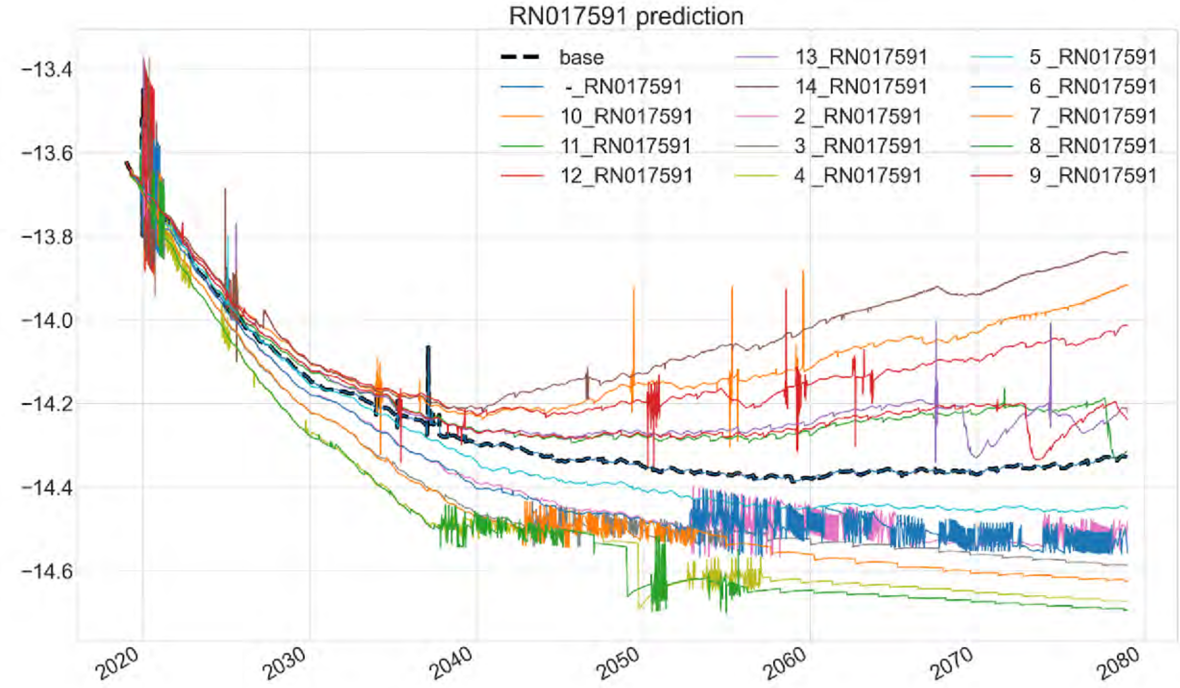
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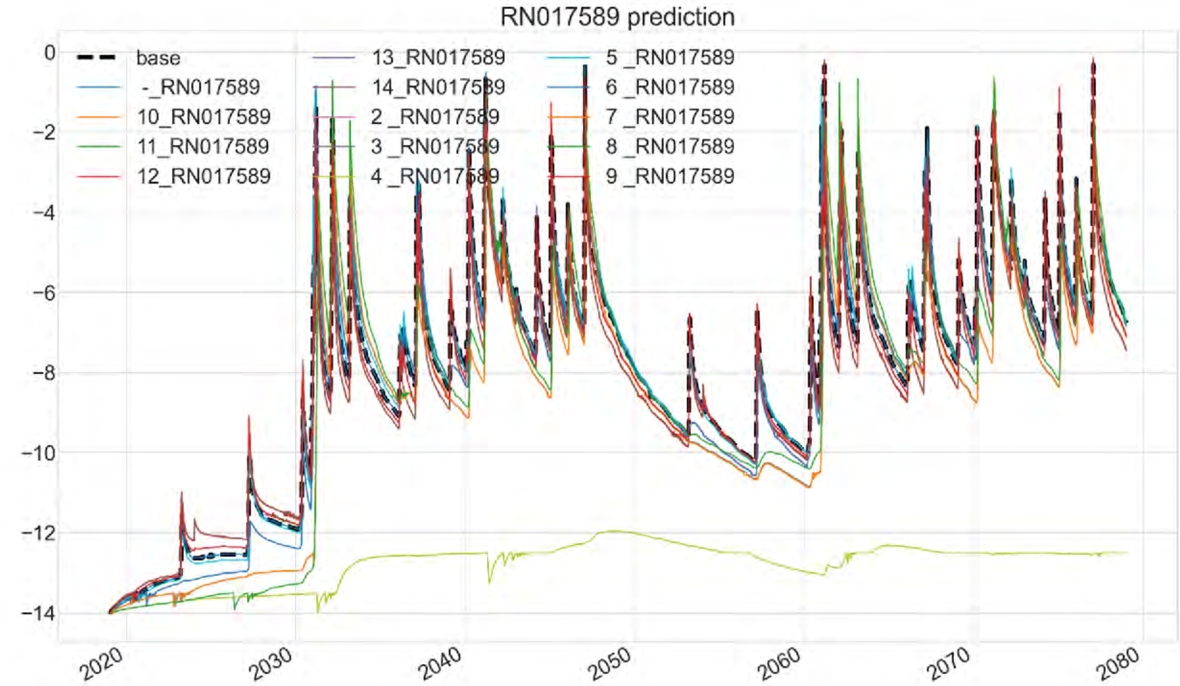
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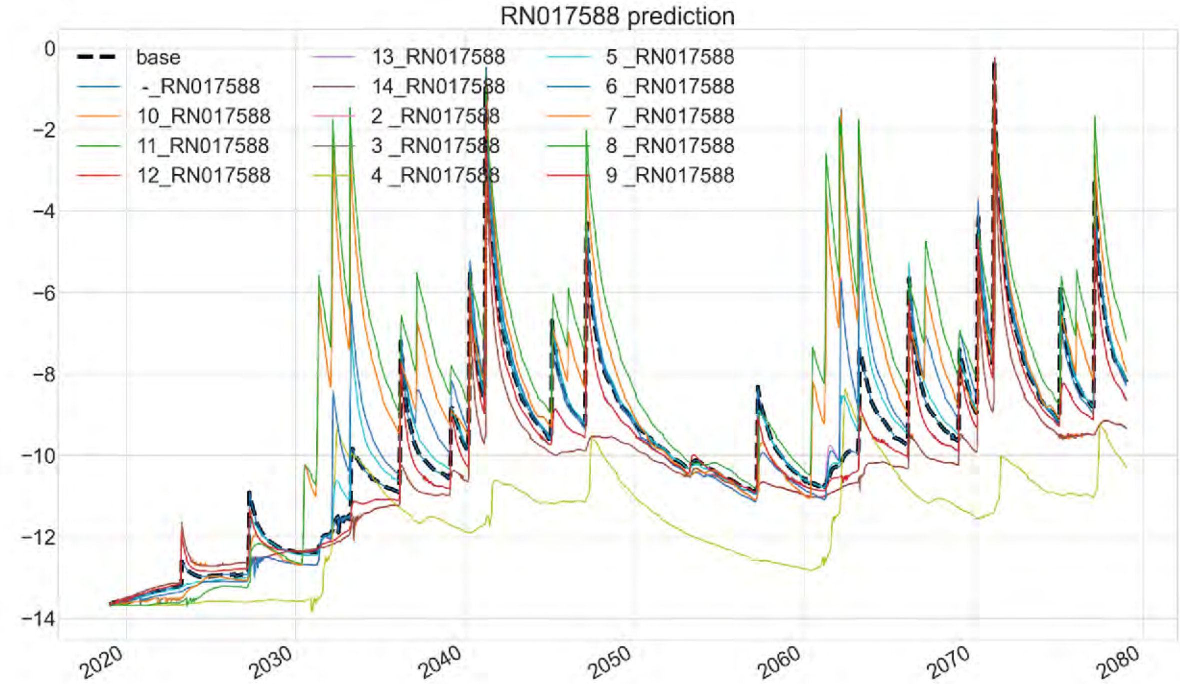
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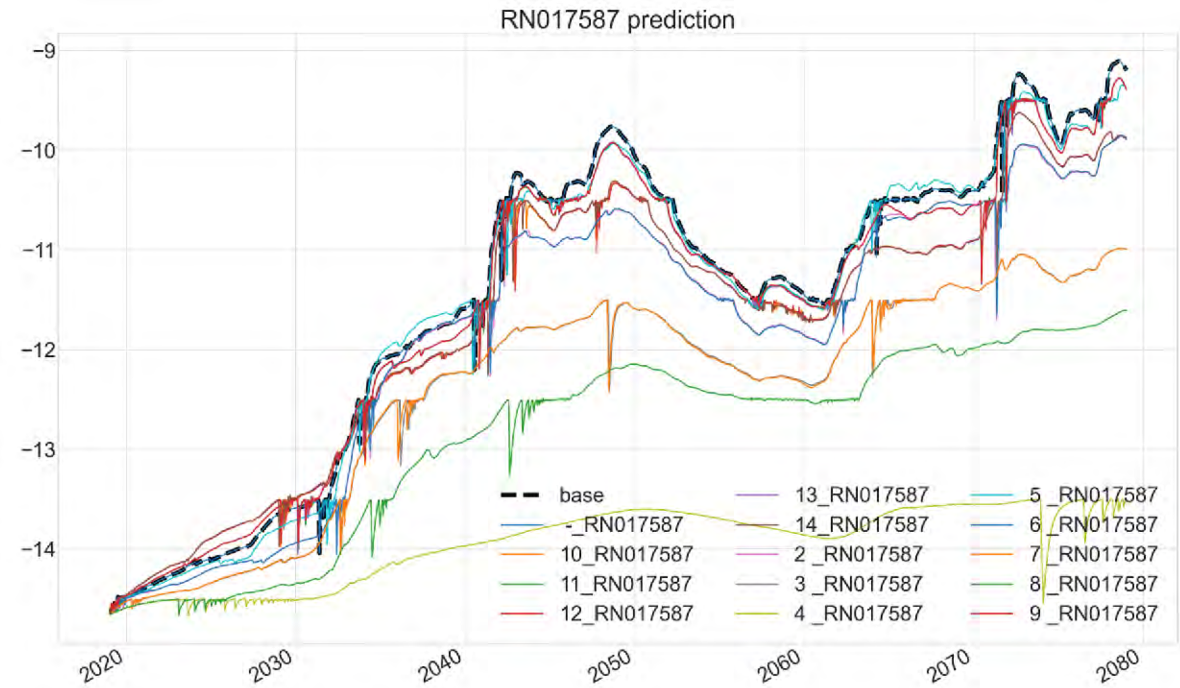
RN017587 prediction
base
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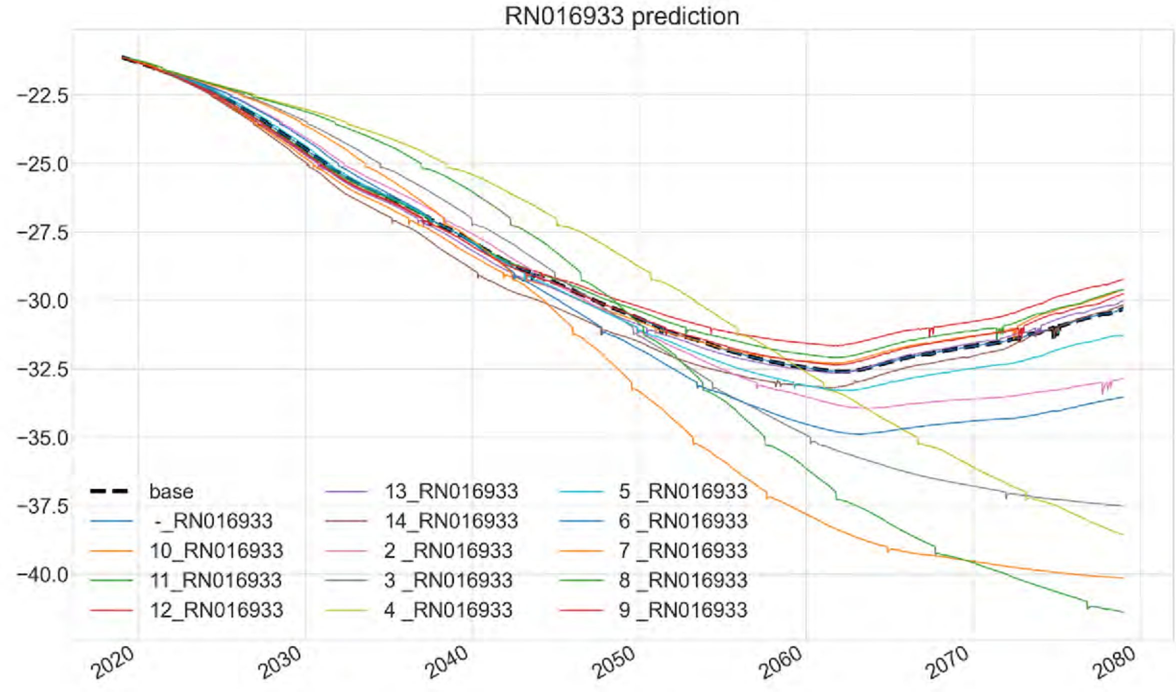
RN016933 prediction
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−32.5
−35.0
−37.5
−40.0
base
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11_RN016933
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3 _RN016933
4 _RN016933
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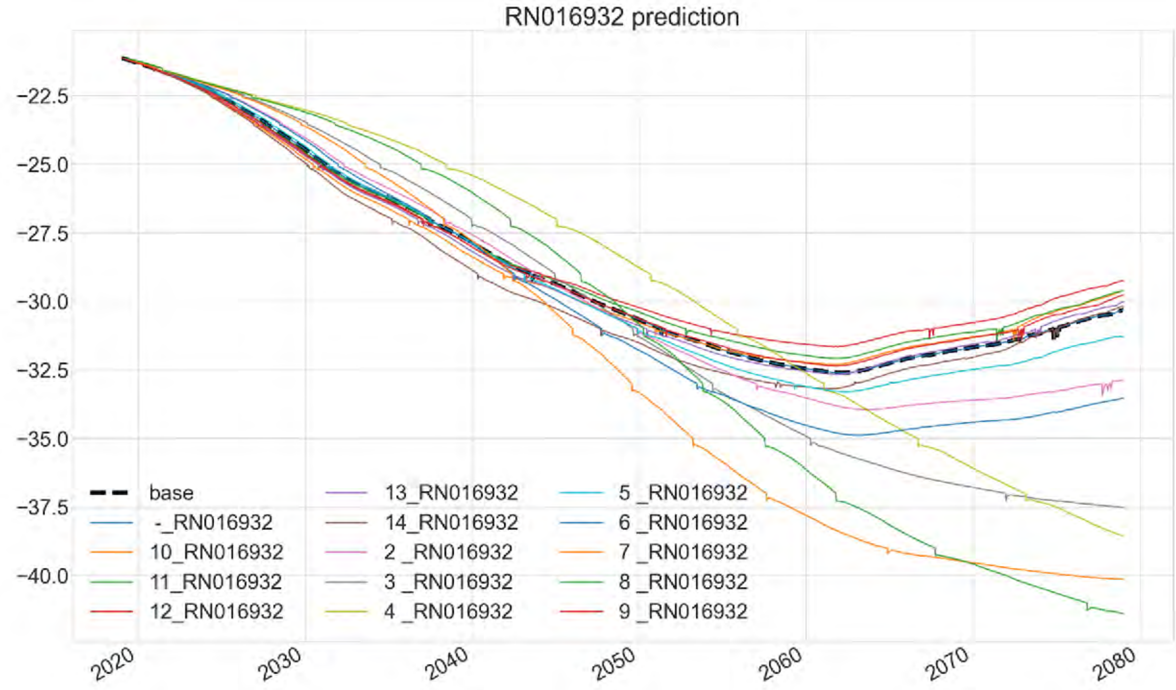
RN016932 prediction
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−30.0
−32.5
−35.0
−37.5
−40.0
base
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10_RN016932
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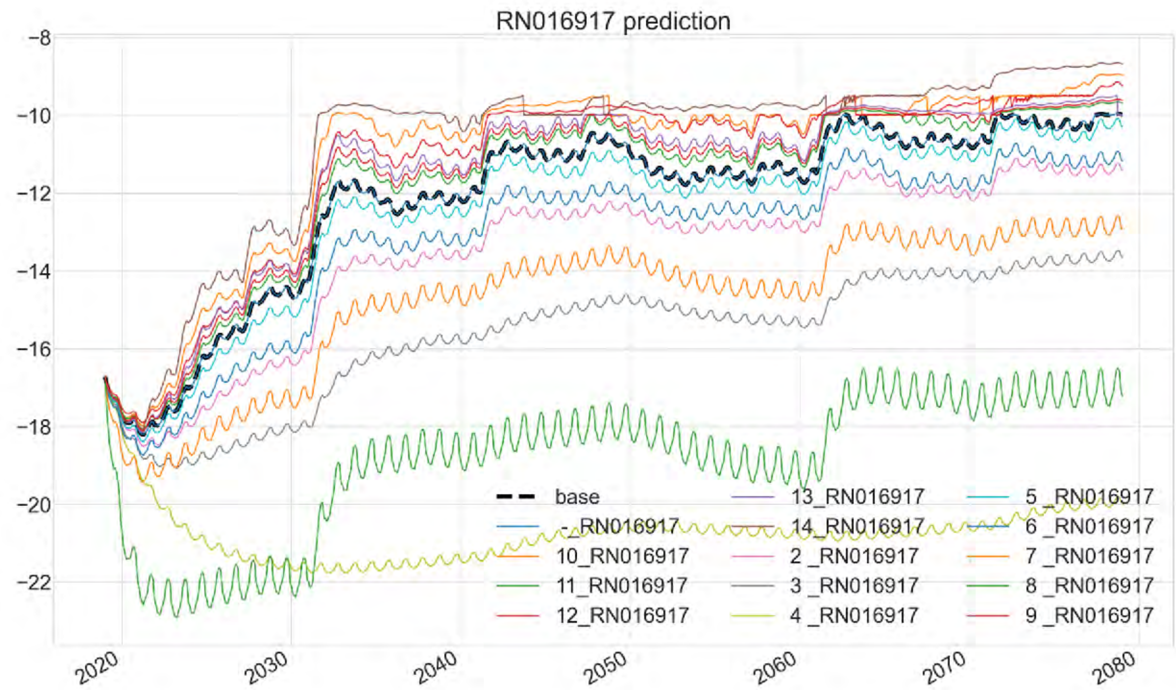
RN016917 prediction
−8
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−14
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−18
−20
−22
2020
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2040
2050
2060
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2080
base
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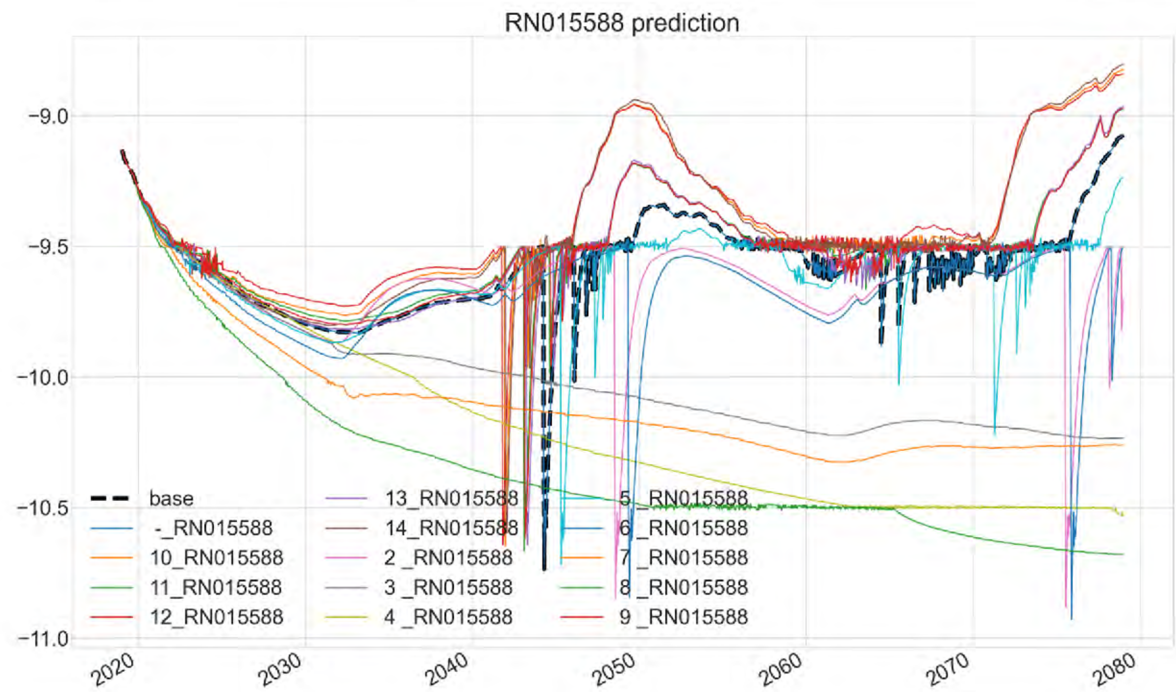
RN015588 prediction
−9.0
−9.5
−10.0
−10.5
−11.0
2020
2030
2040
2050
2060
2070
2080
base
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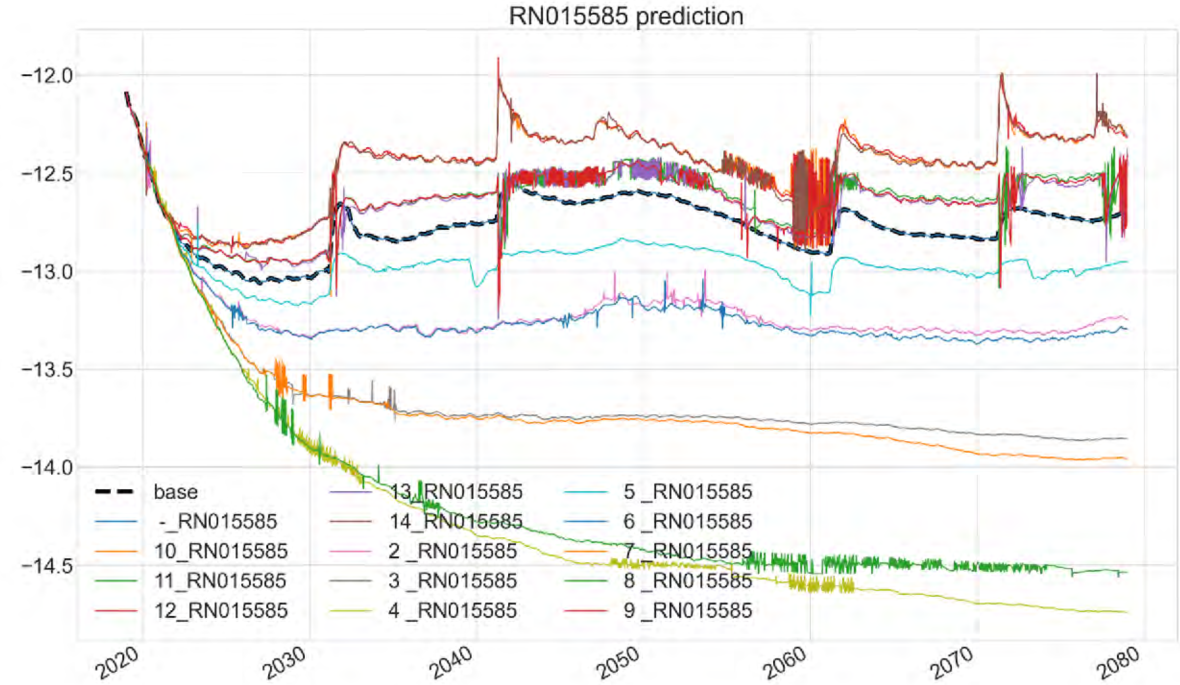
RN015585 prediction
−12.0
−12.5
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−13.5
−14.0
−14.5
base
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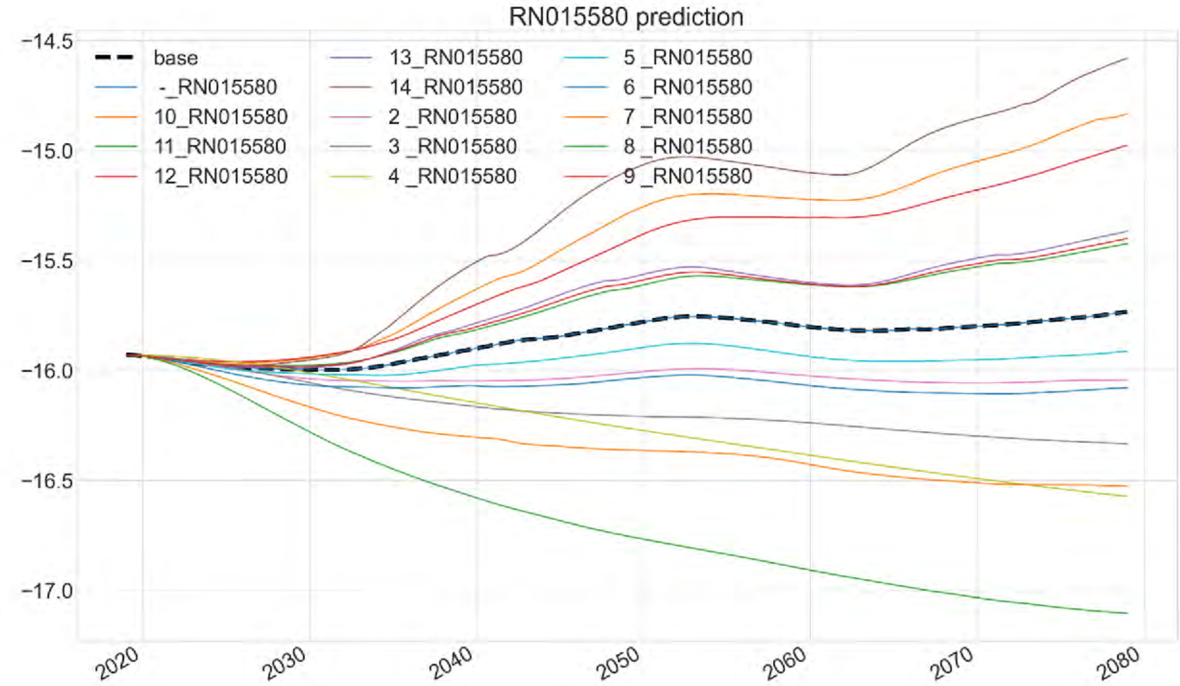
RN015580 prediction
−14.5
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−16.0
−16.5
−17.0
base
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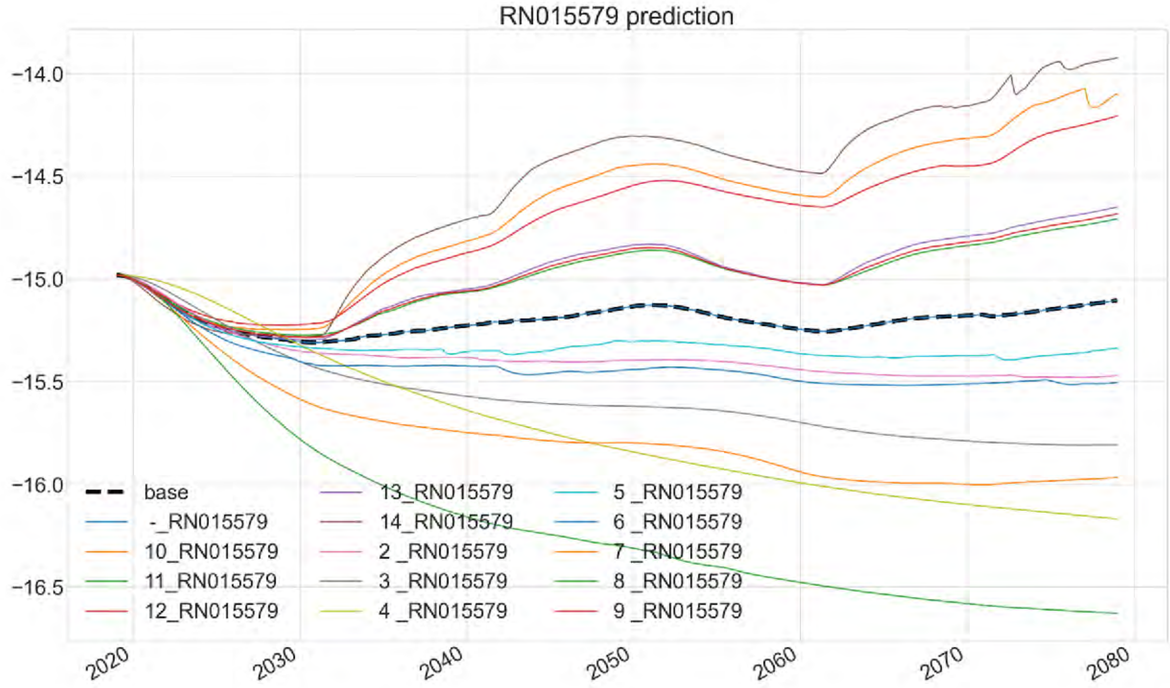
RN015579 prediction
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−14.5
−15.0
−15.5
−16.0
−16.5
2020
2030
2040
2050
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2070
2080
base
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10_RN015579
11_RN015579
12_RN015579
13_RN015579
14_RN015579
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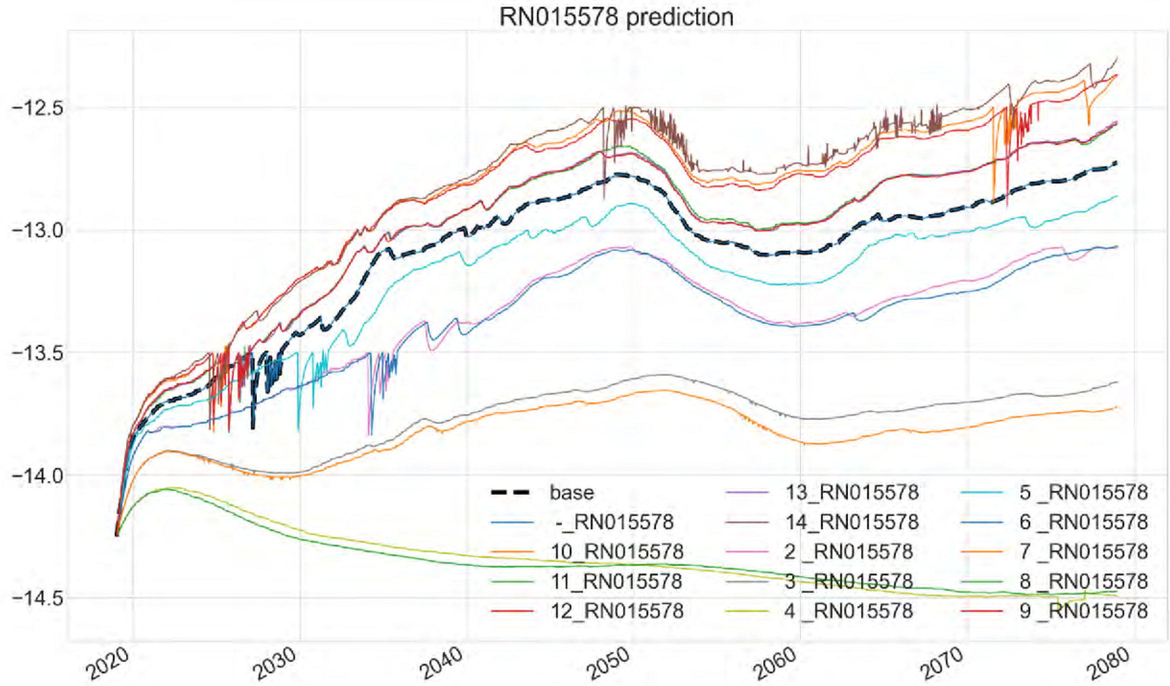
8 _RN015579
9 _RN015579


RN015578 prediction
−12.5
−13.0
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−14.0
−14.5
2020
2030
2040
2050
2060
2070
2080
base
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11_RN015578
12_RN015578
13_RN015578
14_RN015578
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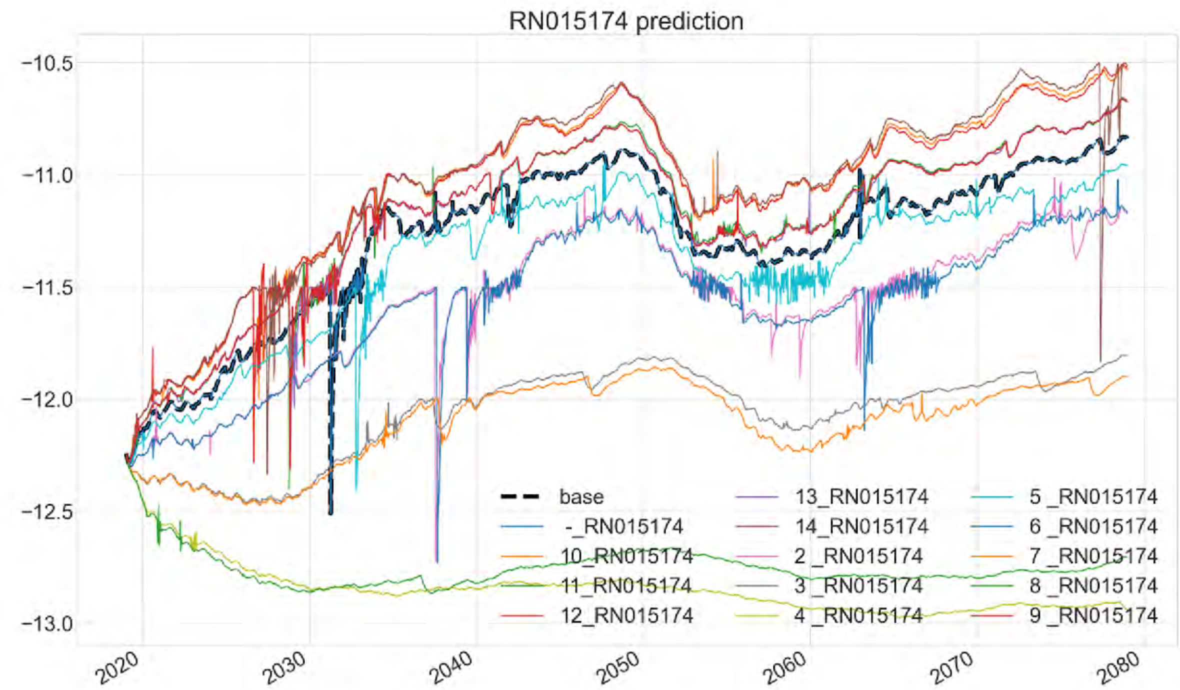
8 _RN015578
9 _RN015578


RN015174 prediction
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−12.5
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2050
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2080
base
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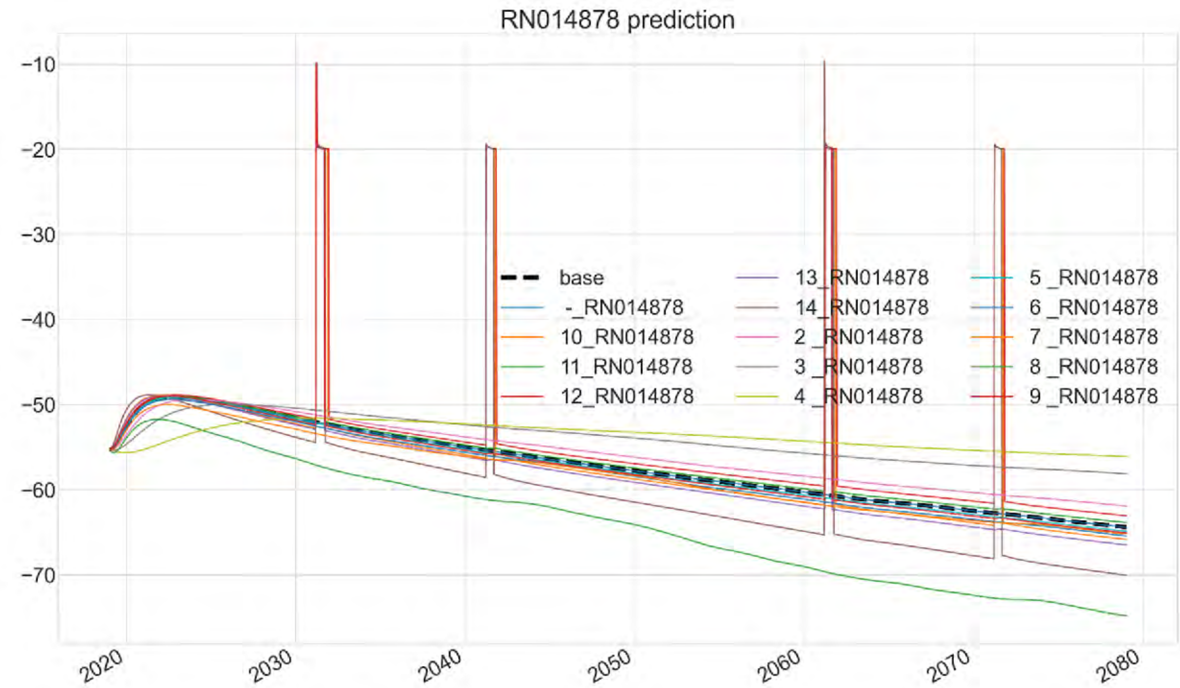
RN014878 prediction
−10
−20
−30
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−50
−60
−70
2020
2030
2040
2050
2060
2070
2080
base
-_RN014878
10_RN014878
11_RN014878
12_RN014878
13_RN014878
14_RN014878
2 _RN014878
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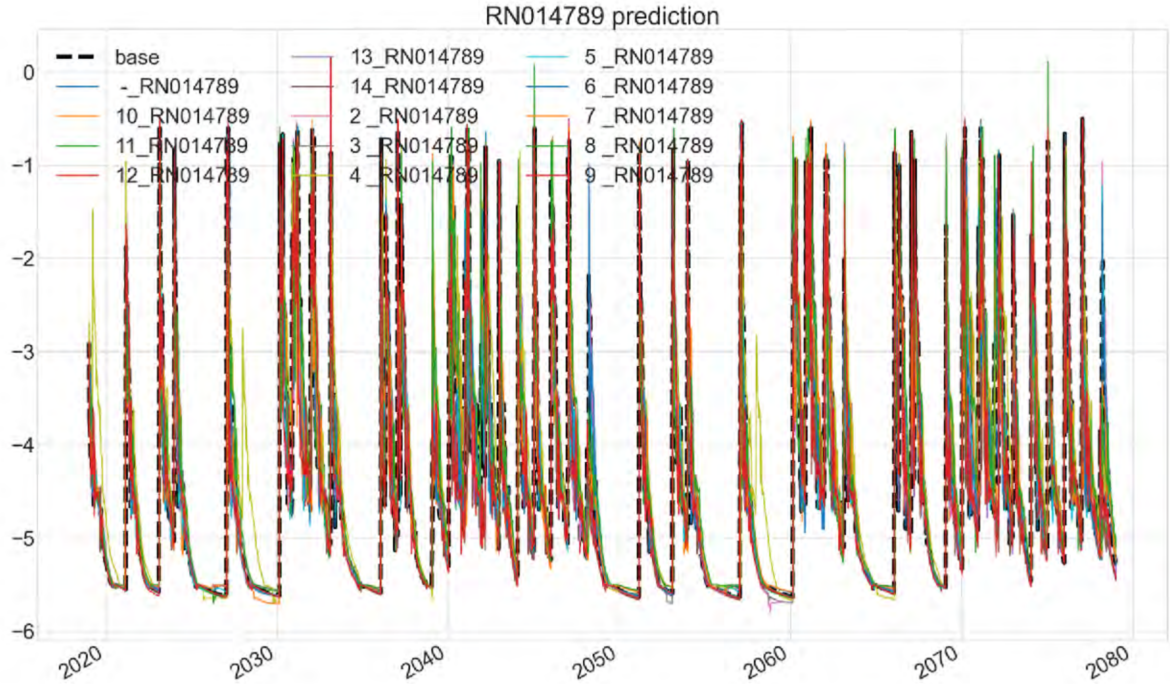
8 _RN014878
9 _RN014878


RN014789 prediction
base
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8_RN014789
9_RN014789
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−6
2020
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2040
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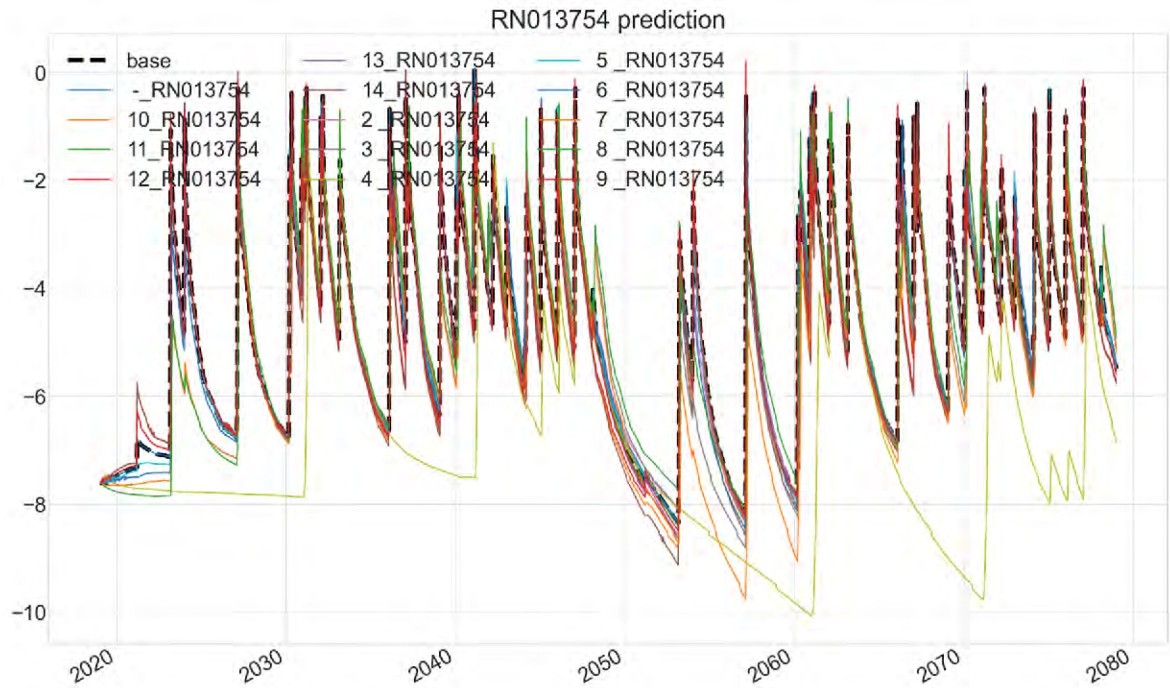
2060
2070
2080


RN013754 prediction
base
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3_RN013754
4_RN013754
5_RN013754
6_RN013754
7_RN013754
8_RN013754
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2060
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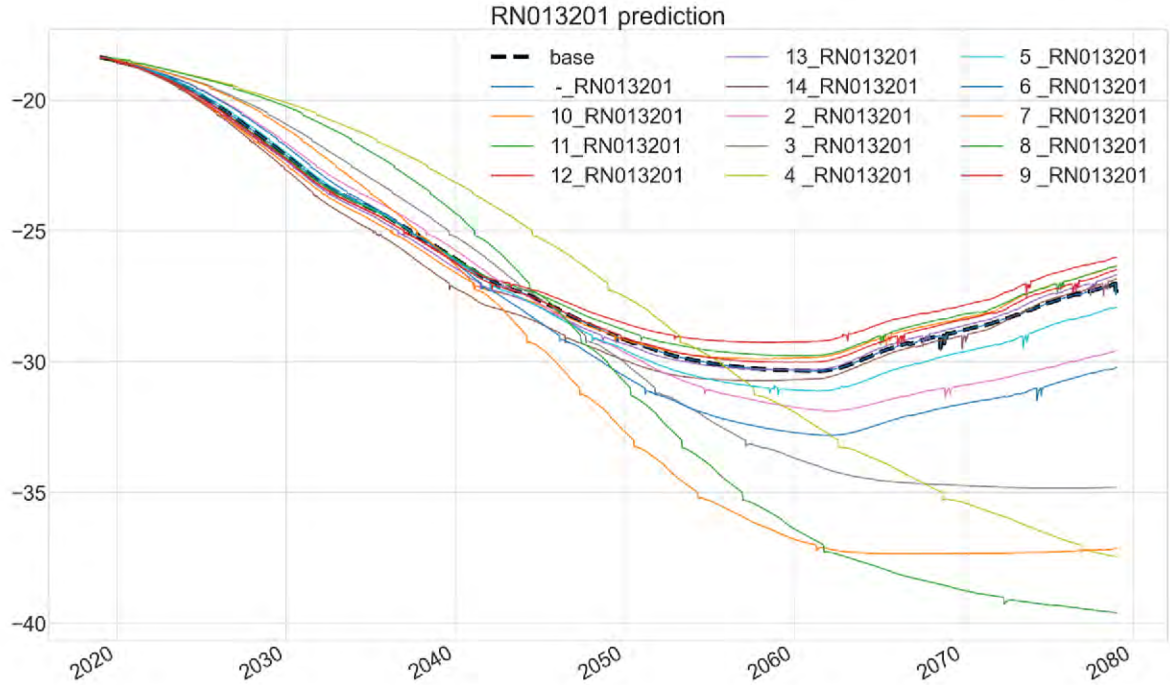
2080



RN013201 prediction
base
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4 _RN013201
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6 _RN013201
7 _RN013201
8 _RN013201
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−20
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−40
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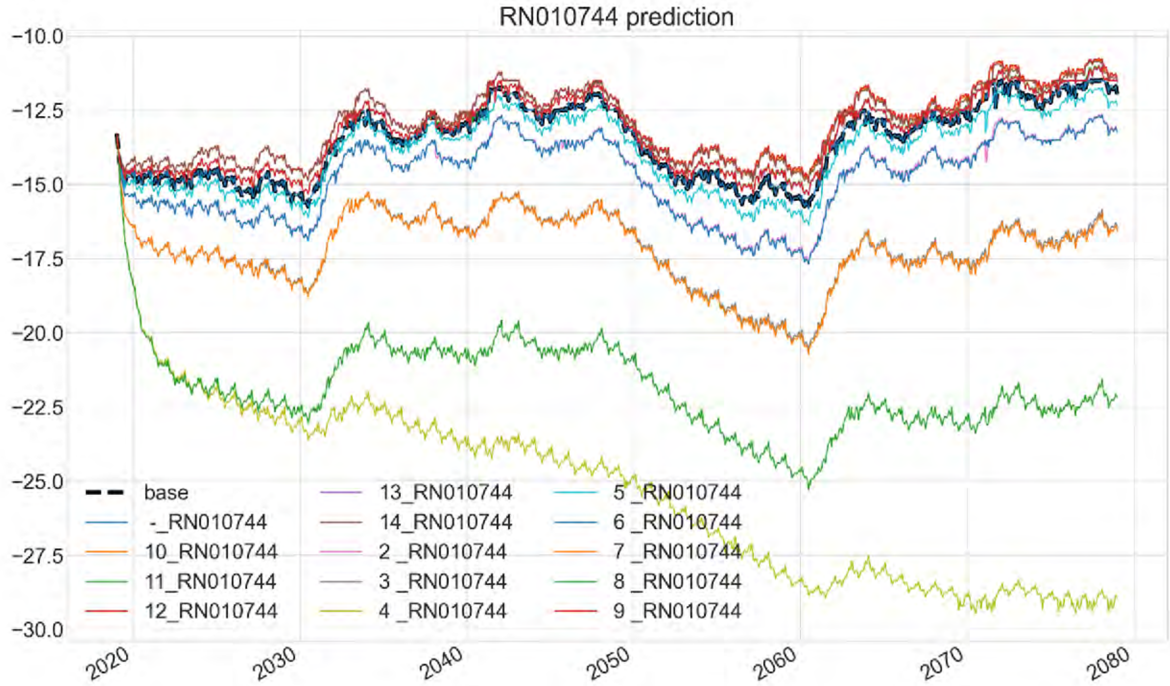
2060
2070
2080



RN010744 prediction
base
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4 _RN010744
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6 _RN010744
7 _RN010744
8 _RN010744
9 _RN010744
−10.0
−12.5
−15.0
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2060
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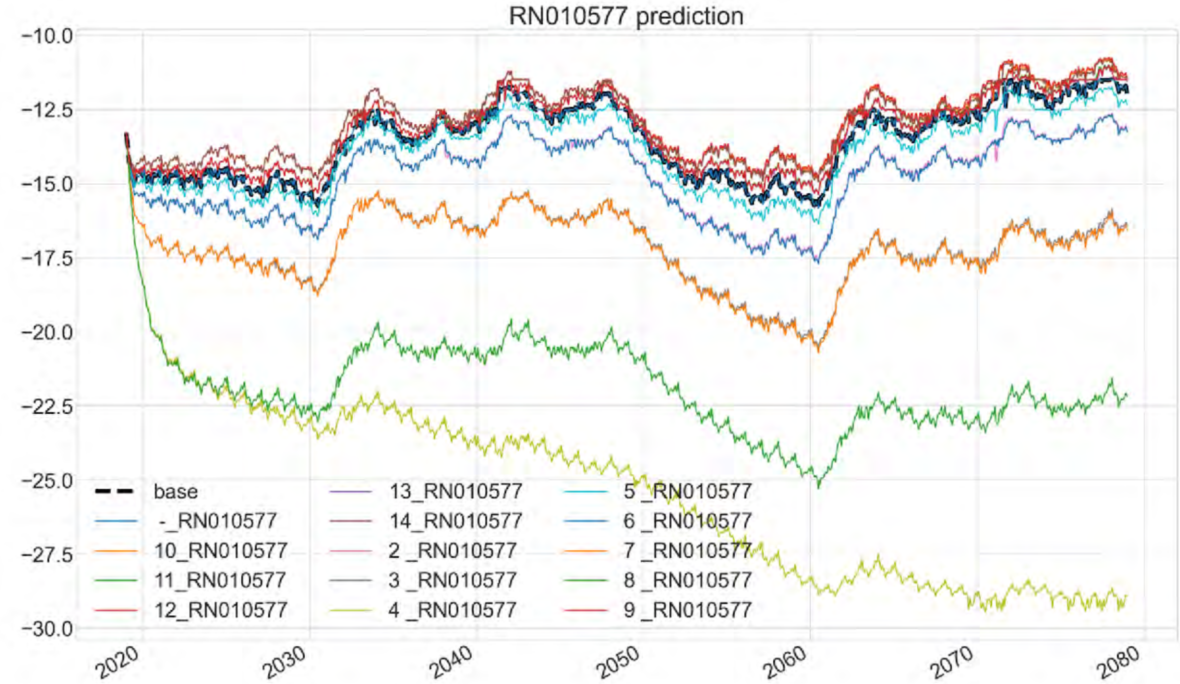
2080


RN010577 prediction
base
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4 _RN010577
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6 _RN010577
7 _RN010577
8 _RN010577
9 _RN010577
−10.0
−12.5
−15.0
−17.5
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2060
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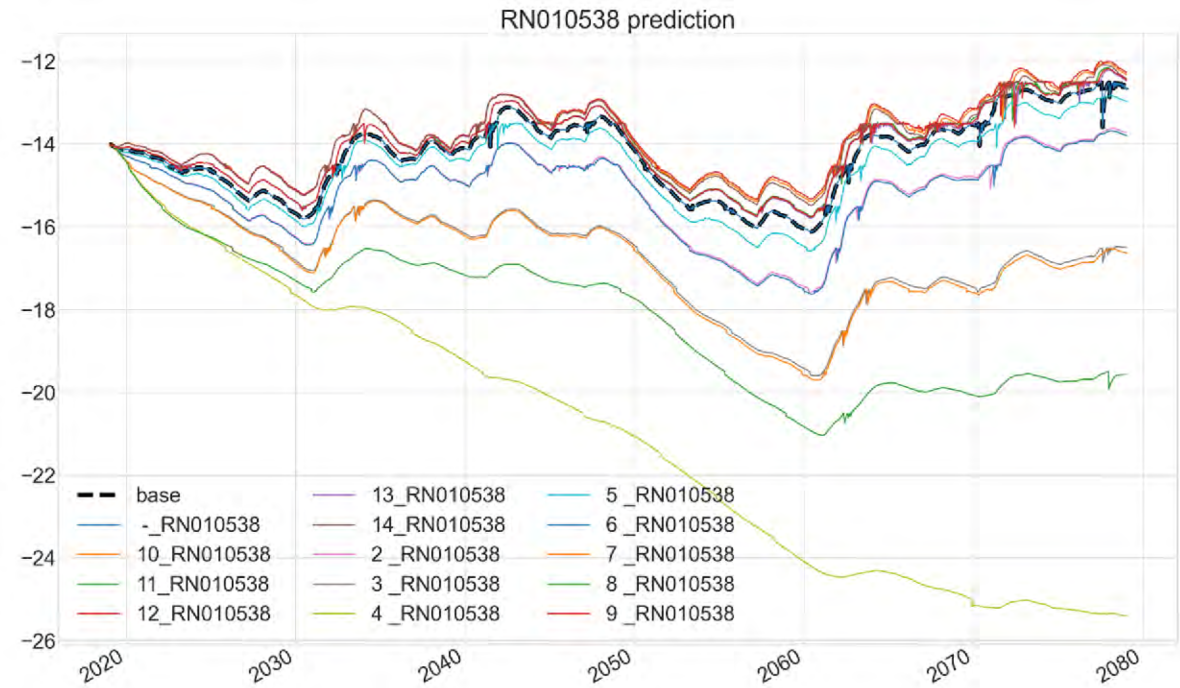
RN010538 prediction
base
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11_RN010538
12_RN010538
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14_RN010538
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4 _RN010538
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6 _RN010538
7 _RN010538
8 _RN010538
9 _RN010538
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−14
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−18
−20
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−26
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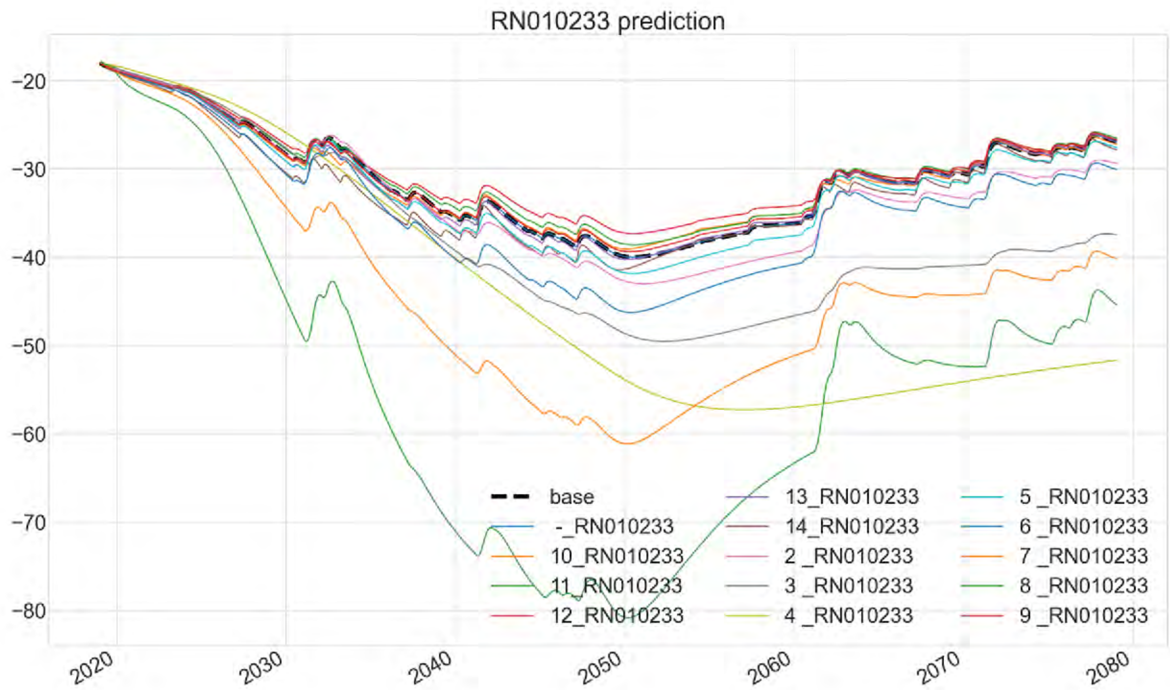
2060
2070
2080


RN010233 prediction
-20
-30
-40
-50
-60
-70
-80
2020
2030
2040
2050
2060
2070
2080
base
-_RN010233
10_RN010233
11_RN010233
12_RN010233
13_RN010233
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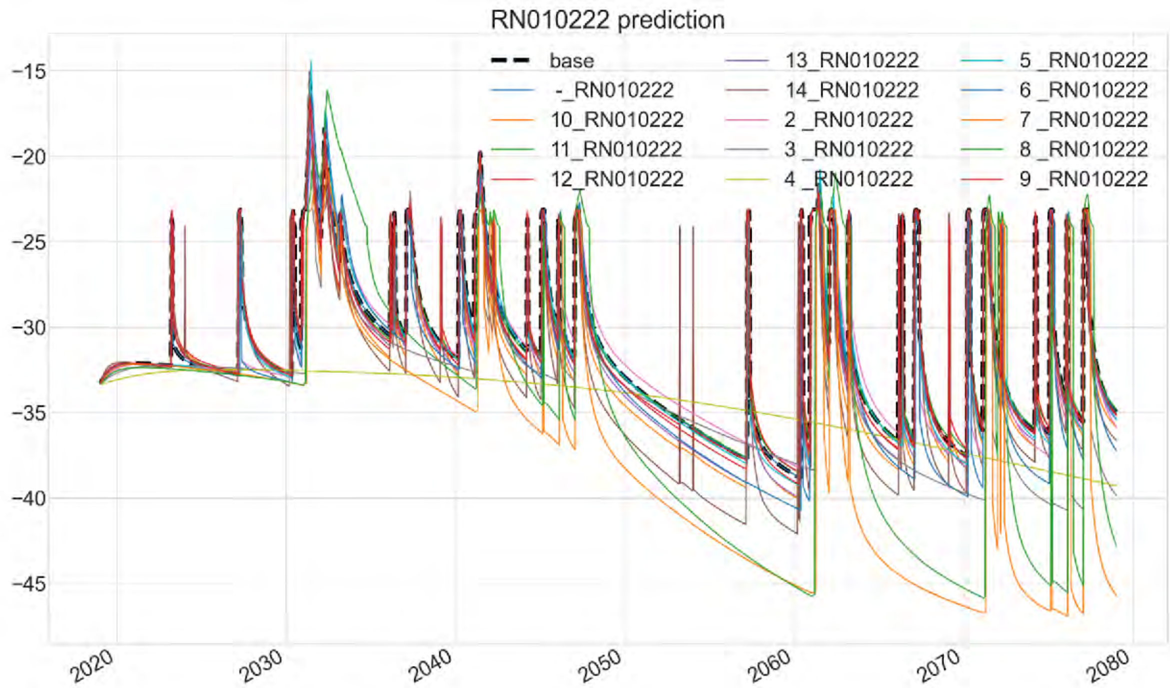
9 _RN010233


RN010222 prediction
-15
-20
-25
-30
-35
-40
-45
2020
2030
2040
2050
2060
2070
2080
base
-_RN010222
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12_RN010222
13_RN010222
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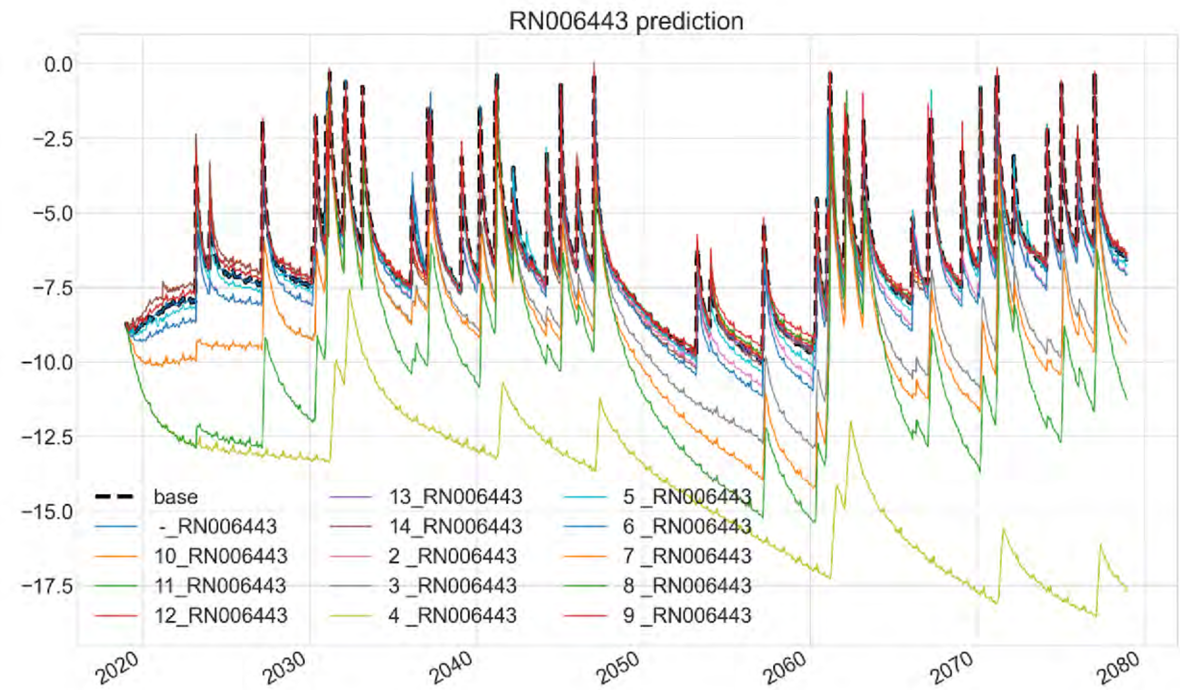
RN006443 prediction
0.0
−2.5
−5.0
−7.5
−10.0
−12.5
−15.0
−17.5
base
-_RN006443
10_RN006443
11_RN006443
12_RN006443
13_RN006443
14_RN006443
2 _RN006443
3 _RN006443
4 _RN006443
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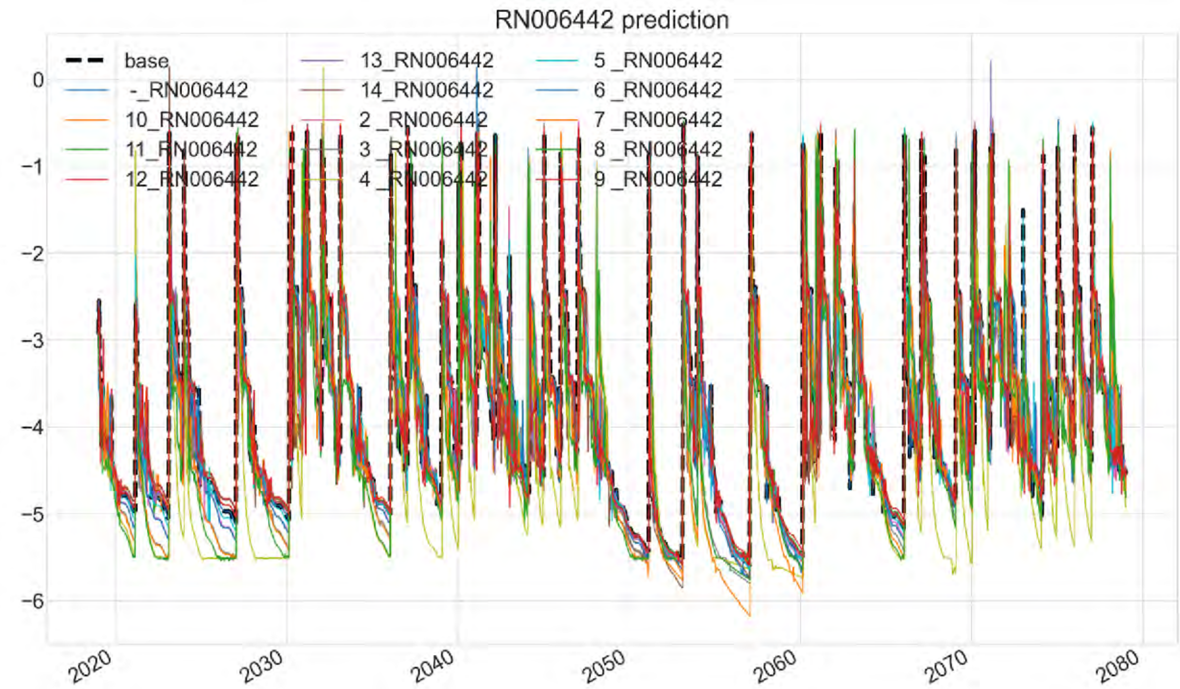
2060
2070
2080


RN006442 prediction
0
−1
−2
−3
−4
−5
−6
base
-_RN006442
10_RN006442
11_RN006442
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14_RN006442
2 _RN006442
3 _RN006442
4 _RN006442
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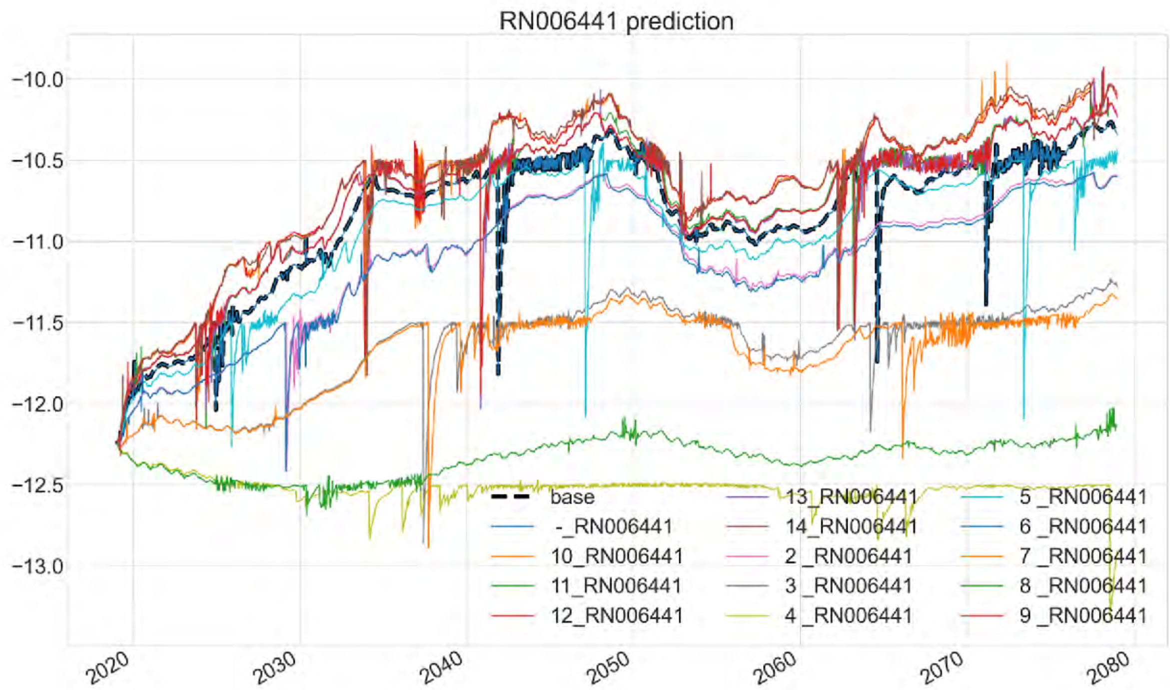
2060
2070
2080



RN006441 prediction
−10.0
−10.5
−11.0
−11.5
−12.0
−12.5
−13.0
2020
2030
2040
2050
2060
2070
2080
base
-_RN006441
10_RN006441
11_RN006441
12_RN006441
13_RN006441
14_RN006441
2 _RN006441
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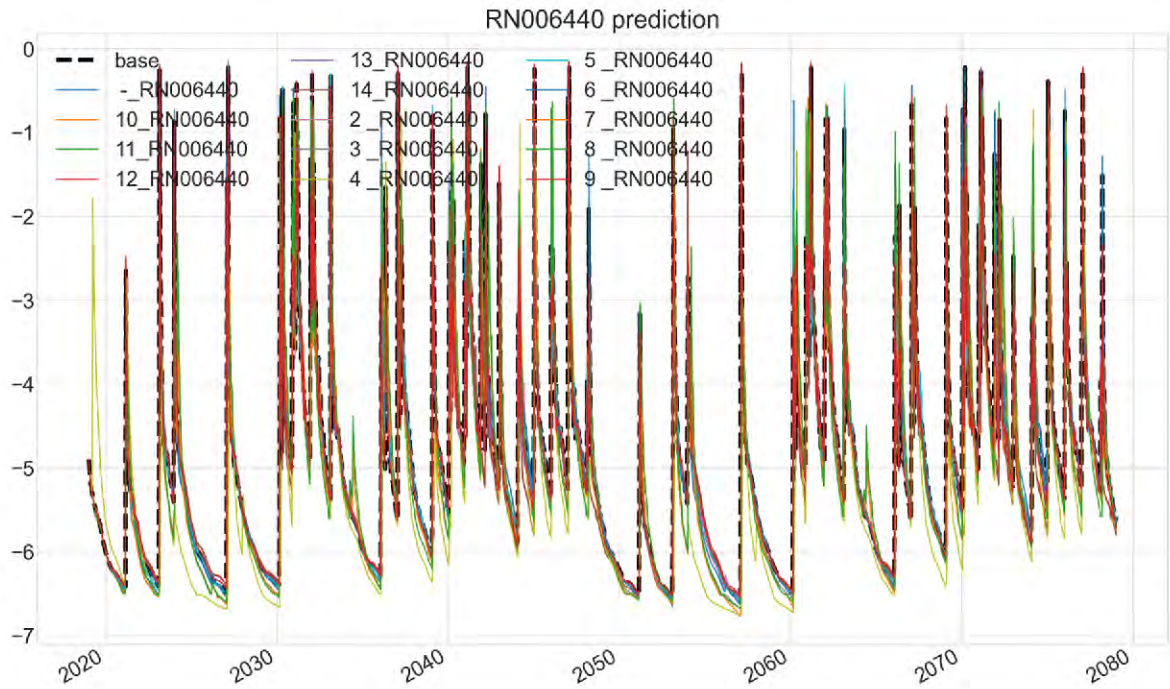

RN006440 prediction
0
−1
−2
−3
−4
−5
−6
−7
2020
2030
2040
2050
2060
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2080
base
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10_RN006440
11_RN006440
12_RN006440
13_RN006440
14_RN006440
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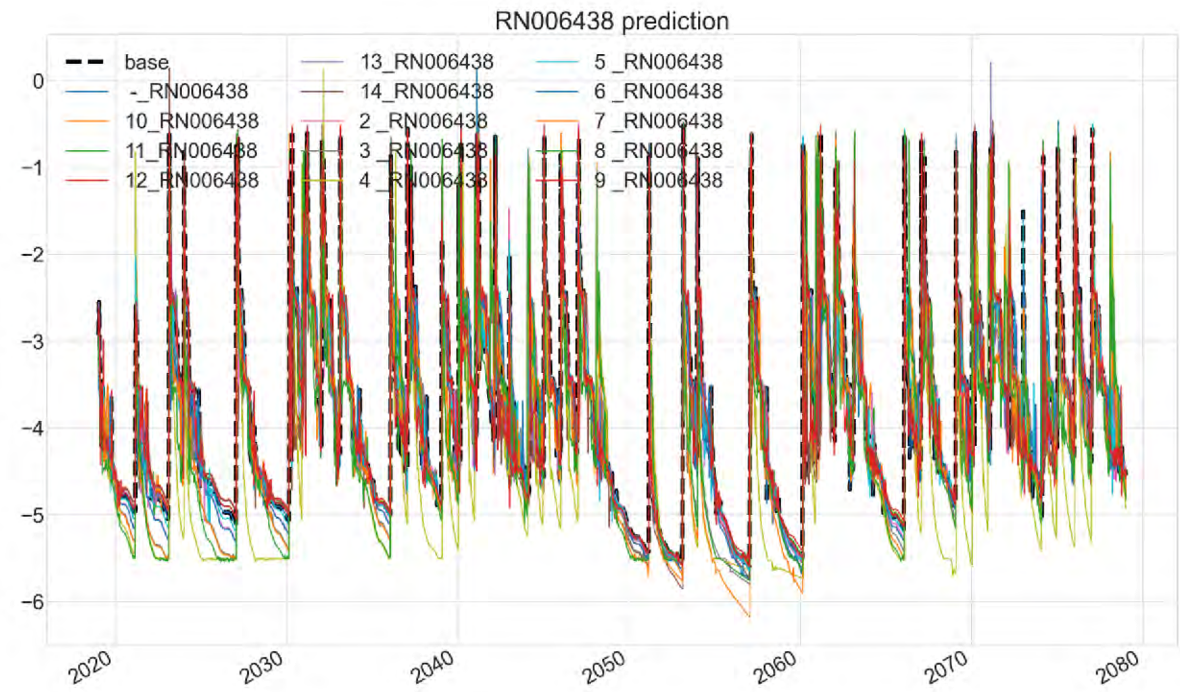
RN006438 prediction
base
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14_RN006438
2 _RN006438
3 _RN006438
4 _RN006438
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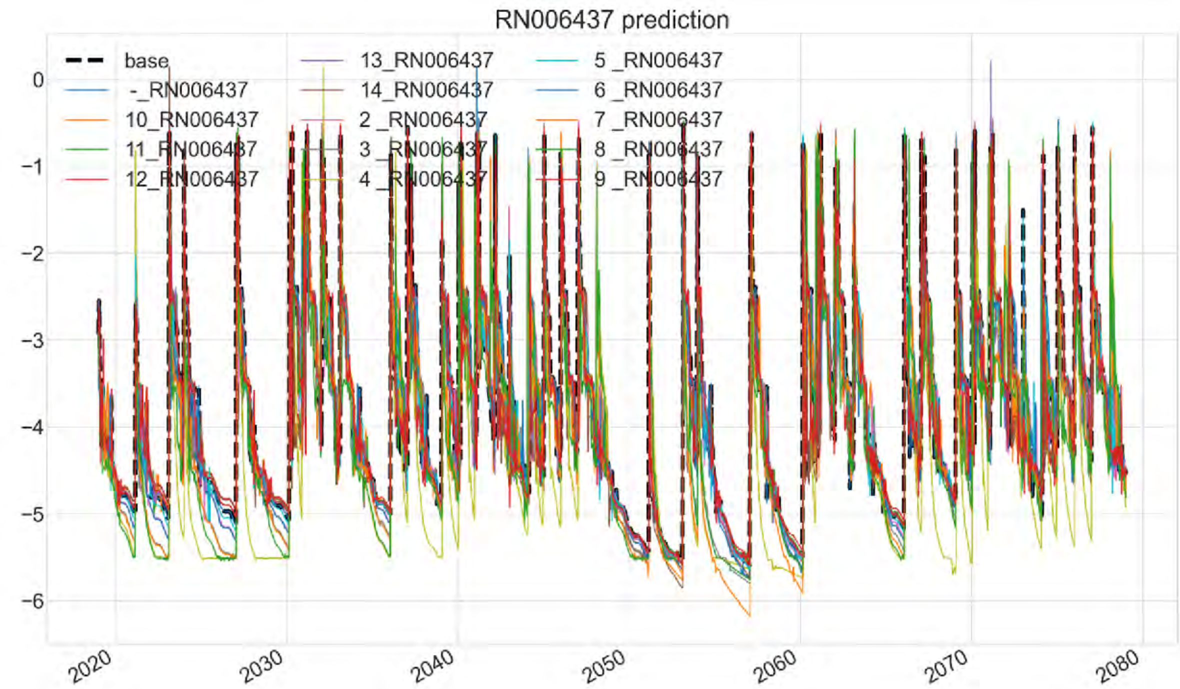
6 _RN006438
7 _RN006438
8 _RN006438
9 _RN006438
0
−1
−2
−3
−4
−5
−6
2020
2030
2040
2050
2060
2070
2080


RN006437 prediction
base
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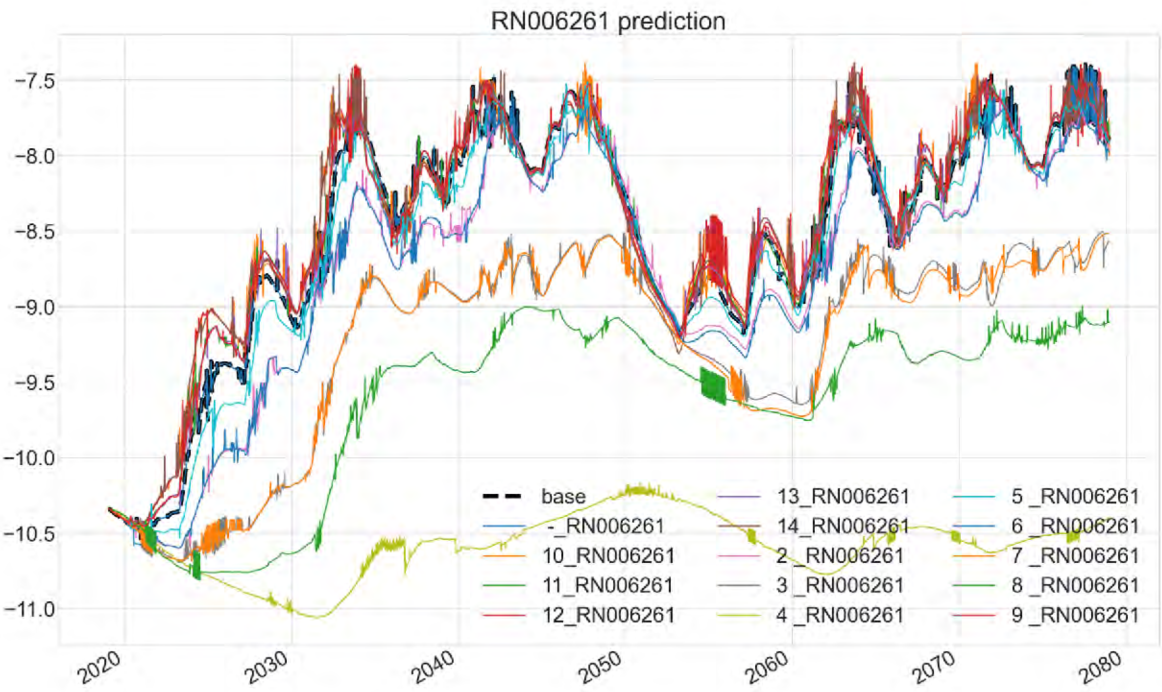
10_RN006437
11_RN006437
12_RN006437
13_RN006437
14_RN006437
2 _RN006437
3 _RN006437
4 _RN006437
5 _RN006437
6 _RN006437
7 _RN006437
8 _RN006437
9 _RN006437
0
−1
−2
−3
−4
−5
−6
2020
2030
2040
2050
2060
2070
2080



RN006261 prediction
-7.5
-8.0
-8.5
-9.0
-9.5
-10.0
-10.5
-11.0
2020
2030
2040
2050
2060
2070
2080
base
-_RN006261
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11_RN006261
12_RN006261
13_RN006261
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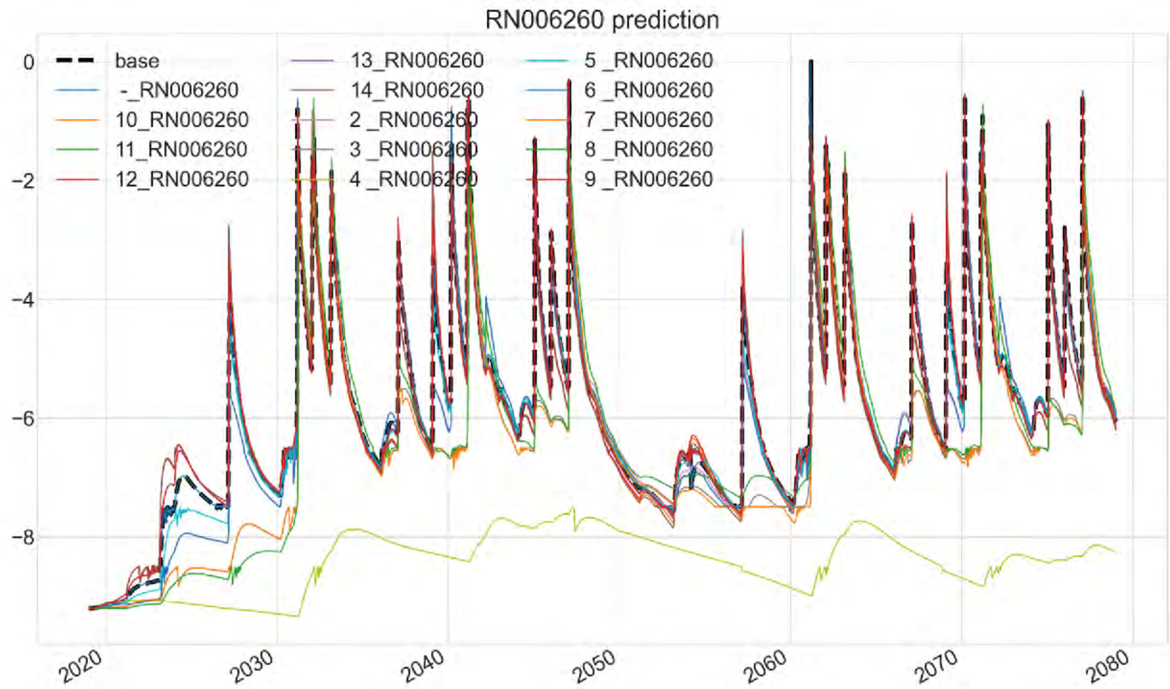

RN006260 prediction
0
-2
-4
-6
-8
2020
2030
2040
2050
2060
2070
2080
base
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11_RN006260
12_RN006260
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14_RN006260
2 _RN006260
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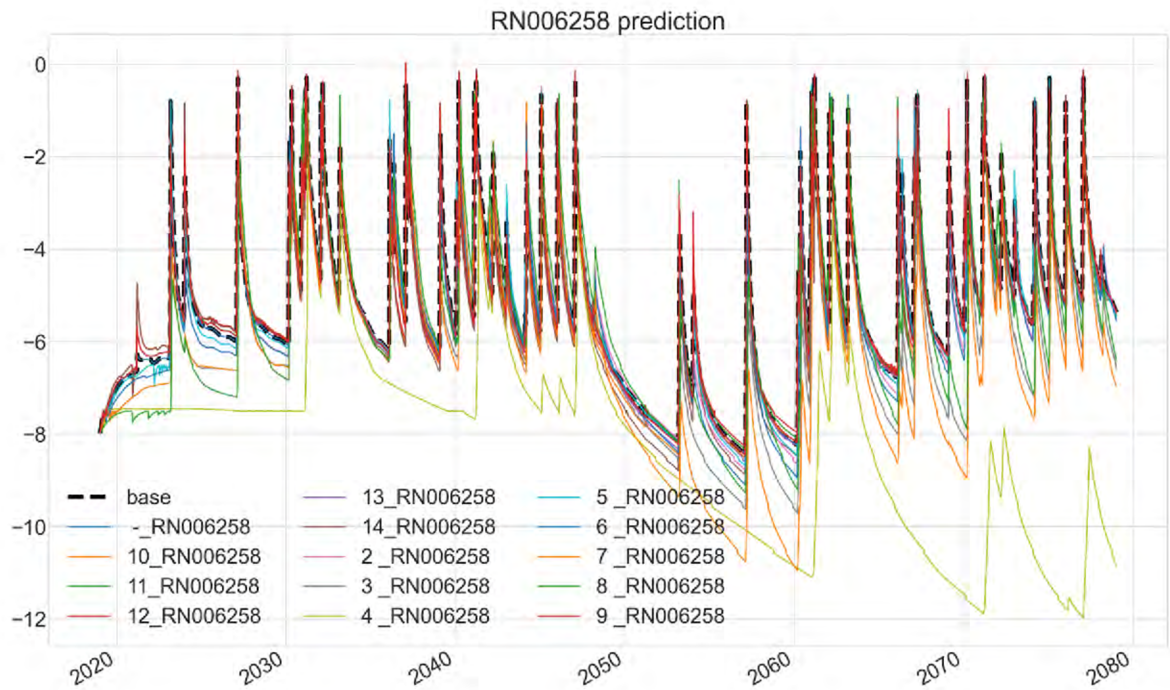
9 _RN006260


RN006258 prediction
0
−2
−4
−6
−8
−10
−12
2020
2030
2040
2050
2060
2070
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base
-_RN006258
10_RN006258
11_RN006258
12_RN006258
13_RN006258
14_RN006258
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3 _RN006258
4 _RN006258
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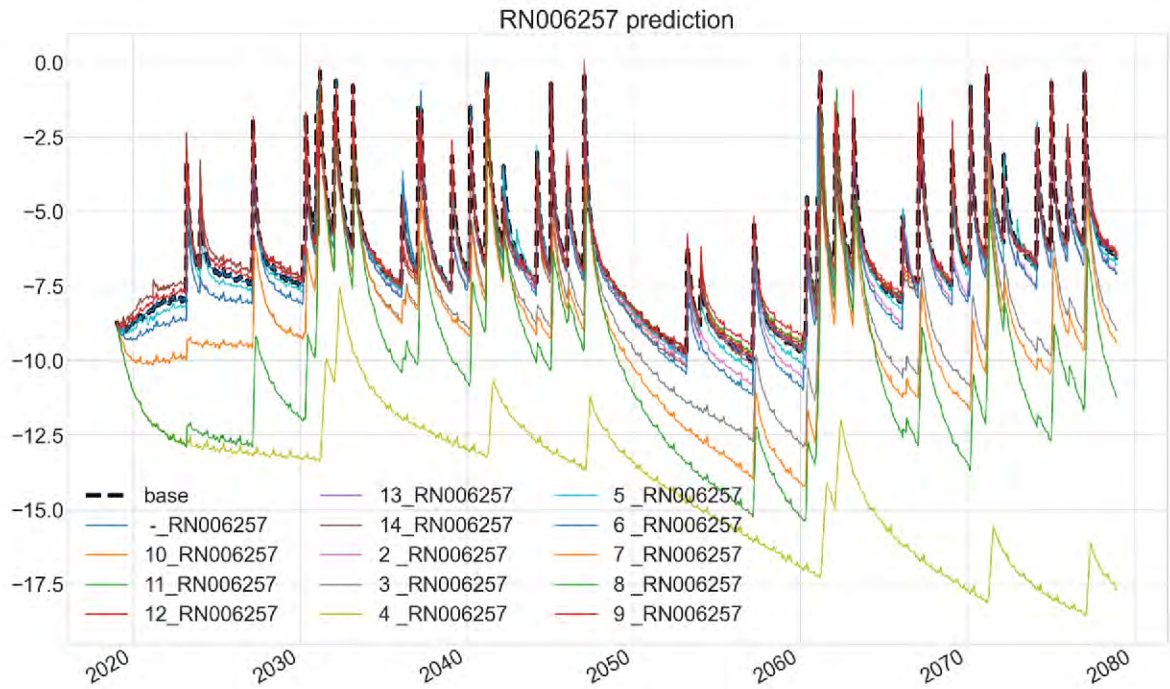
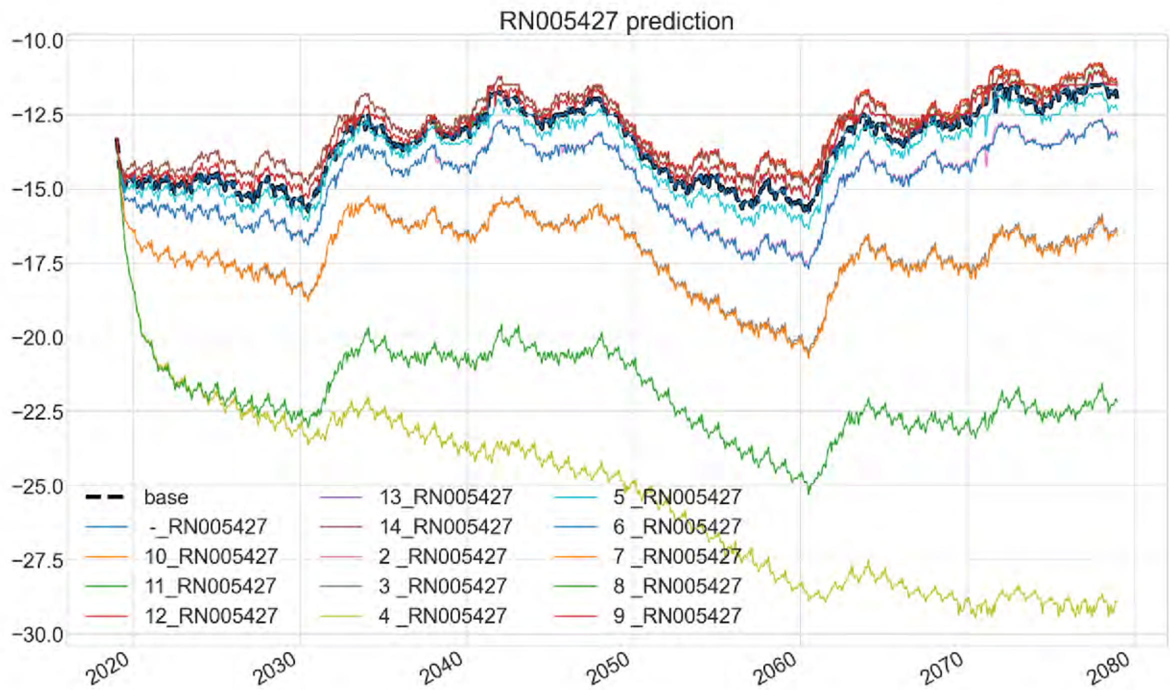
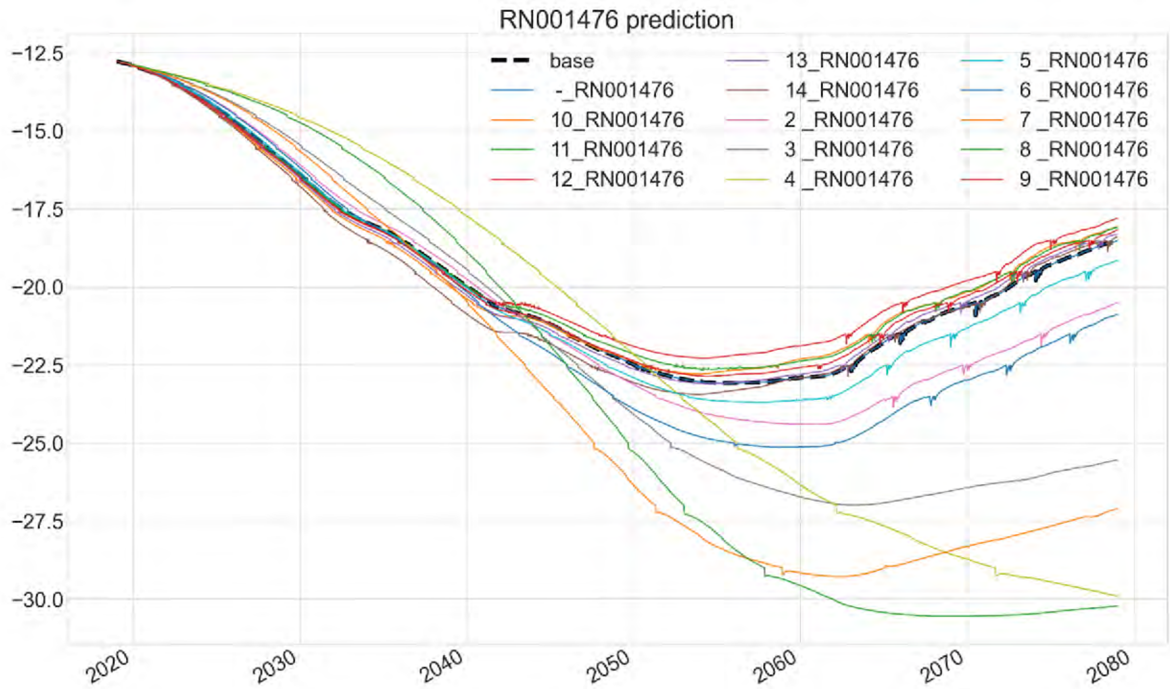
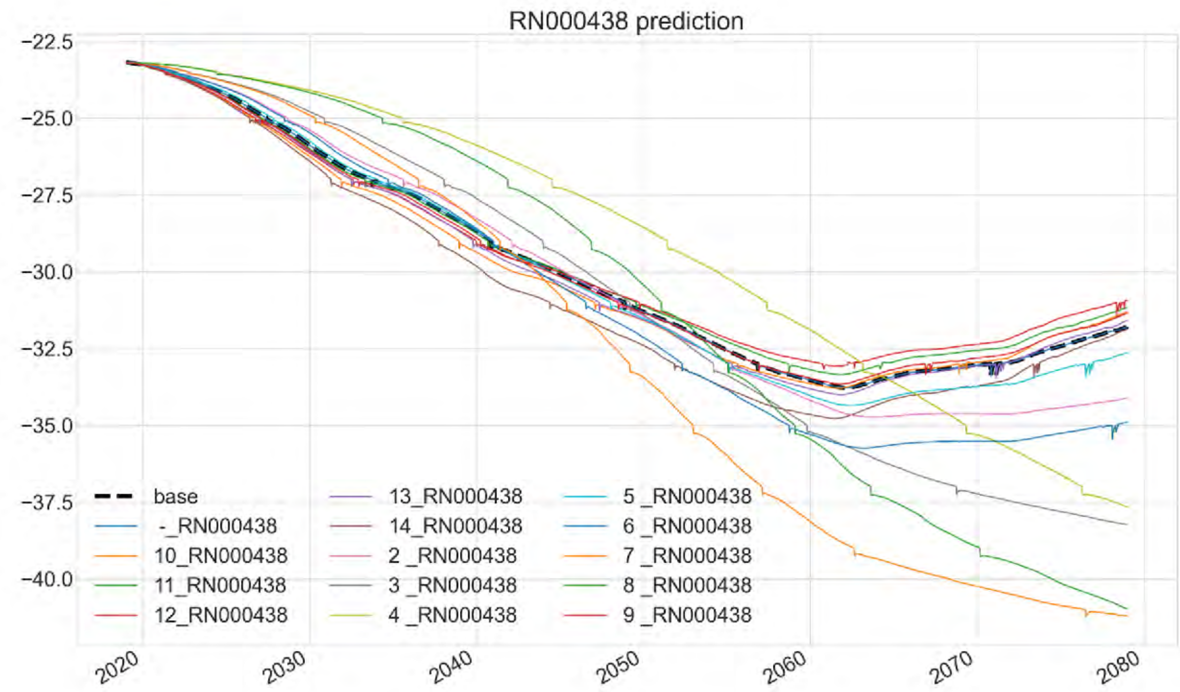
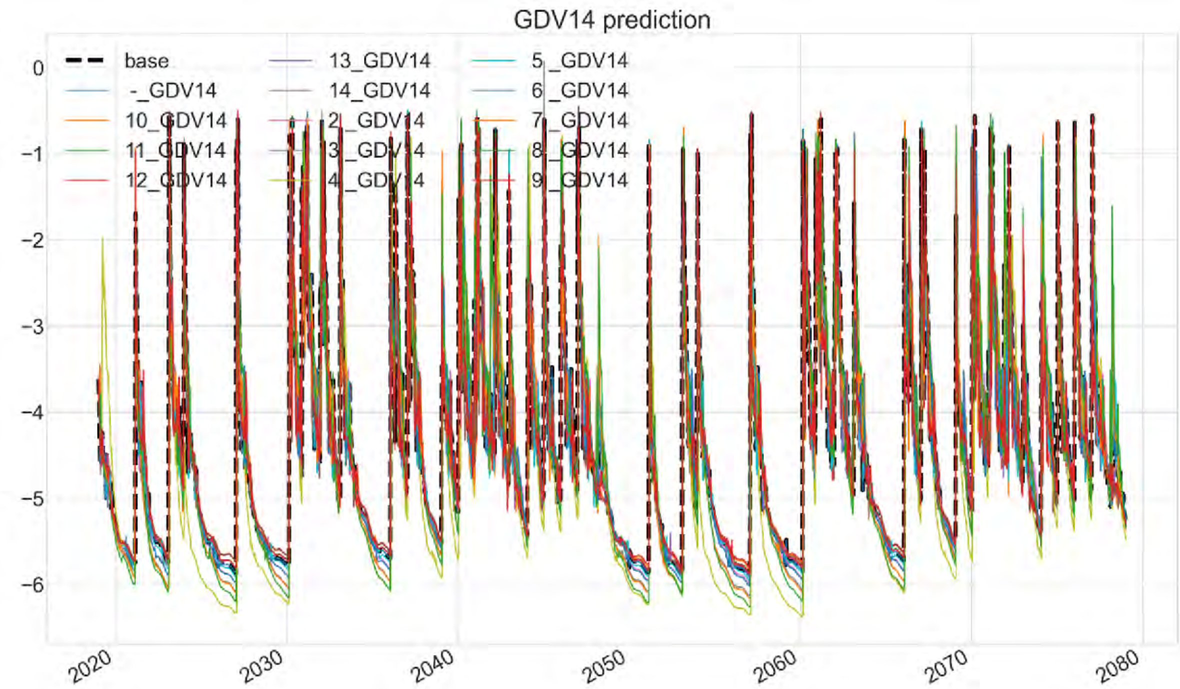
7 _RN006258
8 _RN006258
9 _RN006258

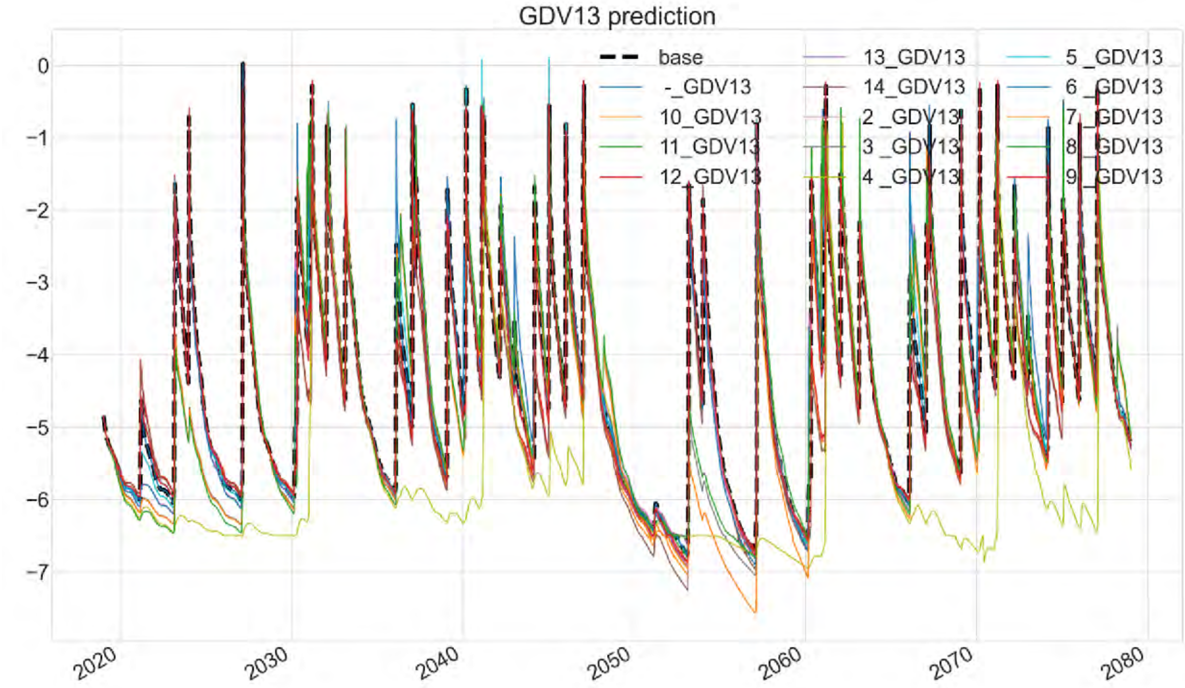

RN006257 prediction
0.0
−2.5
−5.0
−7.5
−10.0
−12.5
−15.0
−17.5
2020
2030
2040
2050
2060
2070
2080
base
-_RN006257
10_RN006257
11_RN006257
12_RN006257
13_RN006257
14_RN006257
2 _RN006257
3 _RN006257
4 _RN006257
5 _RN006257
6 _RN006257
7 _RN006257
8 _RN006257
9 _RN006257

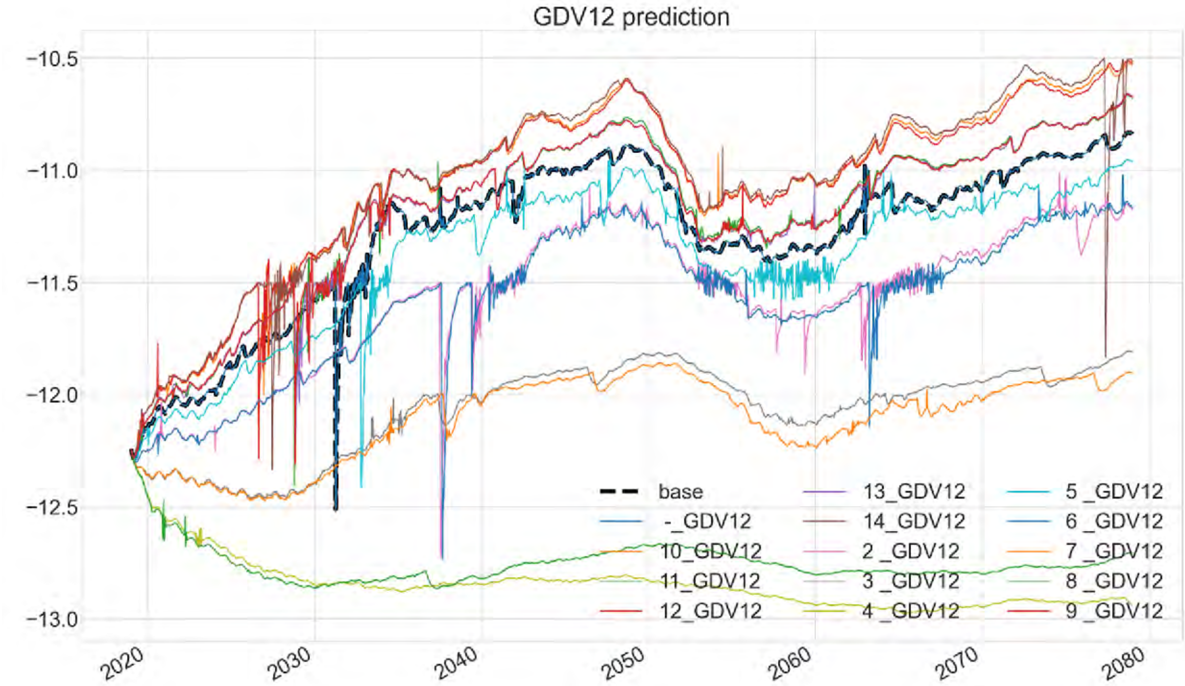

RN005427 prediction
−10.0
−12.5
−15.0
−17.5
−20.0
−22.5
−25.0
−27.5
−30.0
2020
2030
2040
2050
2060
2070
2080
base
-_RN005427
10_RN005427
11_RN005427
12_RN005427
13_RN005427
14_RN005427
2 _RN005427
3 _RN005427
4 _RN005427
5 _RN005427
6 _RN005427
7 _RN005427
8 _RN005427
9 _RN005427

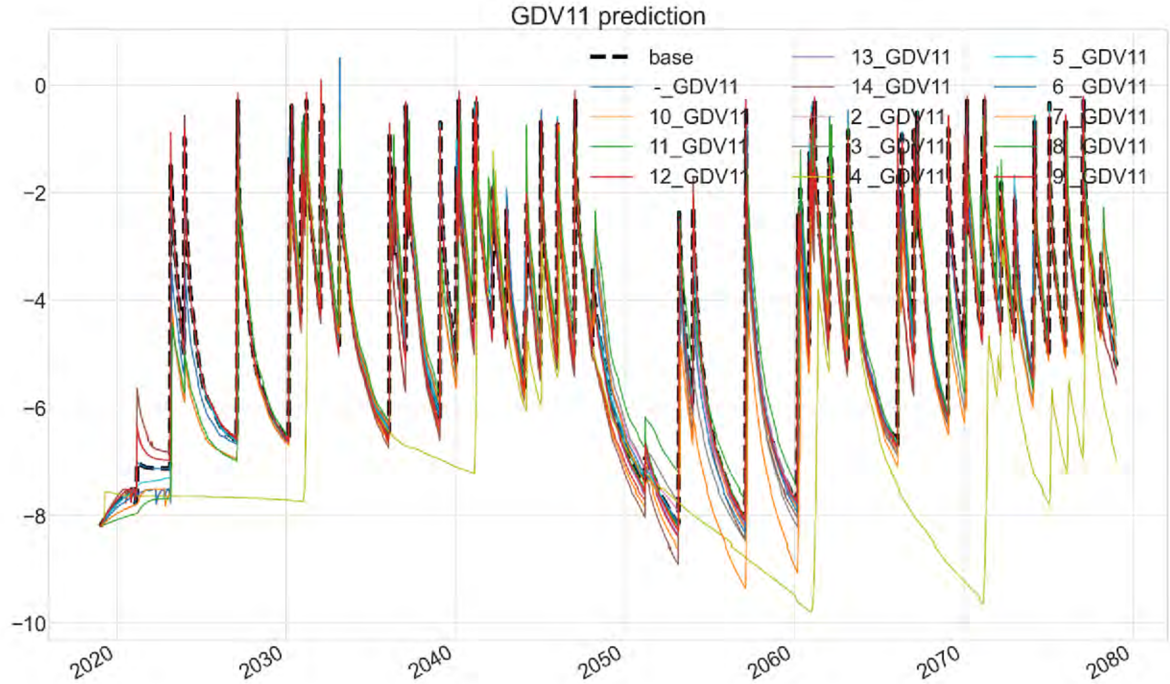

RN001476 prediction
−12.5
−15.0
−17.5
−20.0
−22.5
−25.0
−27.5
−30.0
2020
2030
2040
2050
2060
2070
2080
base
-_RN001476
10_RN001476
11_RN001476
12_RN001476
13_RN001476
14_RN001476
2 _RN001476
3 _RN001476
4 _RN001476
5 _RN001476
6 _RN001476
7 _RN001476
8 _RN001476
9 _RN001476

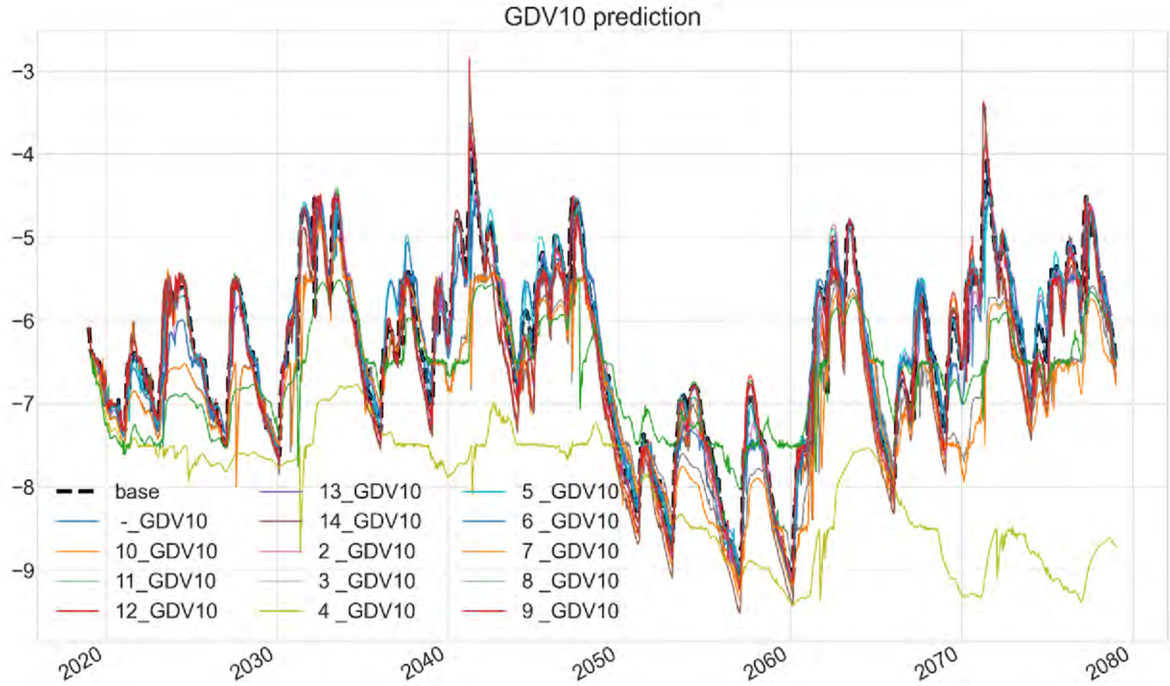

RN000438 prediction
−22.5
−25.0
−27.5
−30.0
−32.5
−35.0
−37.5
−40.0
base
-_RN000438
10_RN000438
11_RN000438
12_RN000438
13_RN000438
14_RN000438
2 _RN000438
3 _RN000438
4 _RN000438
5 _RN000438
6 _RN000438
7 _RN000438
8 _RN000438
9 _RN000438
2020
2030
2040
2050
2060
2070
2080

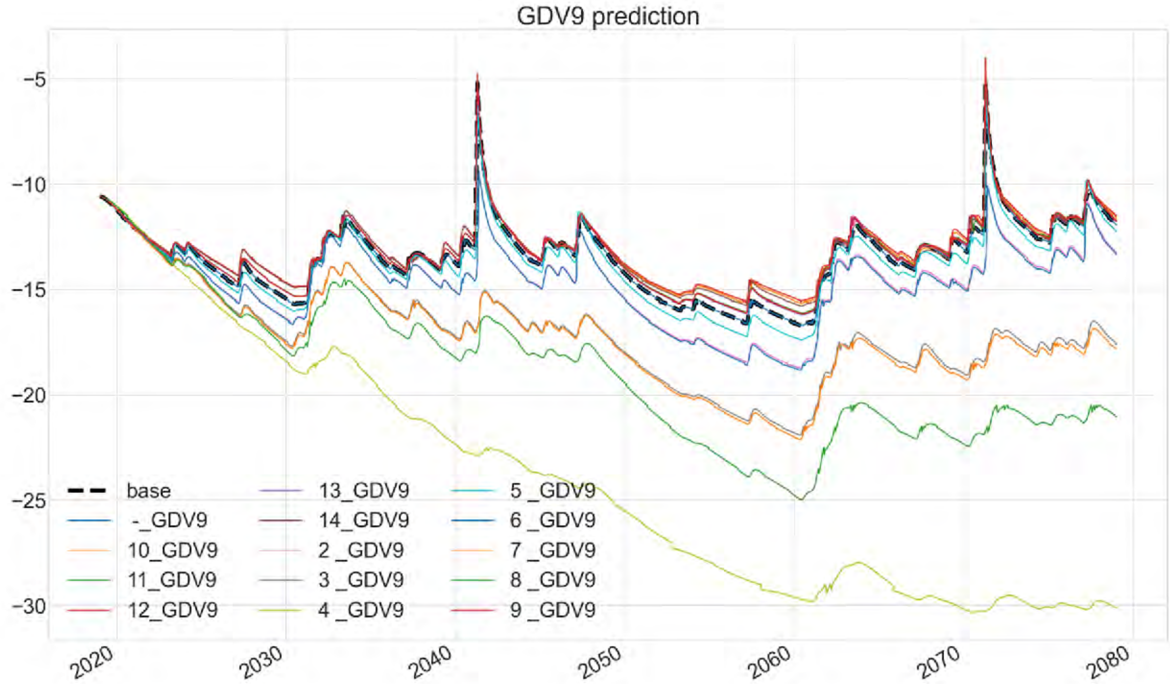

GDV14 prediction
0
−1
−2
−3
−4
−5
−6
base
-_GDV14
10_GDV14
11_GDV14
12_GDV14
13_GDV14
14_GDV14
2 _GDV14
3 _GDV14
4 _GDV14
5 _GDV14
6 _GDV14
7 _GDV14
8 _GDV14
9 _GDV14
2020
2030
2040
2050
2060
2070
2080


GDV13 prediction
base
-_GDV13
10_GDV13
11_GDV13
12_GDV13
13_GDV13
14_GDV13
2 _GDV13
3 _GDV13
4 _GDV13
5 _GDV13
6 _GDV13
7 _GDV13
8 _GDV13
9 _GDV13
0
−1
−2
−3
−4
−5
−6
−7
2020
2030
2040
2050
2060
2070
2080

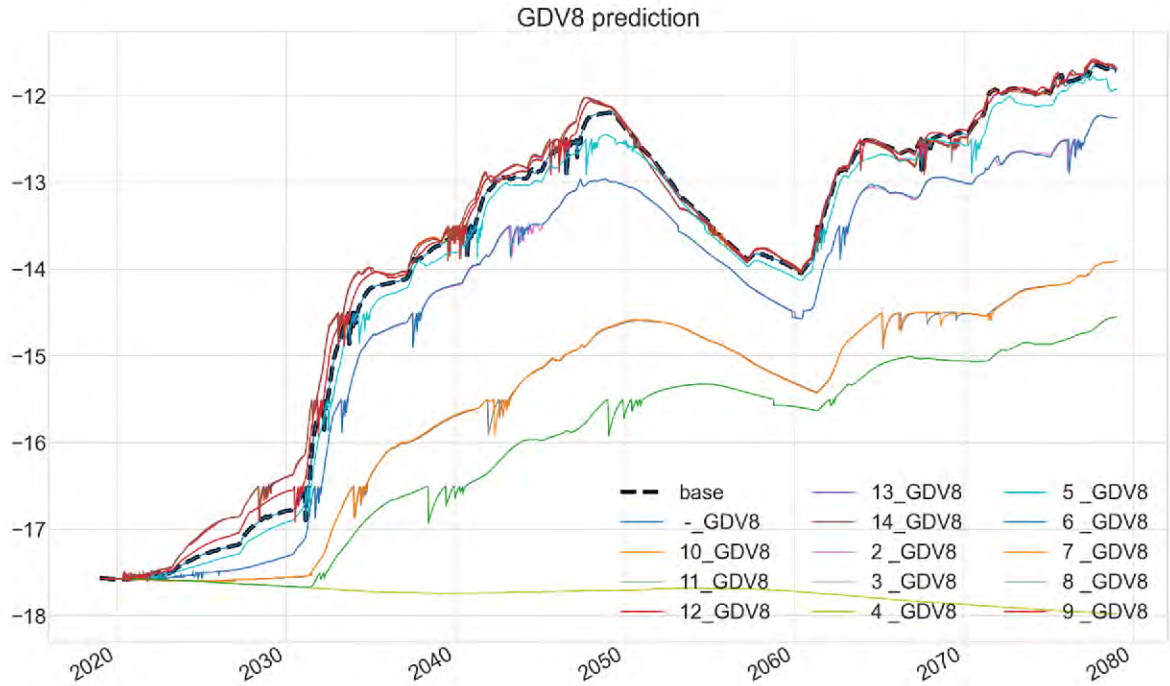

GDV12 prediction
base
-_GDV12
10_GDV12
11_GDV12
12_GDV12
13_GDV12
14_GDV12
2 _GDV12
3 _GDV12
4 _GDV12
5 _GDV12
6 _GDV12
7 _GDV12
8 _GDV12
9 _GDV12
−10.5
−11.0
−11.5
−12.0
−12.5
−13.0
2020
2030
2040
2050
2060
2070
2080


GDV11 prediction
base
-_GDV11
10_GDV11
11_GDV11
12_GDV11
13_GDV11
14_GDV11
2 _GDV11
3 _GDV11
4 _GDV11
5 _GDV11
6 _GDV11
7 _GDV11
8 _GDV11
9 _GDV11
0
−2
−4
−6
−8
−10
2020
2030
2040
2050
2060
2070
2080

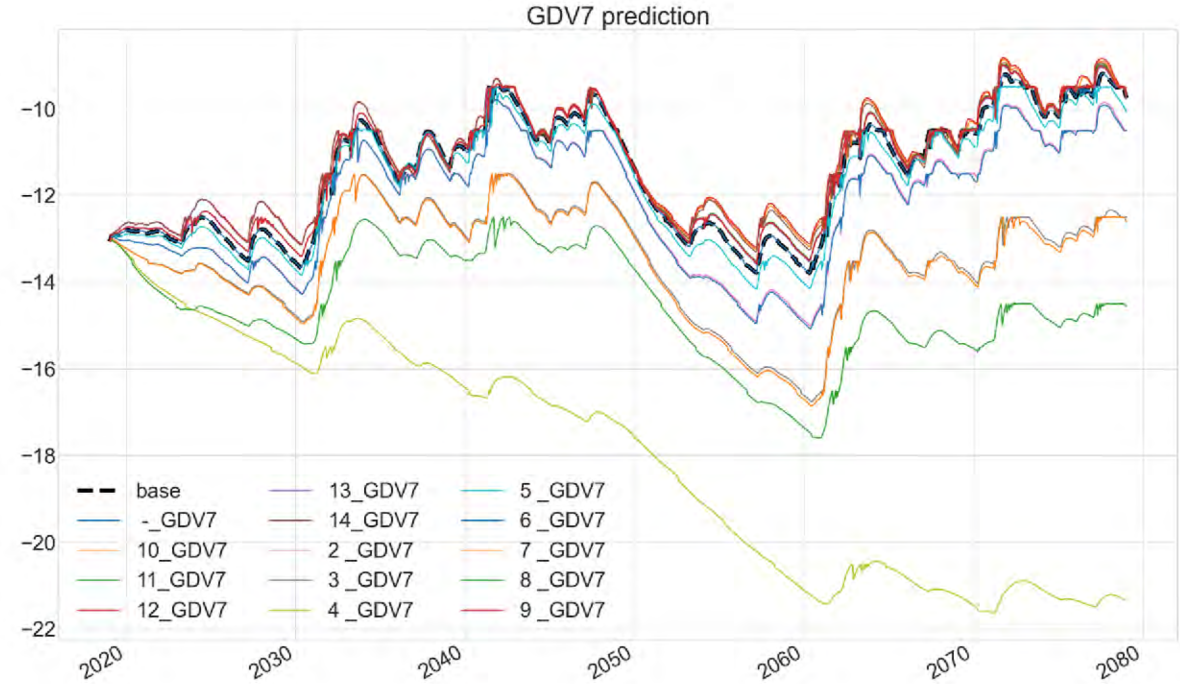

GDV10 prediction
−3
−4
−5
−6
−7
−8
−9
base
-_GDV10
10_GDV10
11_GDV10
12_GDV10
13_GDV10
14_GDV10
2 _GDV10
3 _GDV10
4 _GDV10
5 _GDV10
6 _GDV10
7 _GDV10
8 _GDV10
9 _GDV10
2020
2030
2040
2050
2060
2070
2080



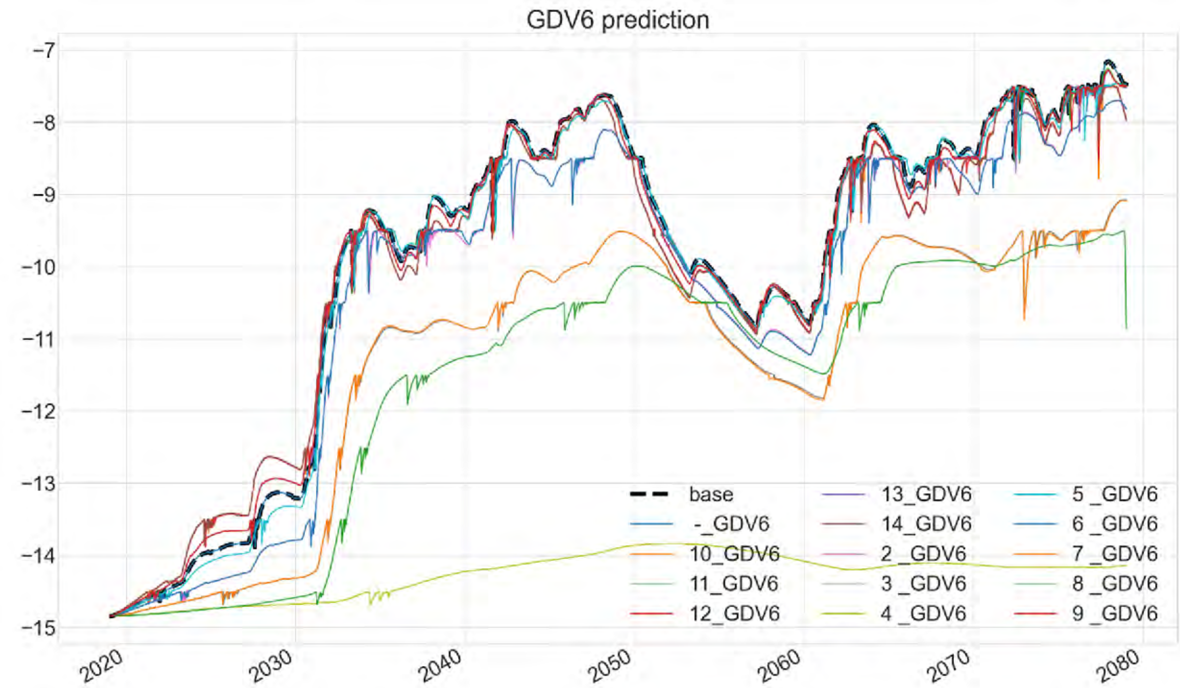
GDV9 prediction
−5
−10
−15
−20
−25
−30
2020
2030
2040
2050
2060
2070
2080
base
-_GDV9
10_GDV9
11_GDV9
12_GDV9
13_GDV9
14_GDV9
2 _GDV9
3 _GDV9
4 _GDV9
5 _GDV9
6 _GDV9
7 _GDV9
8 _GDV9
9 _GDV9



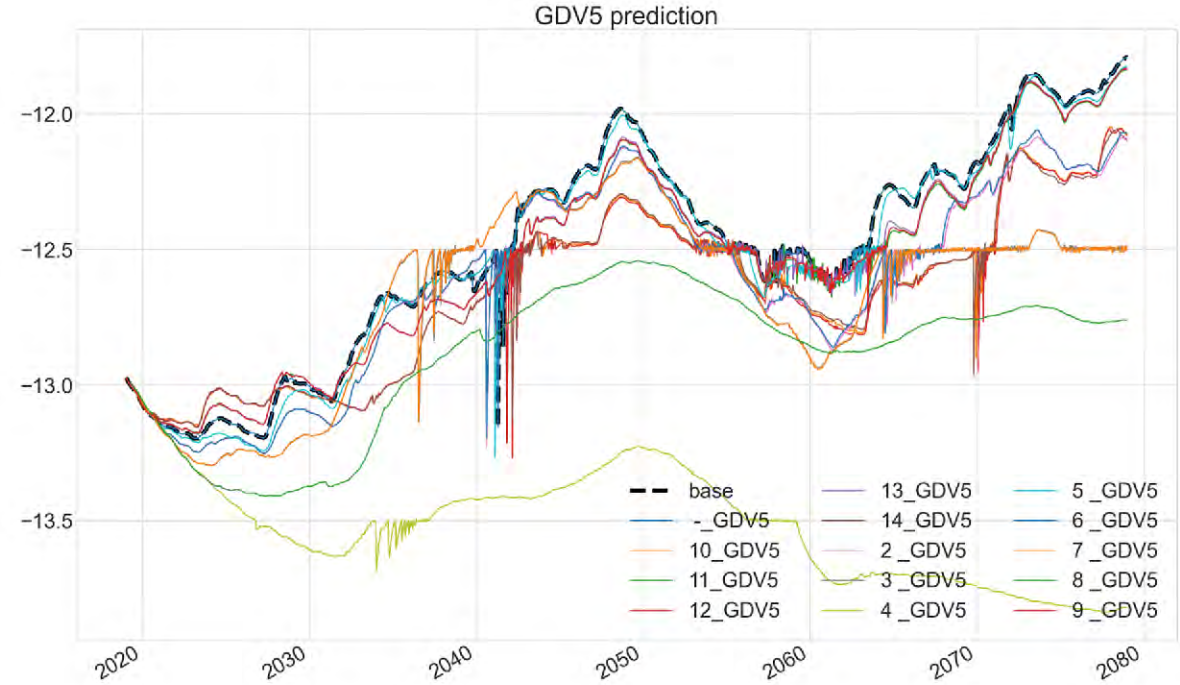
GDV8 prediction
−12
−13
−14
−15
−16
−17
−18
2020
2030
2040
2050
2060
2070
2080
base
-_GDV8
10_GDV8
11_GDV8
12_GDV8
13_GDV8
14_GDV8
2 _GDV8
3 _GDV8
4 _GDV8
5 _GDV8
6 _GDV8
7 _GDV8
8 _GDV8
9 _GDV8

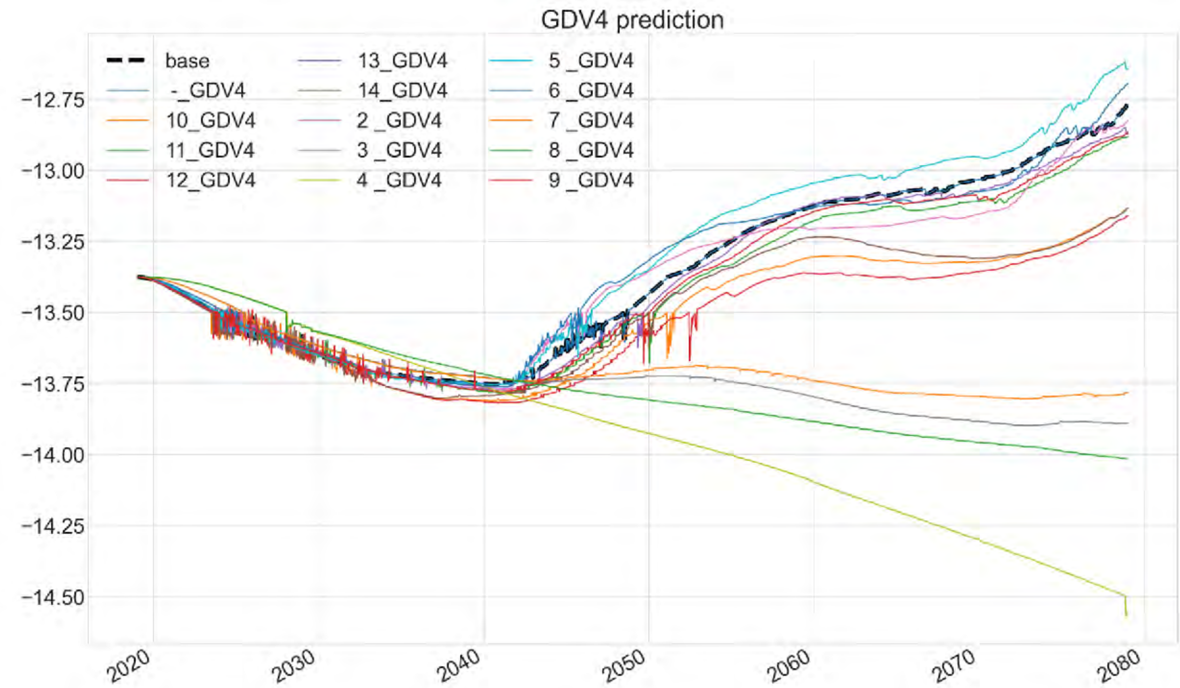


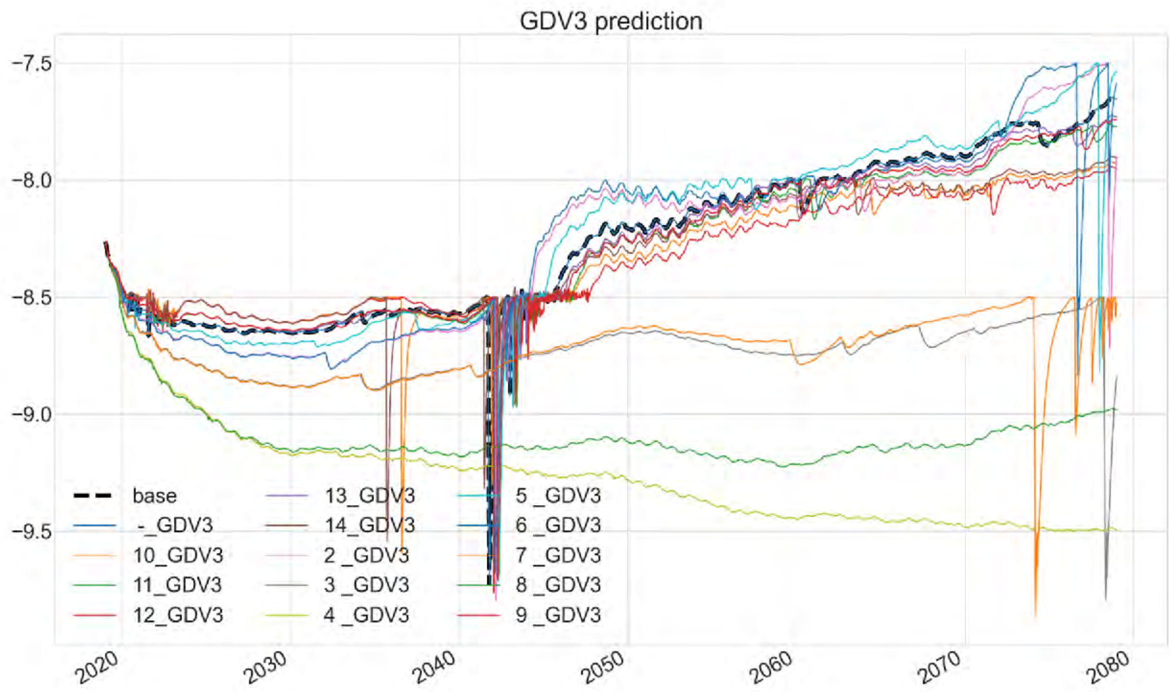
GDV7 prediction
−10
−12
−14
−16
−18
−20
−22
base
-_GDV7
10_GDV7
11_GDV7
12_GDV7
13_GDV7
14_GDV7
2 _GDV7
3 _GDV7
4 _GDV7
5 _GDV7
6 _GDV7
7 _GDV7
8 _GDV7
9 _GDV7
2020
2030
2040
2050
2060
2070
2080

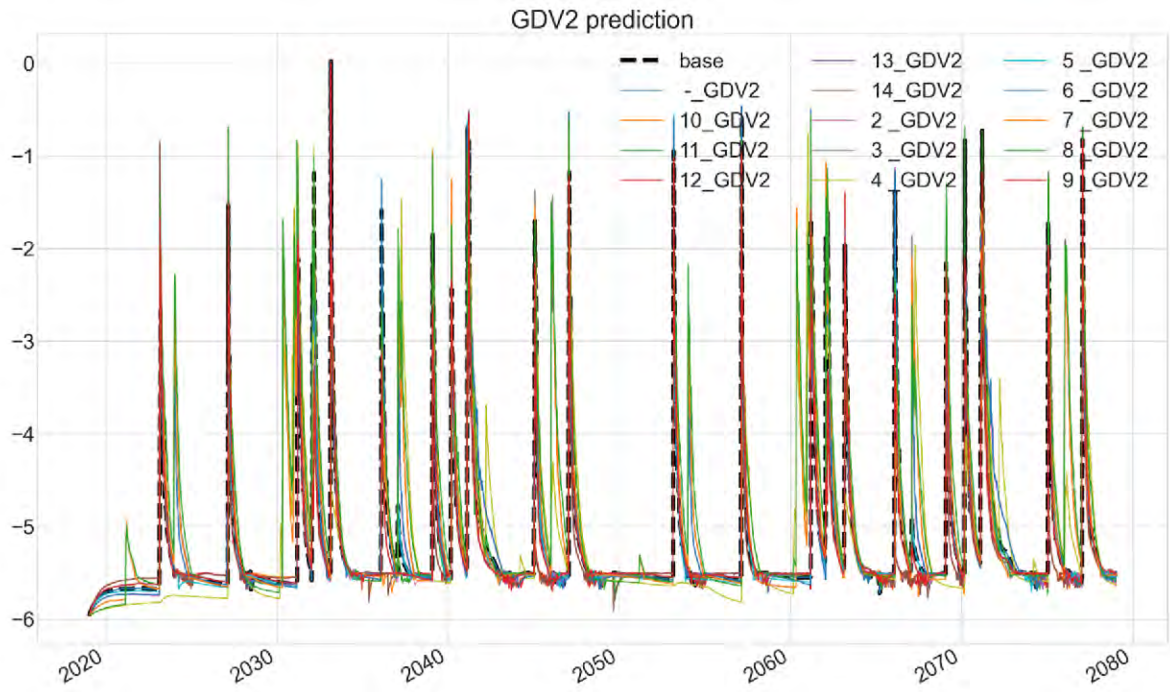


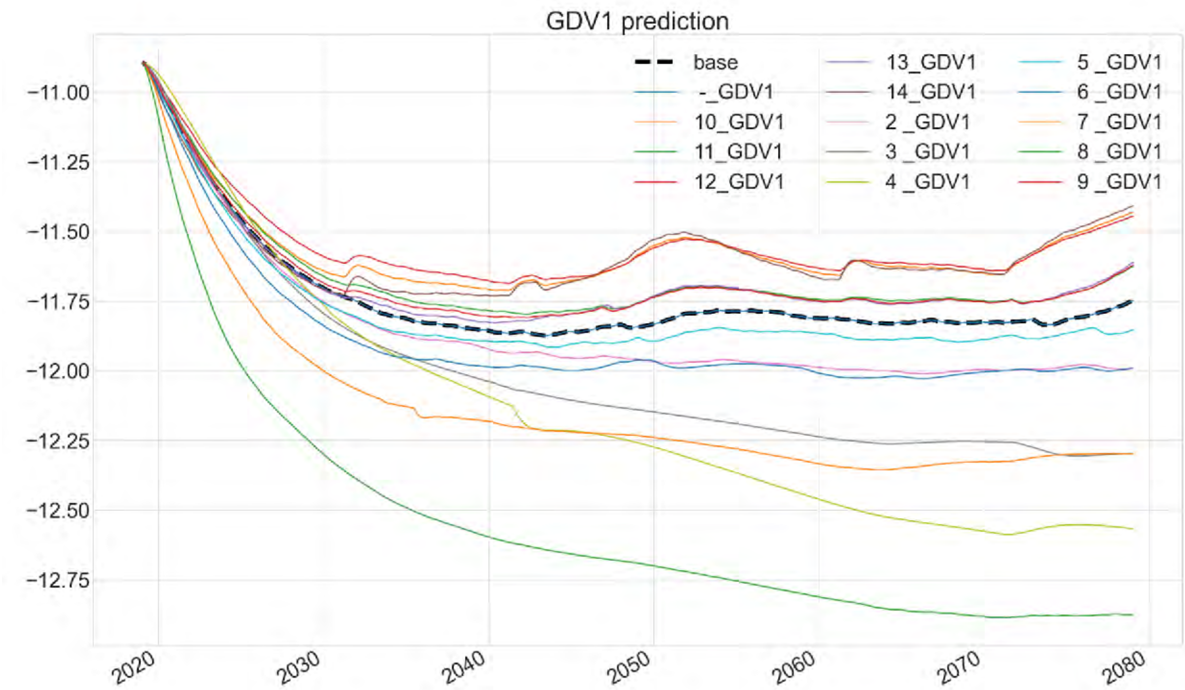
GDV6 prediction
−7
−8
−9
−10
−11
−12
−13
−14
−15
base
-_GDV6
10_GDV6
11_GDV6
12_GDV6
13_GDV6
14_GDV6
2 _GDV6
3 _GDV6
4 _GDV6
5 _GDV6
6 _GDV6
7 _GDV6
8 _GDV6
9 _GDV6
2020
2030
2040
2050
2060
2070
2080


GDV5 prediction
−12.0
−12.5
−13.0
−13.5
2020
2030
2040
2050
2060
2070
2080
base
-_GDV5
10_GDV5
11_GDV5
12_GDV5
13_GDV5
14_GDV5
2 _GDV5
3 _GDV5
4 _GDV5
5 _GDV5
6 _GDV5
7 _GDV5
8 _GDV5
9 _GDV5

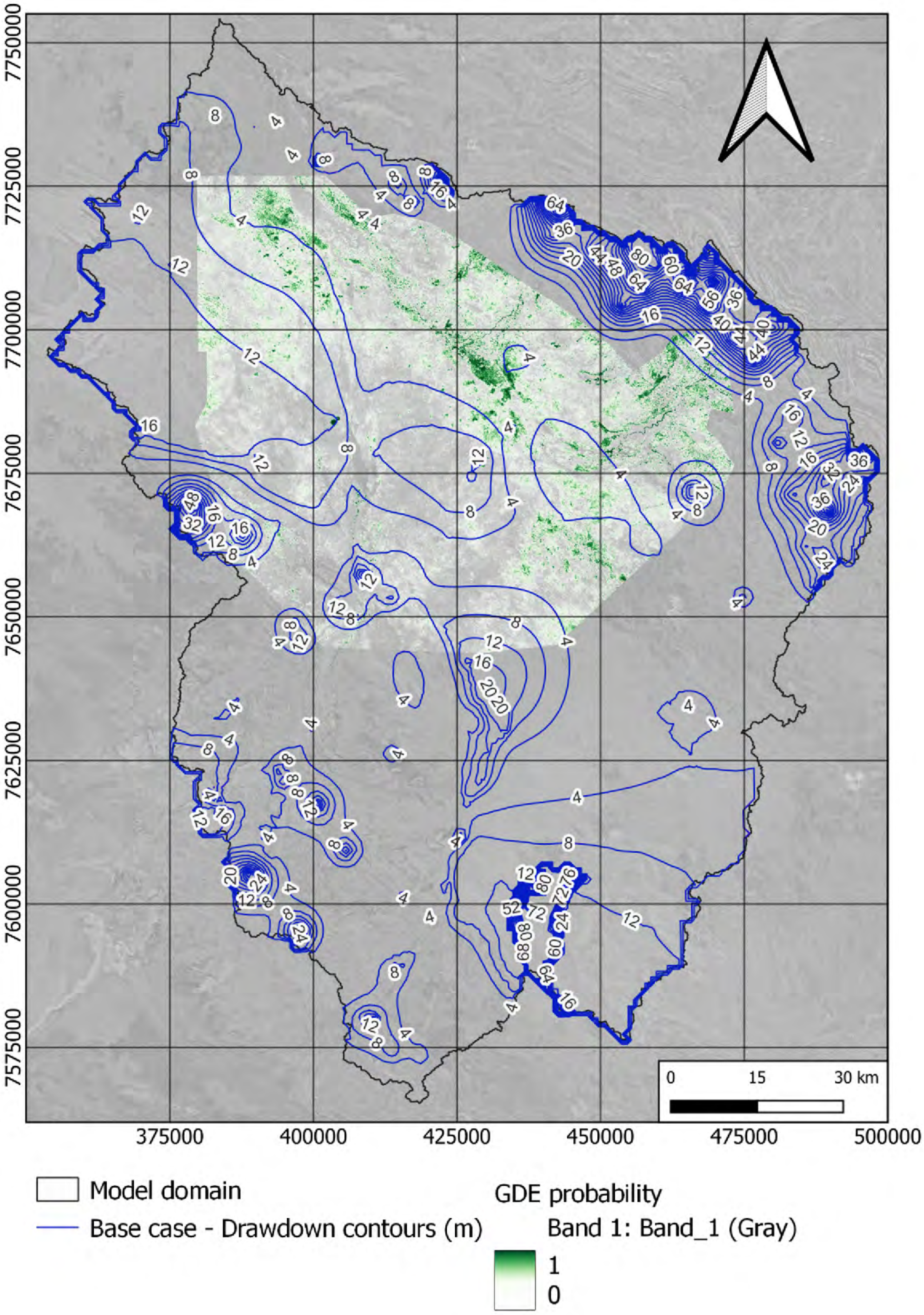

GDV4 prediction
−12.75
−13.00
−13.25
−13.50
−13.75
−14.00
−14.25
−14.50
2020
2030
2040
2050
2060
2070
2080
base
-_GDV4
10_GDV4
11_GDV4
12_GDV4
13_GDV4
14_GDV4
2 _GDV4
3 _GDV4
4 _GDV4
5 _GDV4
6 _GDV4
7 _GDV4
8 _GDV4
9 _GDV4

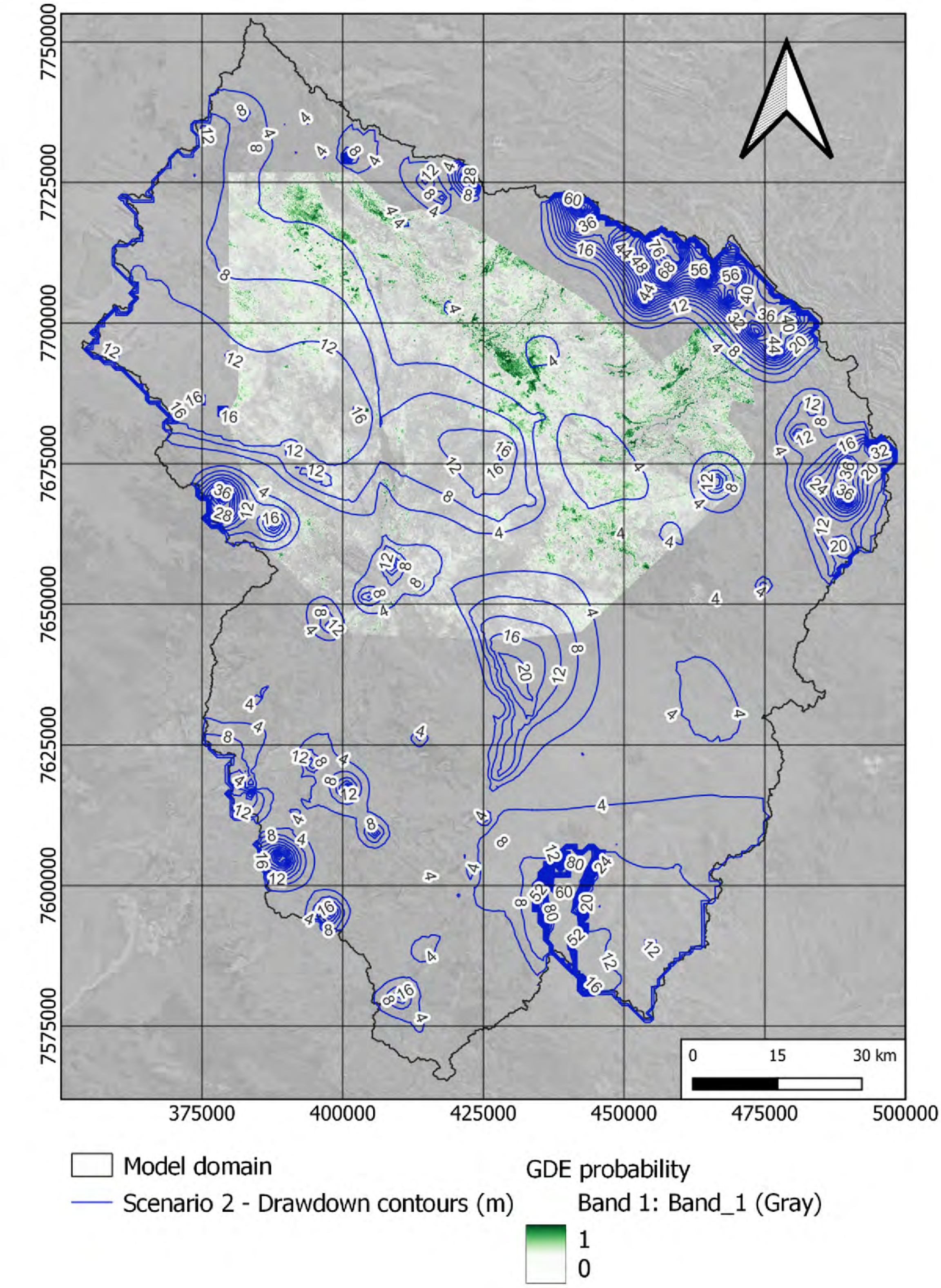

GDV3 prediction
-7.5
-8.0
-8.5
-9.0
-9.5
base
-_GDV3
10_GDV3
11_GDV3
12_GDV3
13_GDV3
14_GDV3
2 _GDV3
3 _GDV3
4 _GDV3
5 _GDV3
6 _GDV3
7 _GDV3
8 _GDV3
9 _GDV3
2020
2030
2040
2050
2060
2070
2080

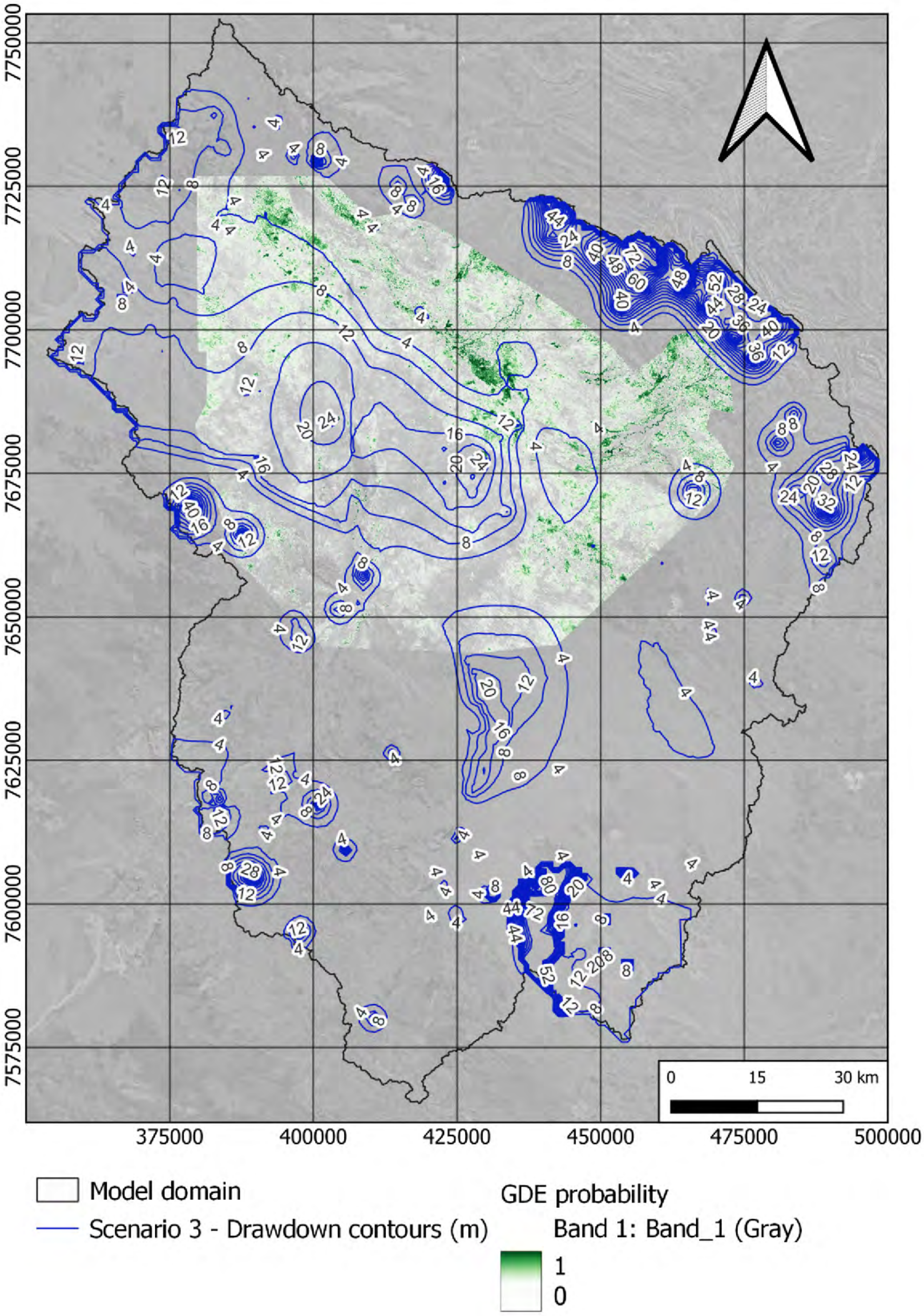

GDV2 prediction
0
-1
-2
-3
-4
-5
-6
base
-_GDV2
10_GDV2
11_GDV2
12_GDV2
13_GDV2
14_GDV2
2 _GDV2
3 _GDV2
4 _GDV2
5 _GDV2
6 _GDV2
7 _GDV2
8 _GDV2
9 _GDV2
2020
2030
2040
2050
2060
2070
2080

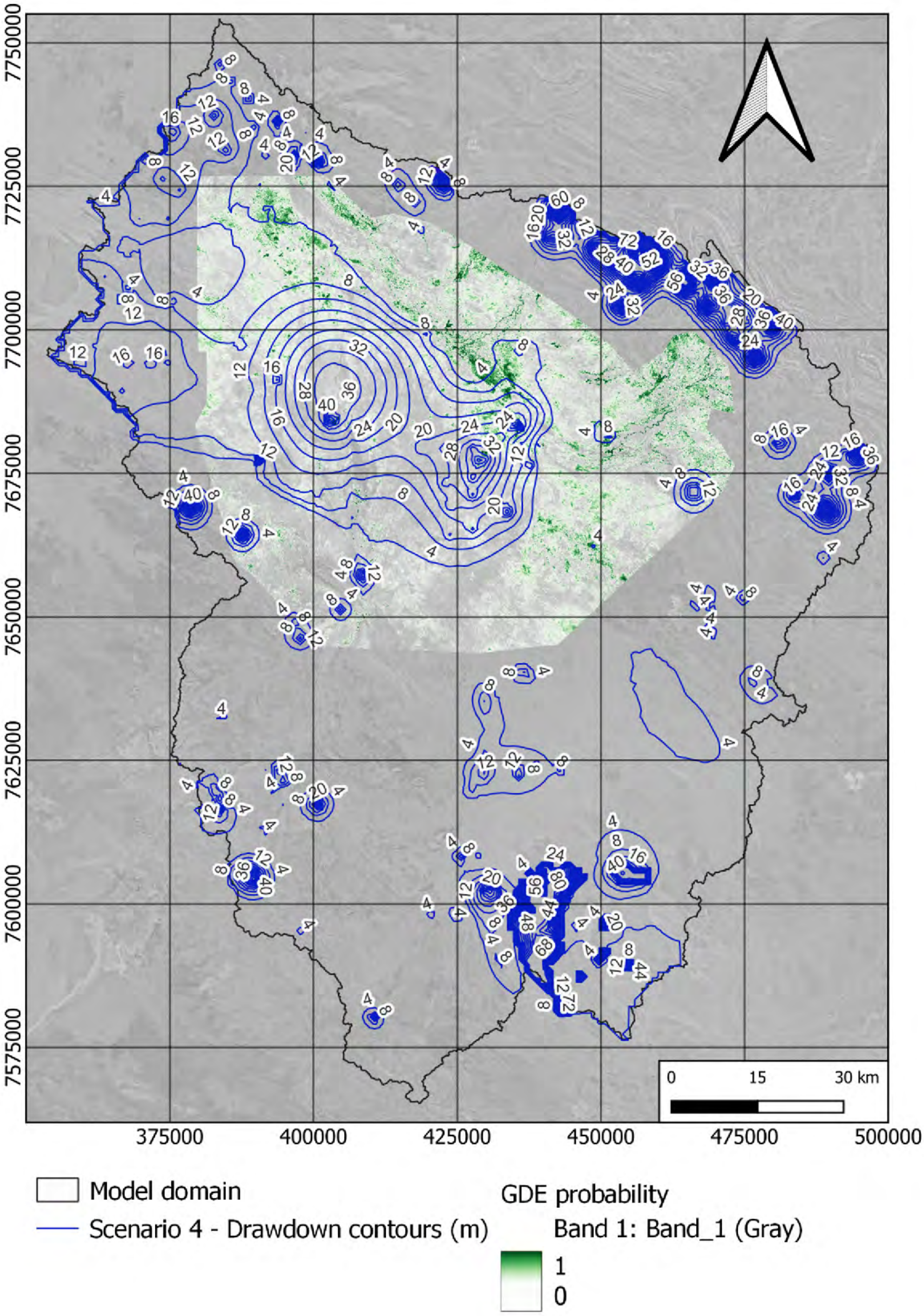

GDV1 prediction
base
-_GDV1
10_GDV1
11_GDV1
12_GDV1
13_GDV1
14_GDV1
2 _GDV1
3 _GDV1
4 _GDV1
5 _GDV1
6 _GDV1
7 _GDV1
8 _GDV1
9 _GDV1
−11.00
−11.25
−11.50
−11.75
−12.00
−12.25
−12.50
−12.75
2020
2030
2040
2050
2060
2070
2080

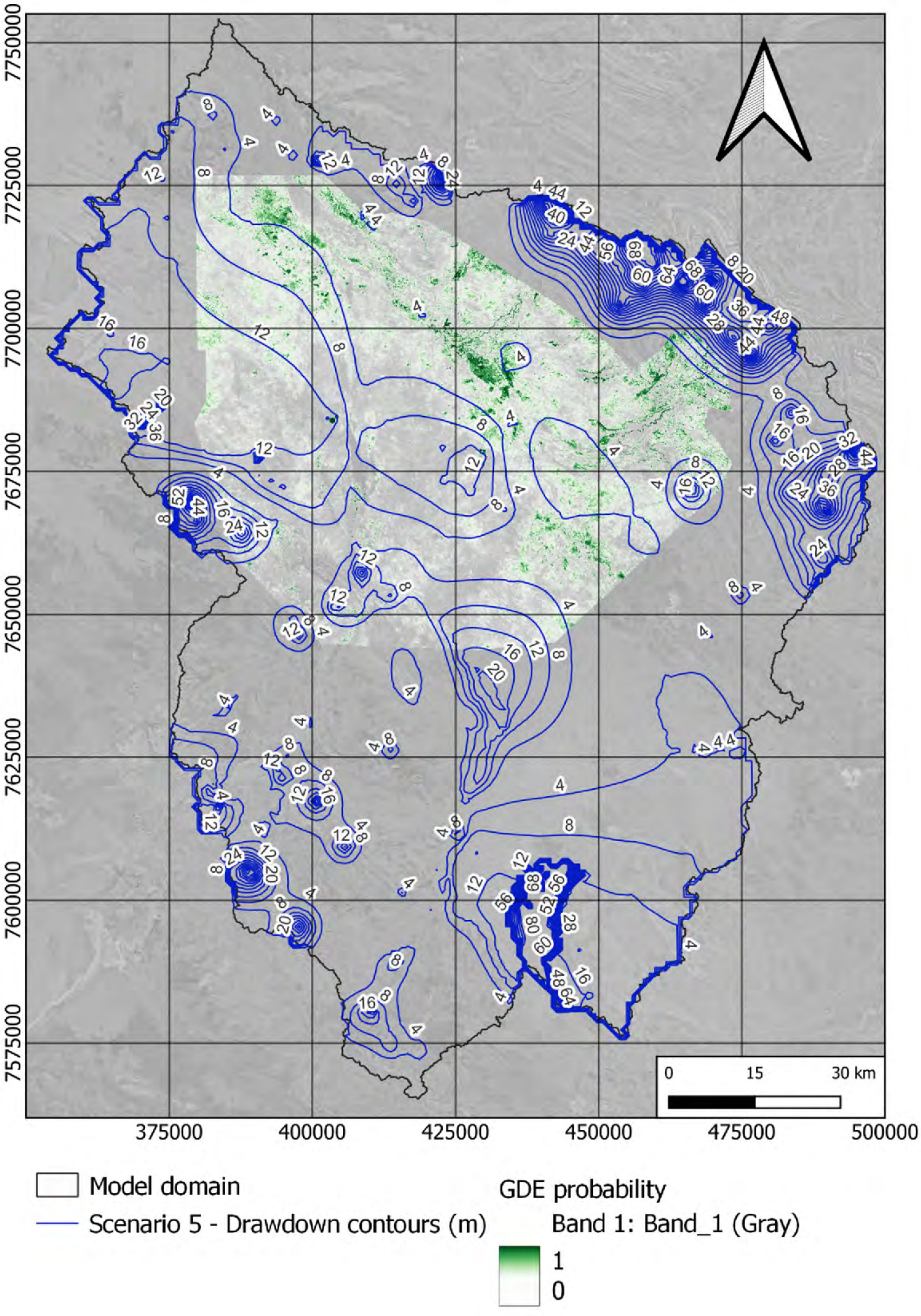
Appendix 3 - PREDICTIVE DRAWDOWN CONTOURS at 2080

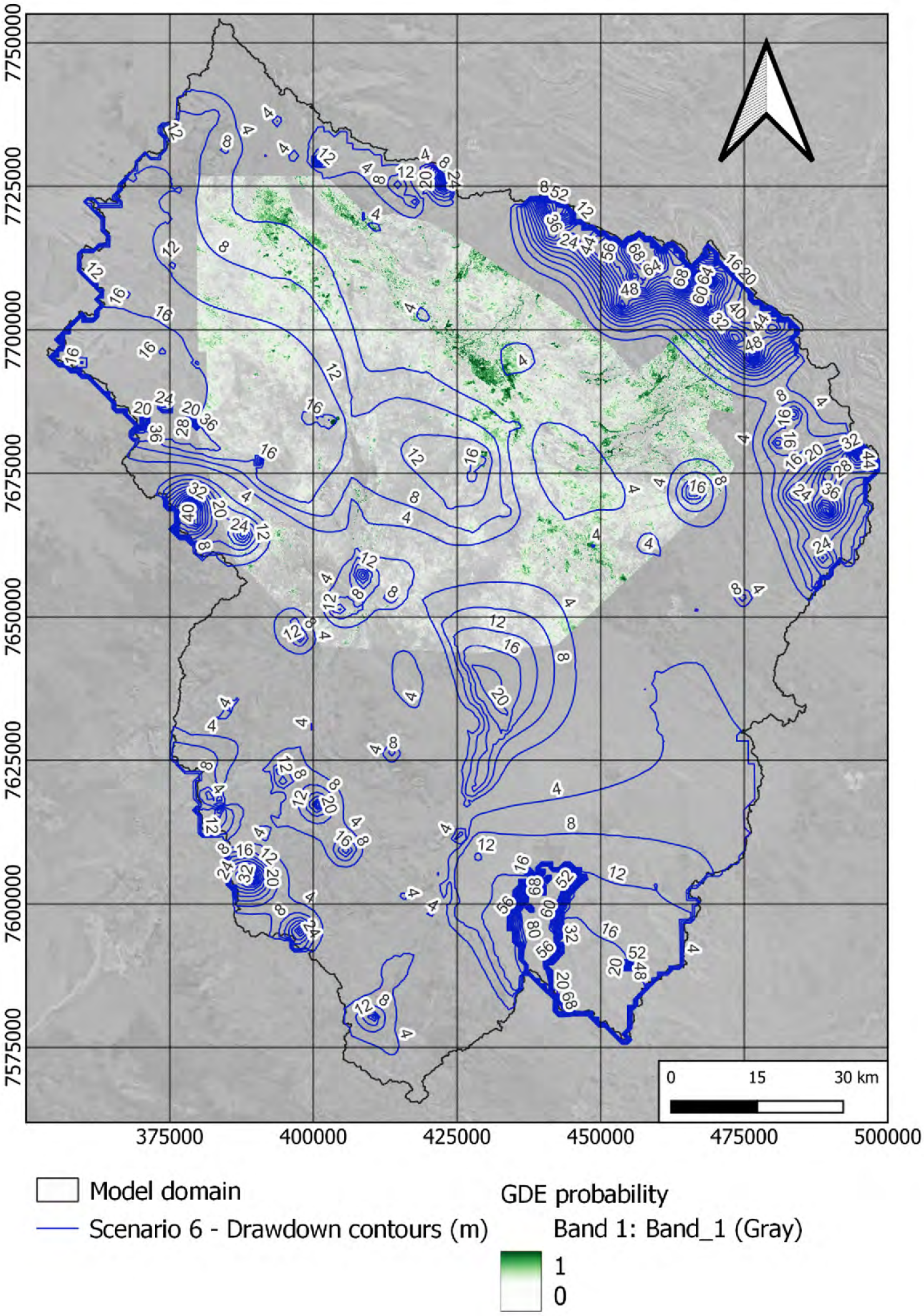



7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 2 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0

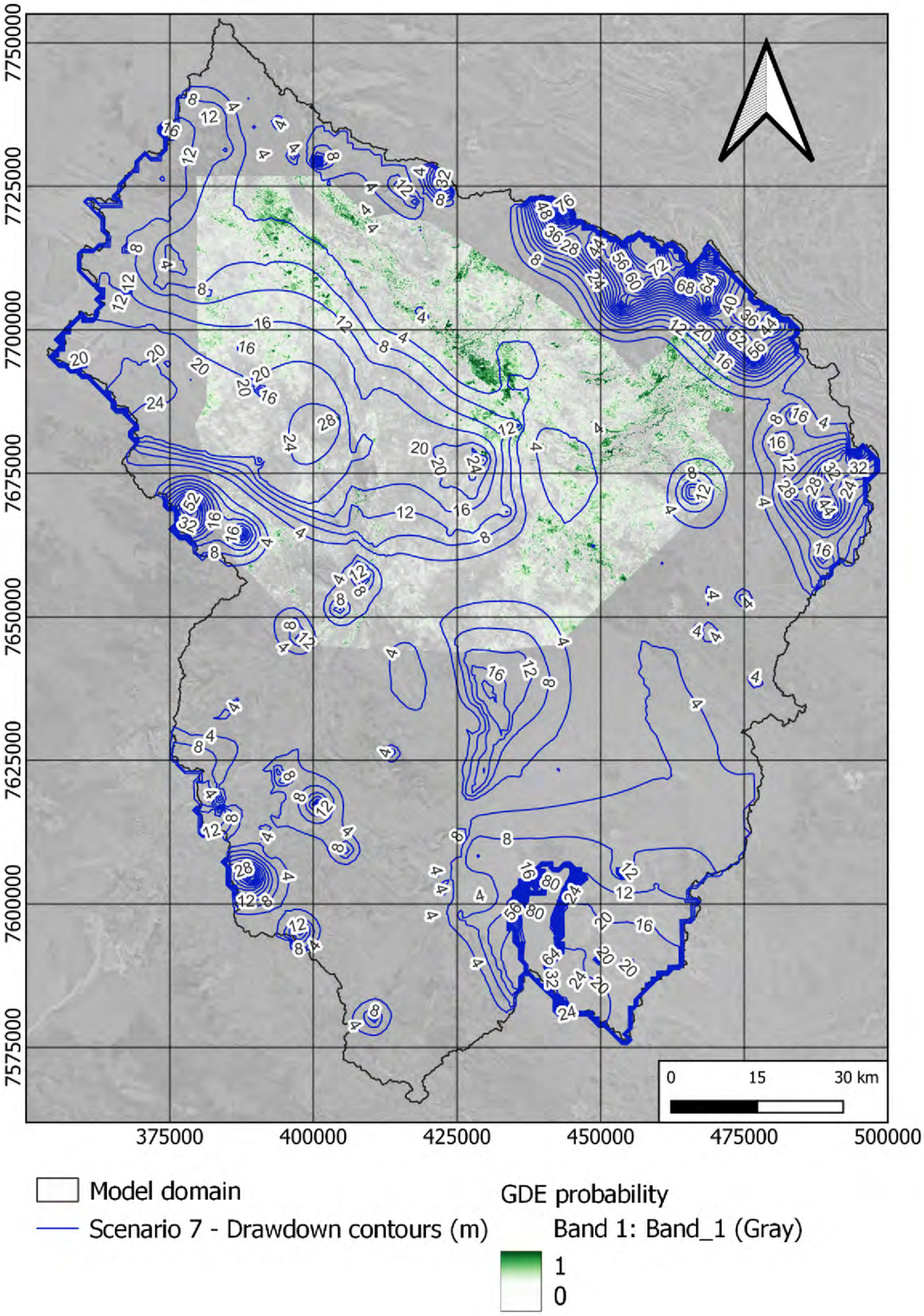

7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 3 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0


7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 4 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0

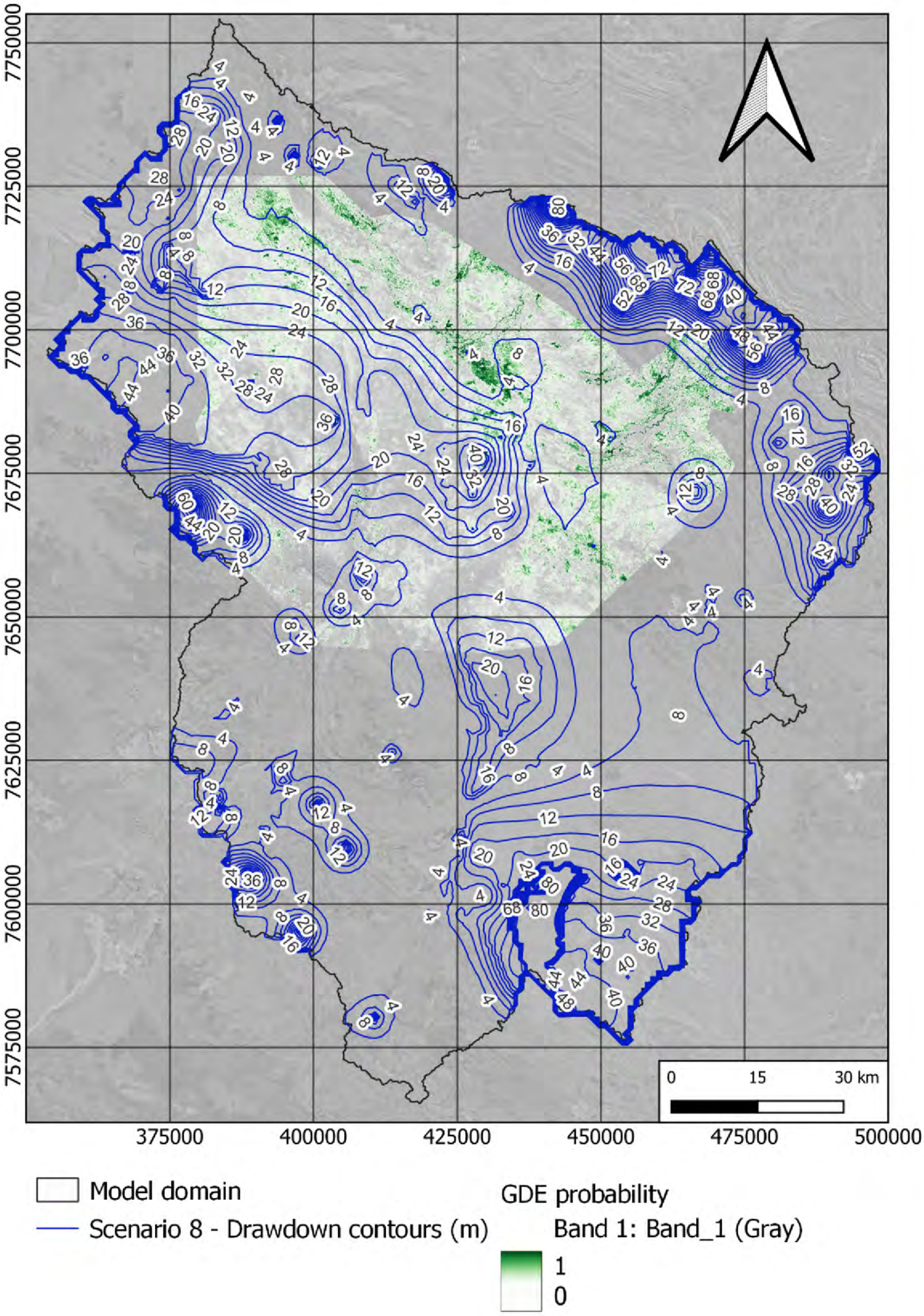

7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0 15 30 km
Model domain
Scenario 5 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0

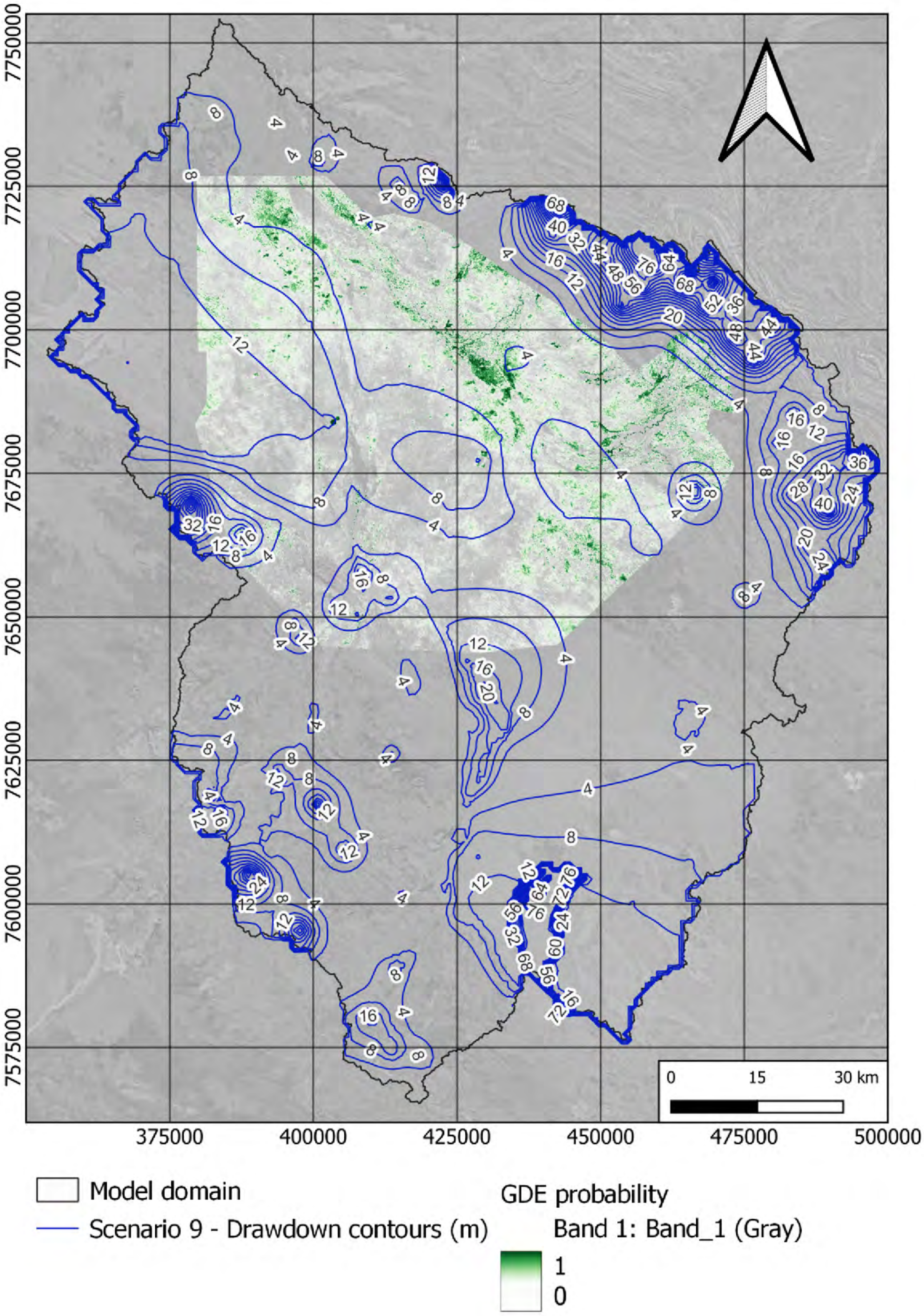


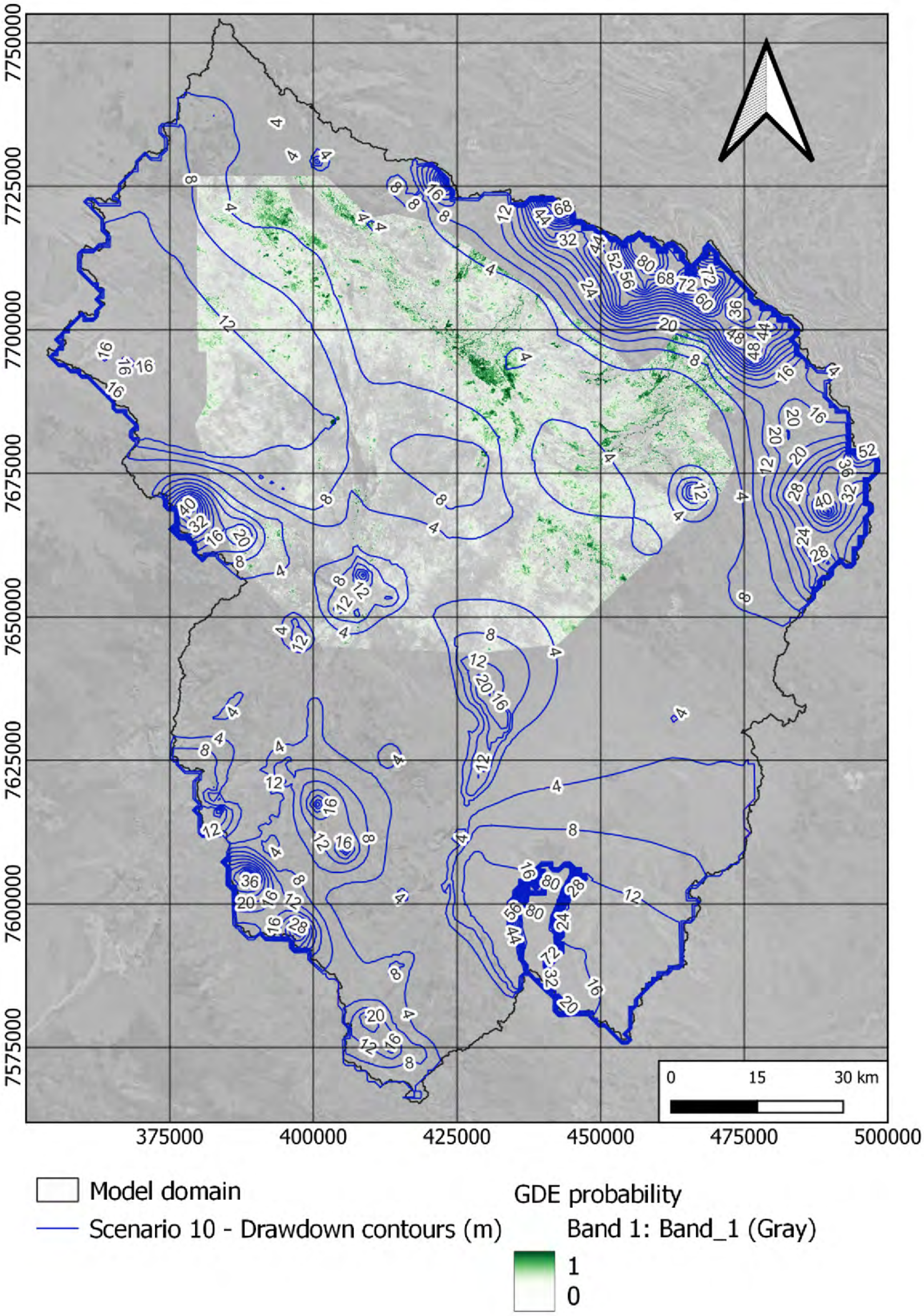
7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 6 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0



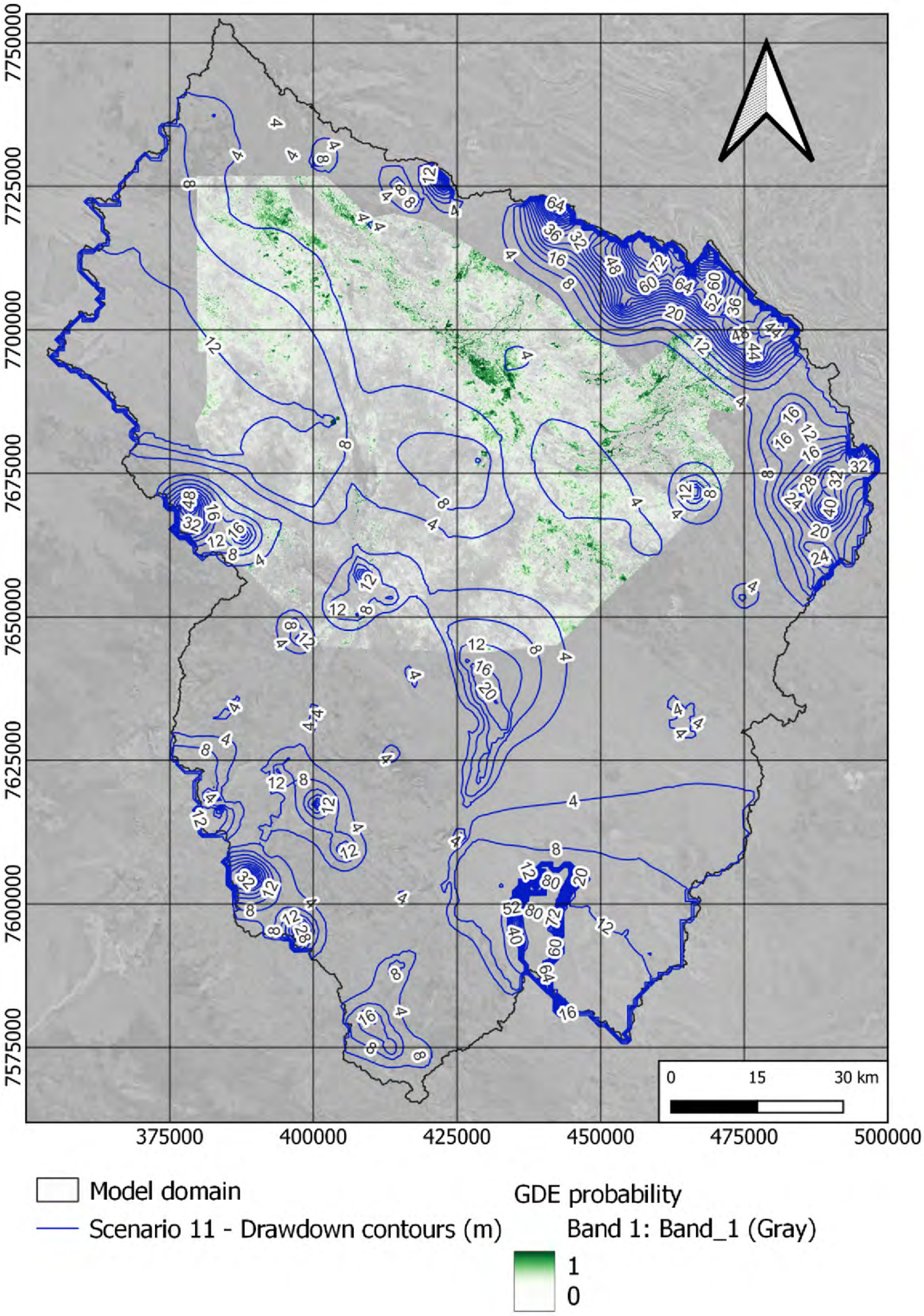
7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 7 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0


7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 8 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0

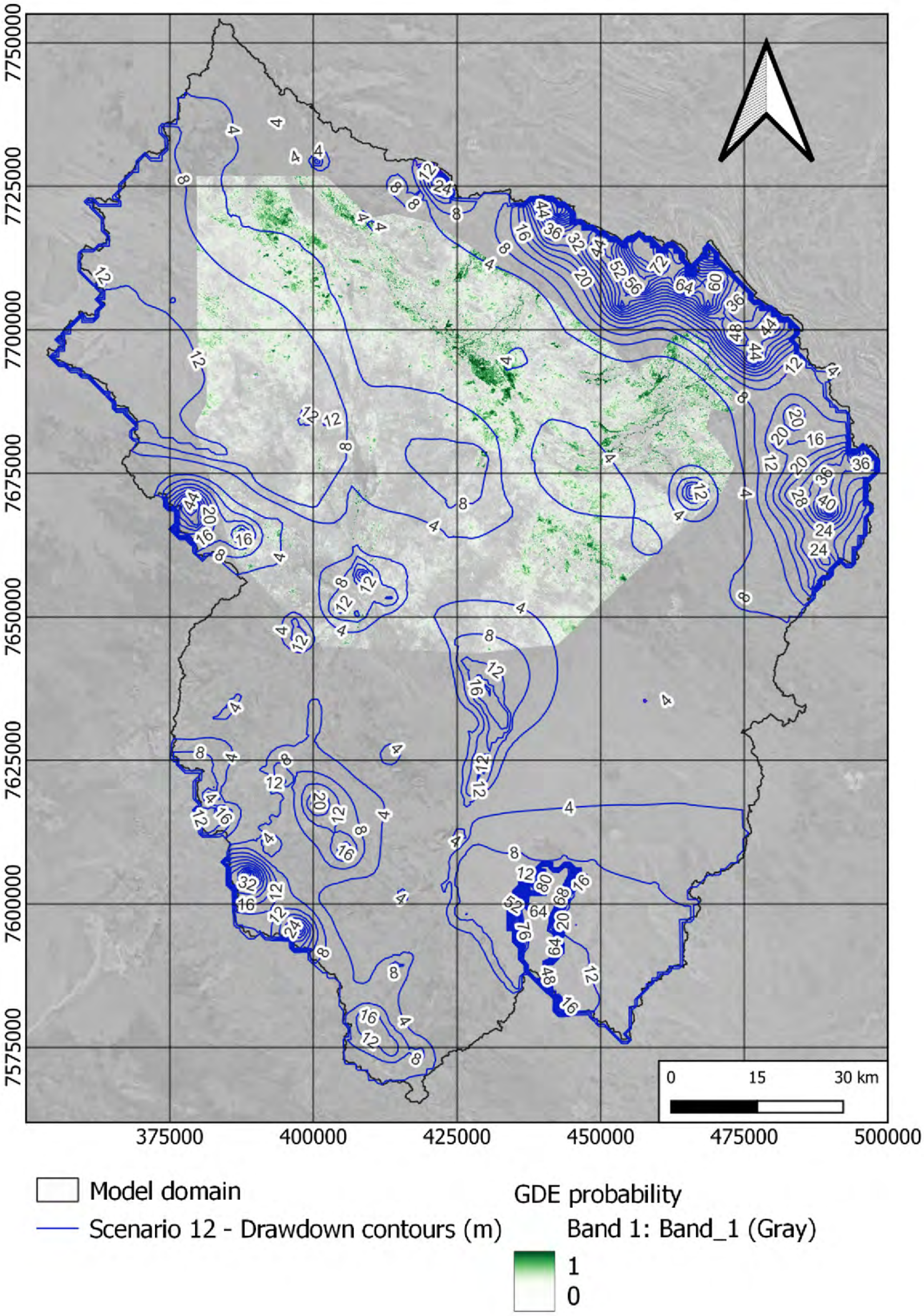

7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 9 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0



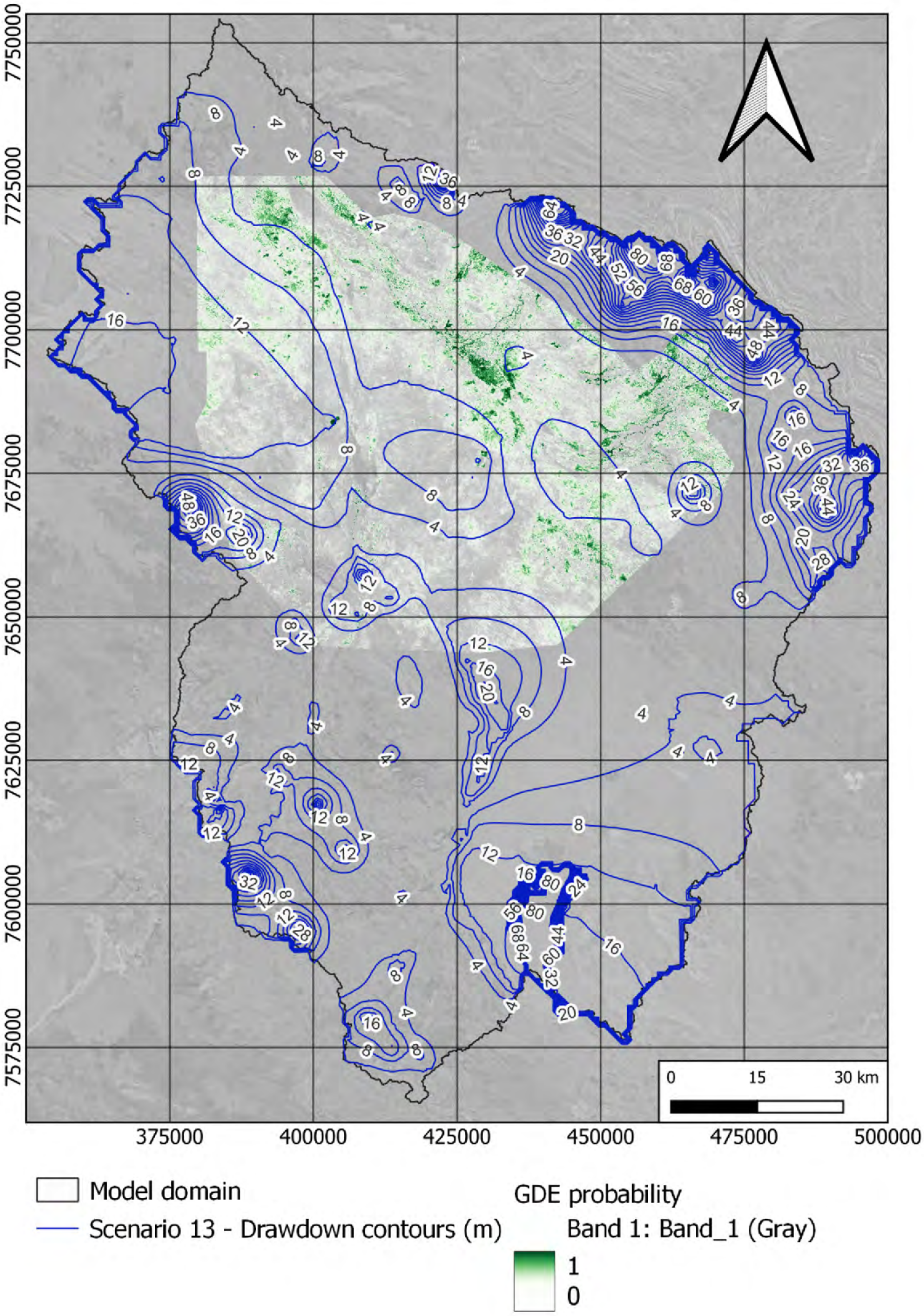
7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 10 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0



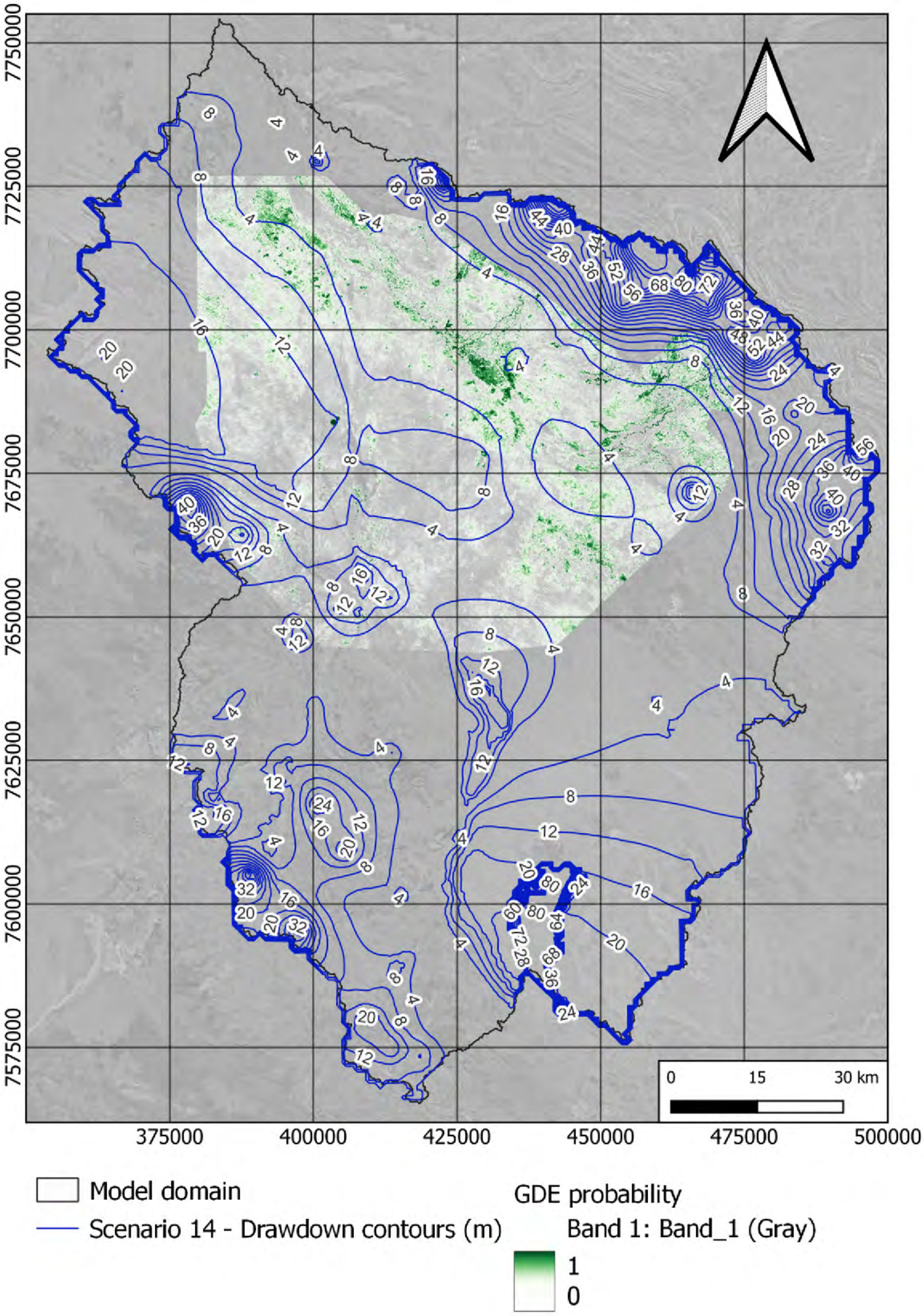
7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 11 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0



7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 12 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0

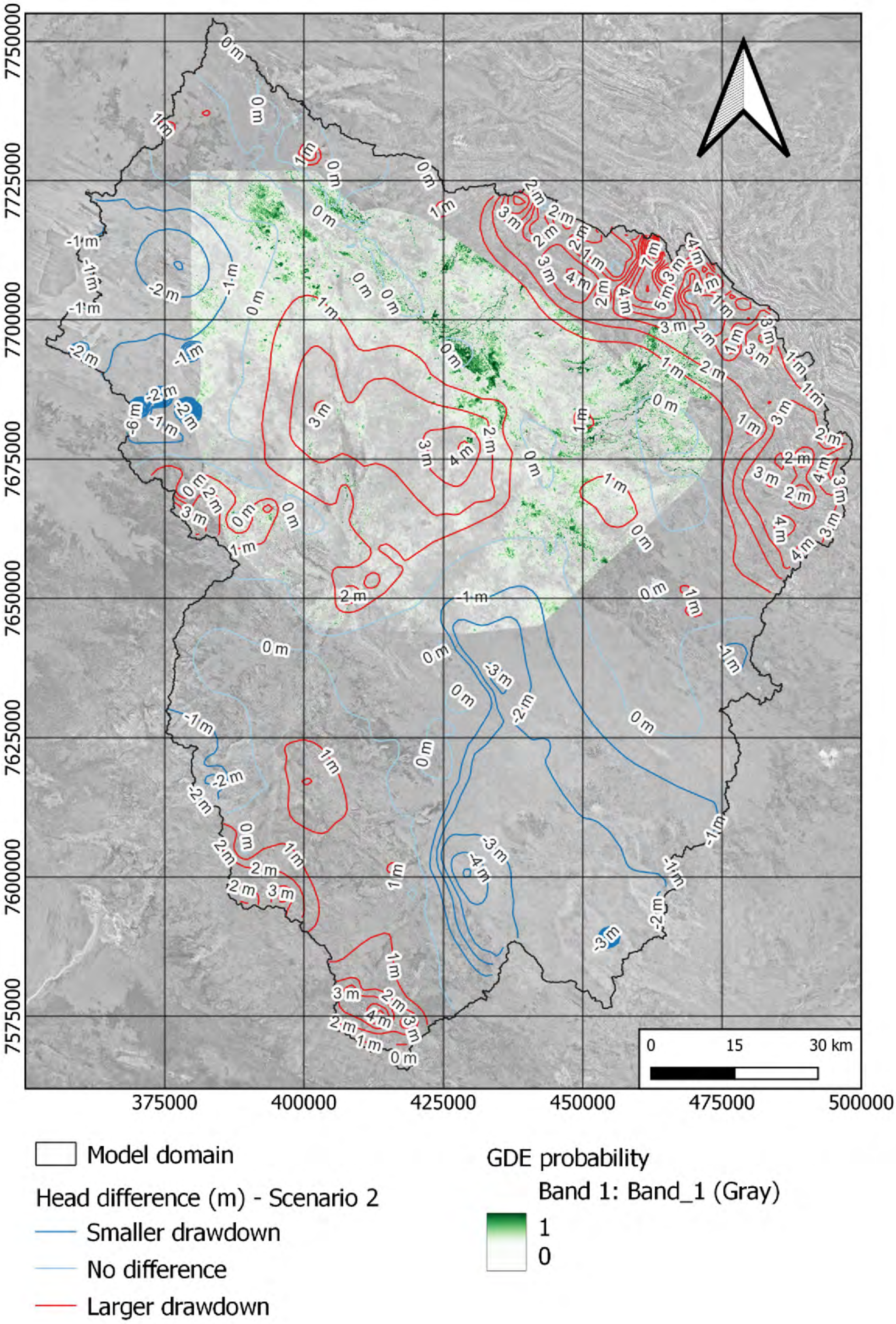


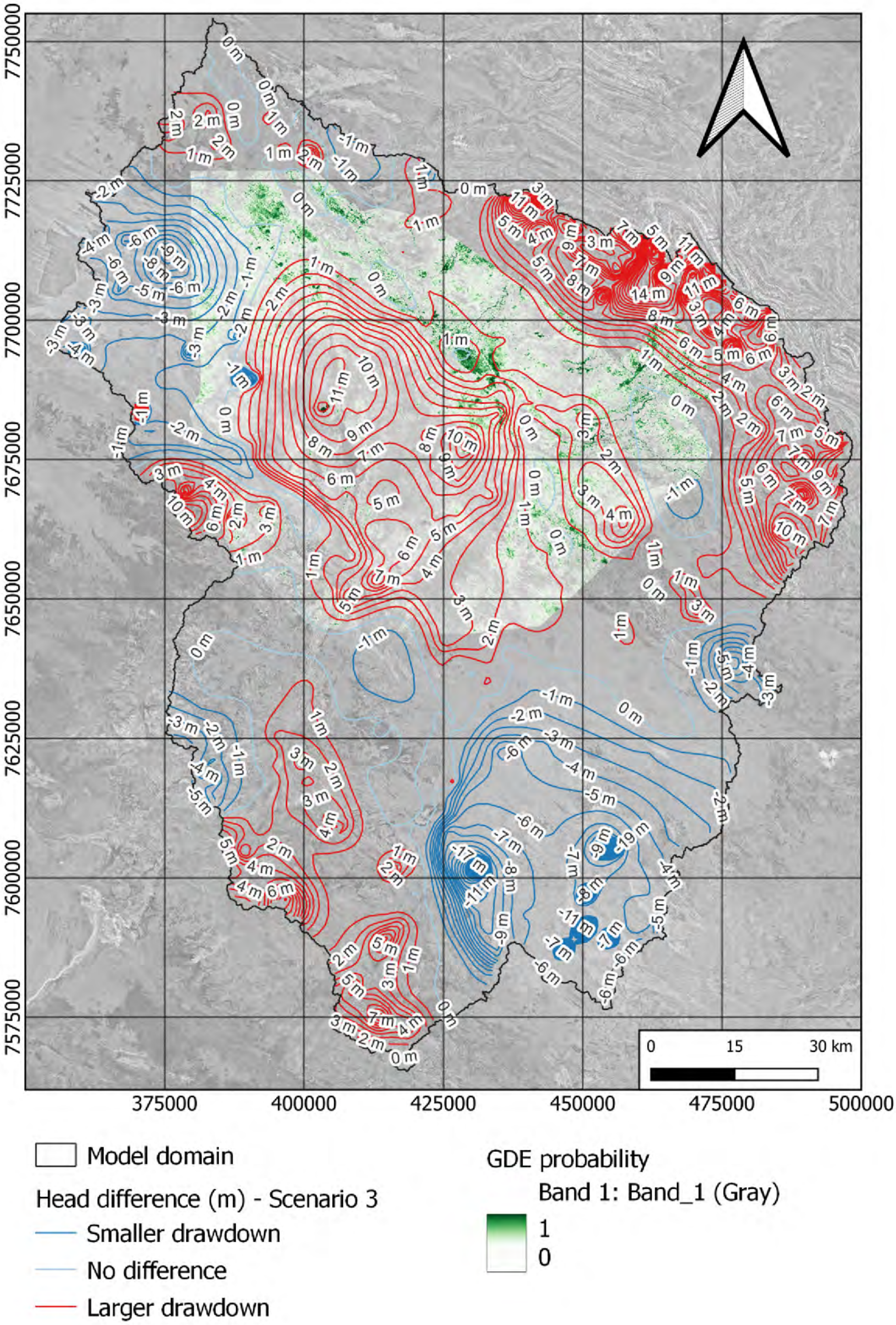
7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 13 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0

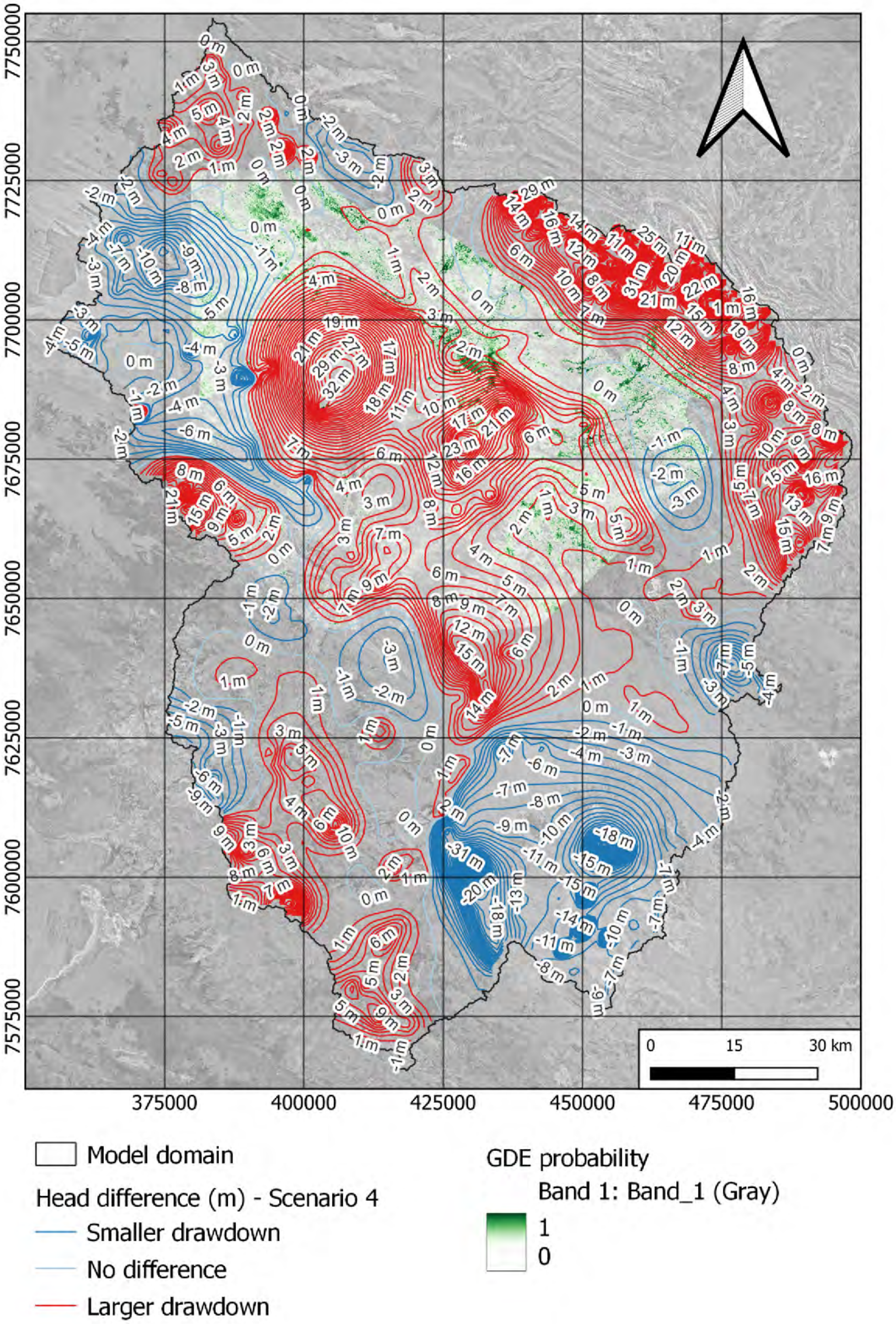


7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Scenario 14 - Drawdown contours (m)
GDE probability
Band 1: Band_1 (Gray)
1
0

Appendix 4 - HEAD DIFFERENCES IN RELATION TO BASE CASE MODEL at 2080




7750000
7725000
7700000
7675000
7650000
7625000
7600000
7575000
375000
400000
425000
450000
475000
500000
0
15
30 km
Model domain
Head difference (m) - Scenario 3
Smaller drawdown
No difference
Larger drawdown
GDE probability
Band 1: Band_1 (Gray)
1
0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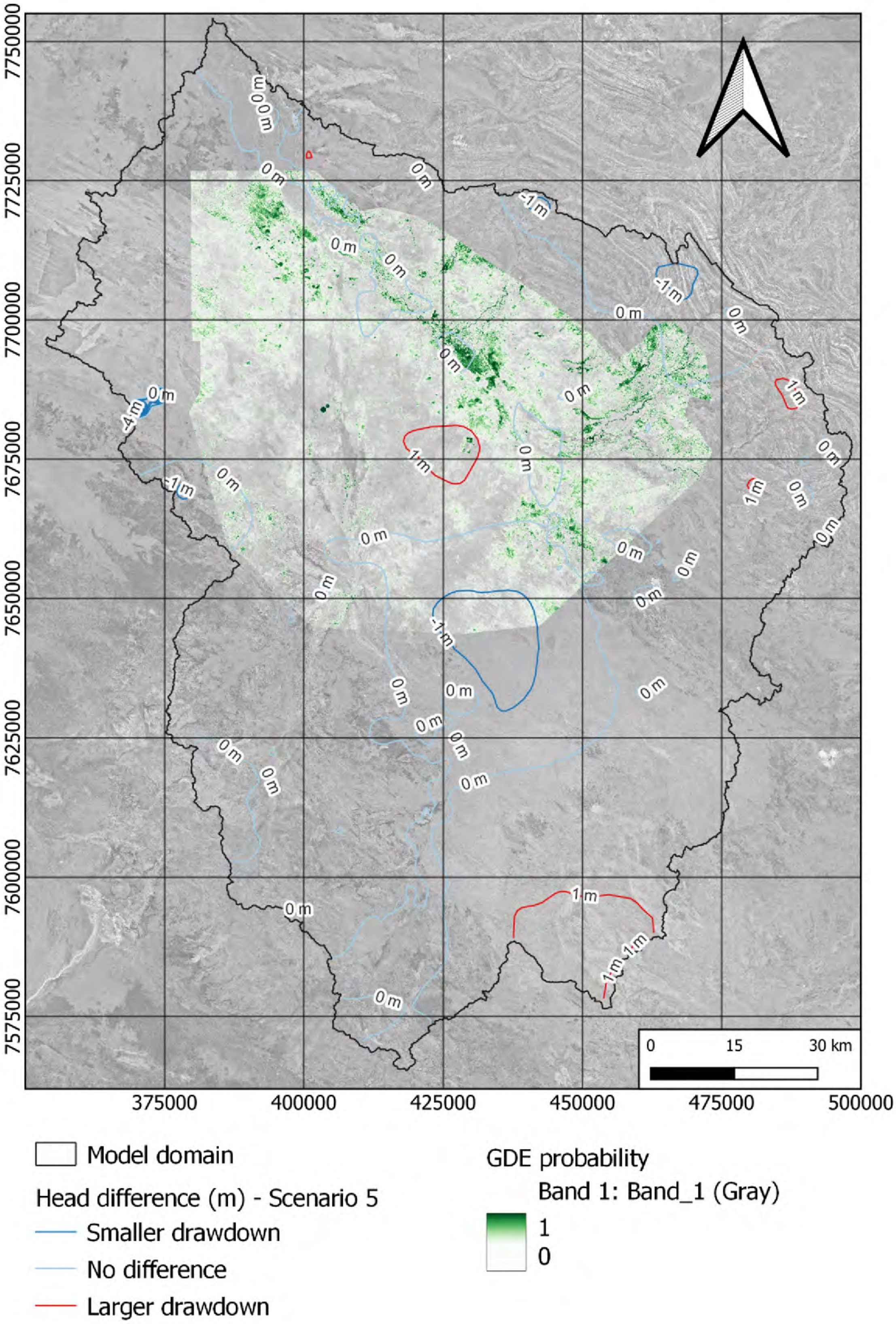
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GDE probability
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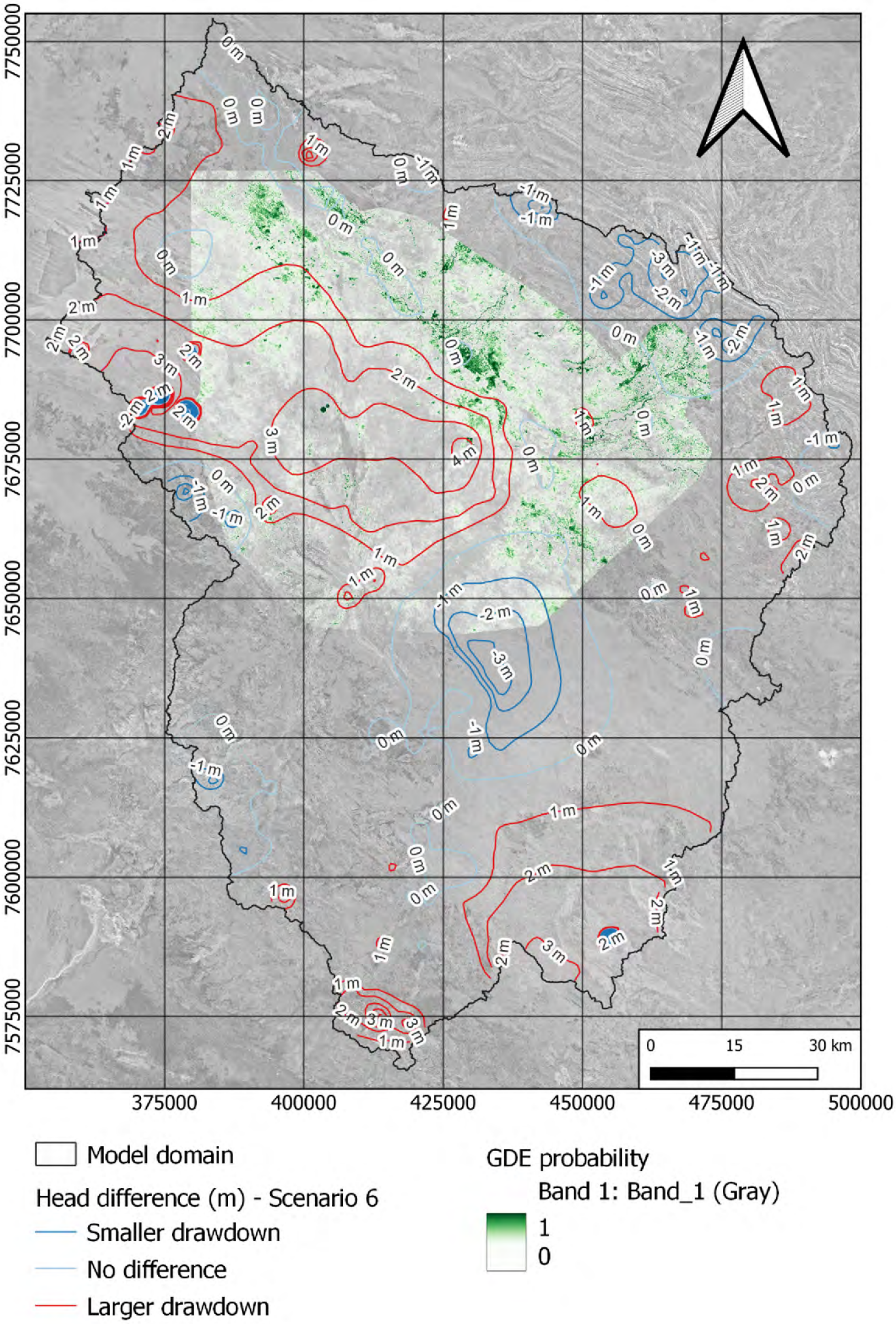
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Head difference (m) - Scenario 6
Smaller drawdown
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Larger drawdown
GDE probability
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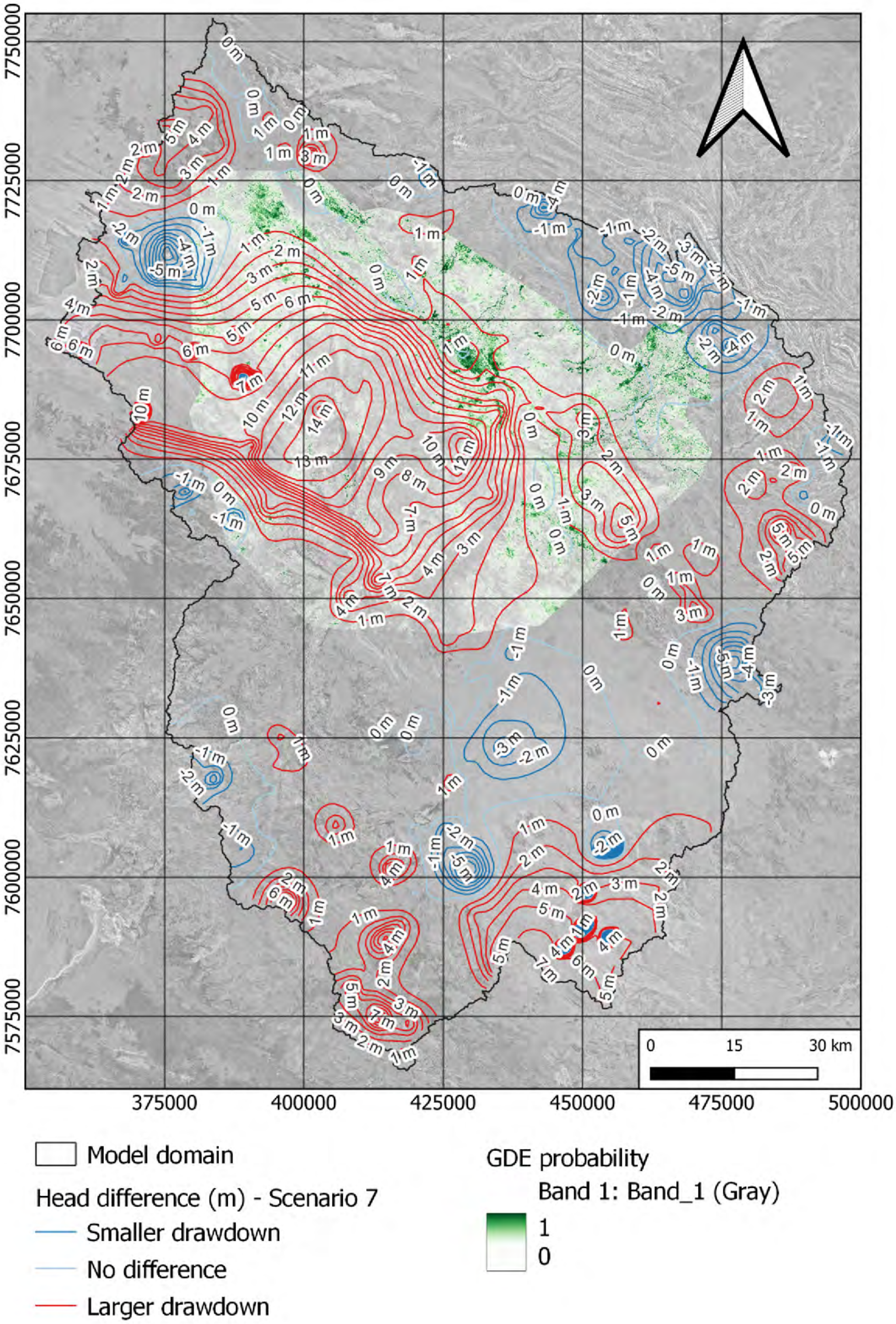

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Head difference (m) - Scenario 7
Smaller drawdown
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Larger drawdown
GDE probability
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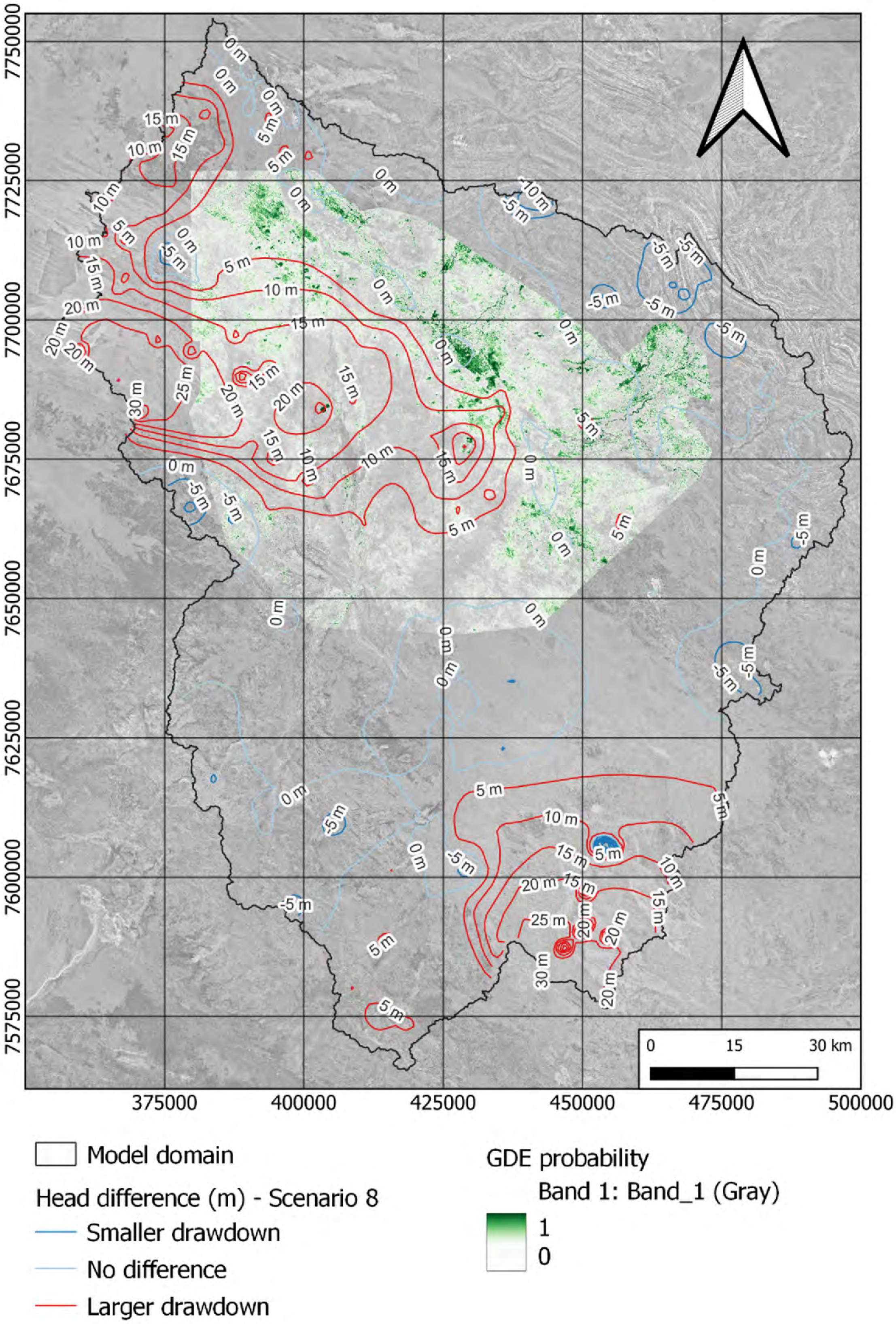

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Larger drawdown
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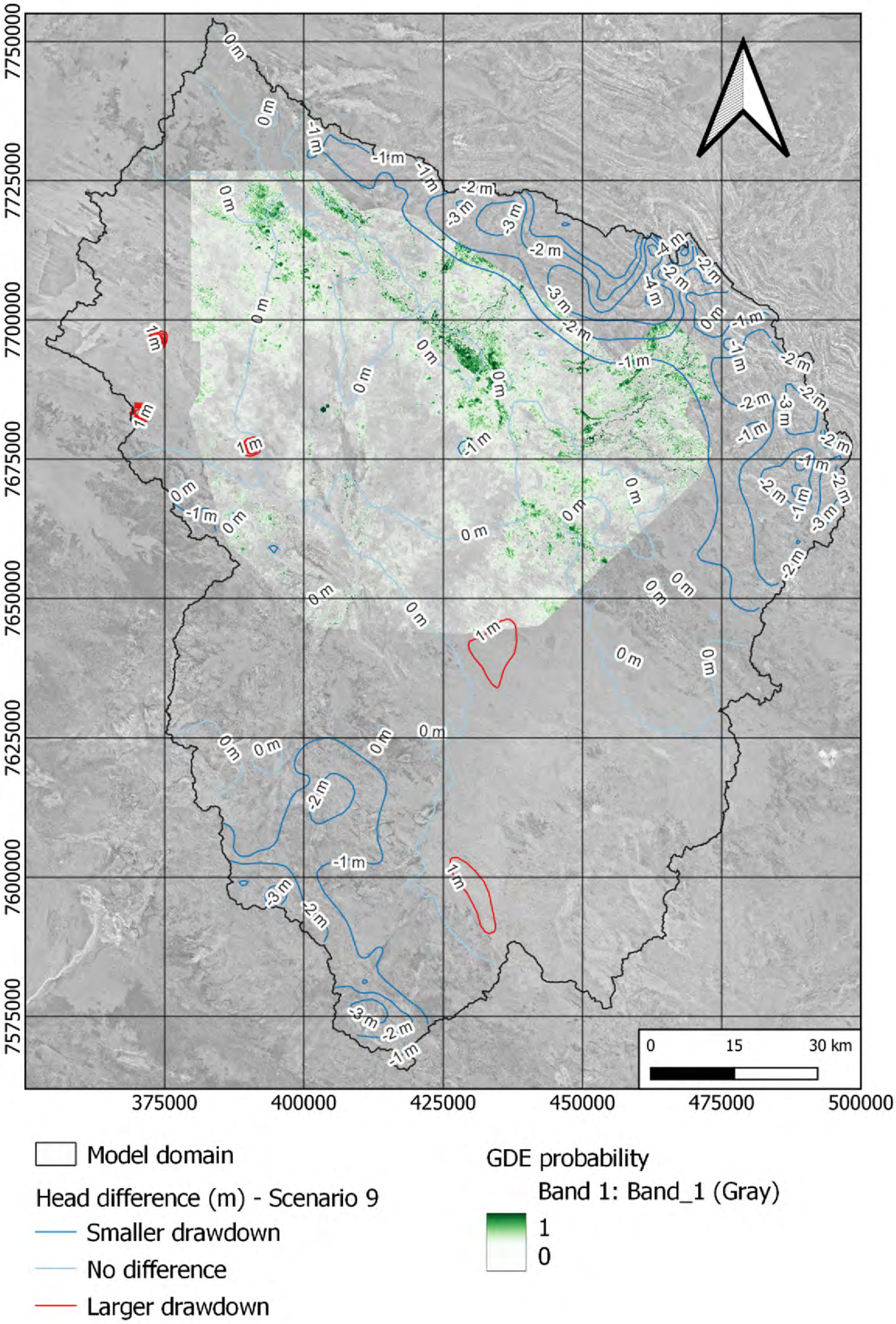
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Model domain
Head difference (m) - Scenario 9
Smaller drawdown
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GDE probability
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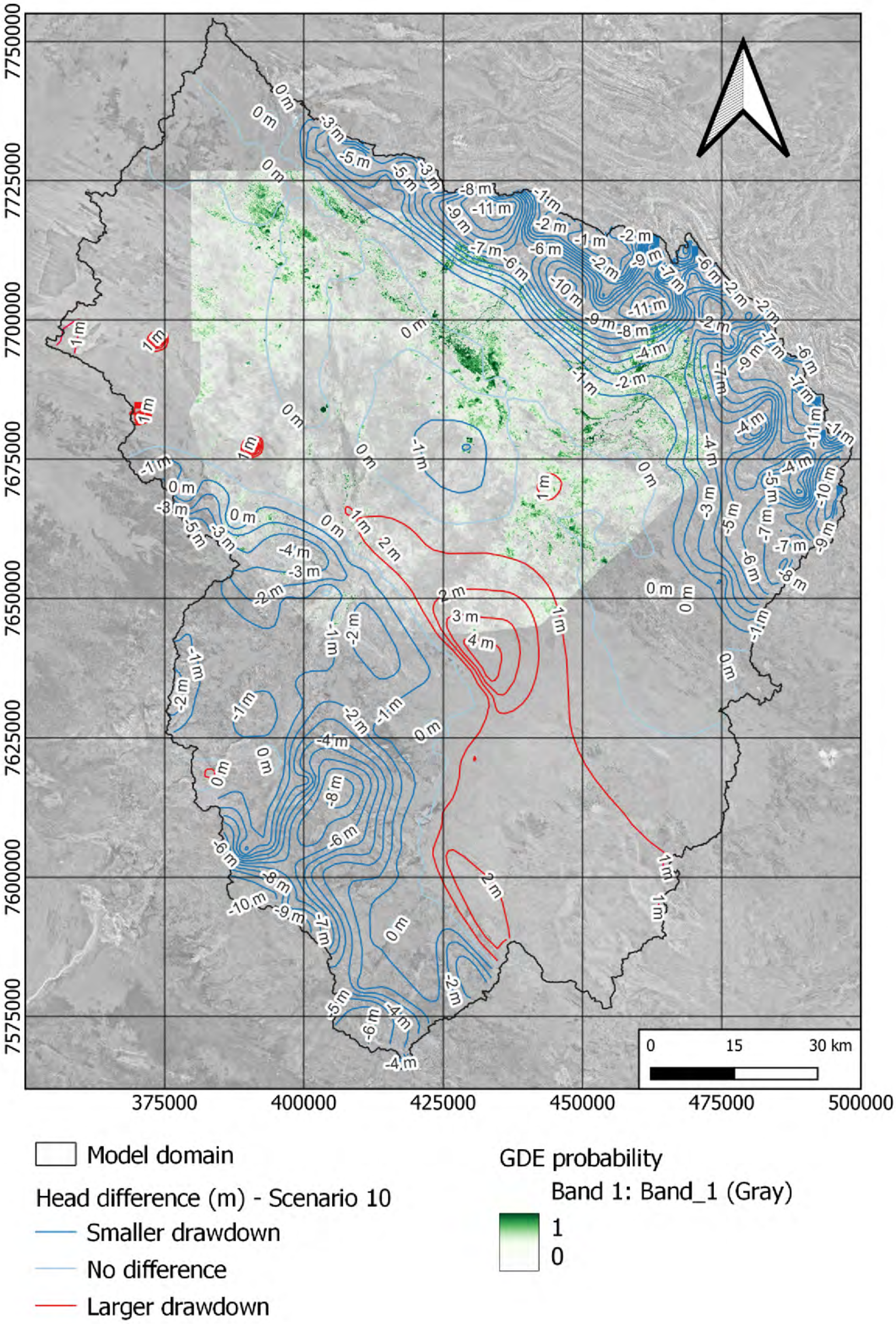

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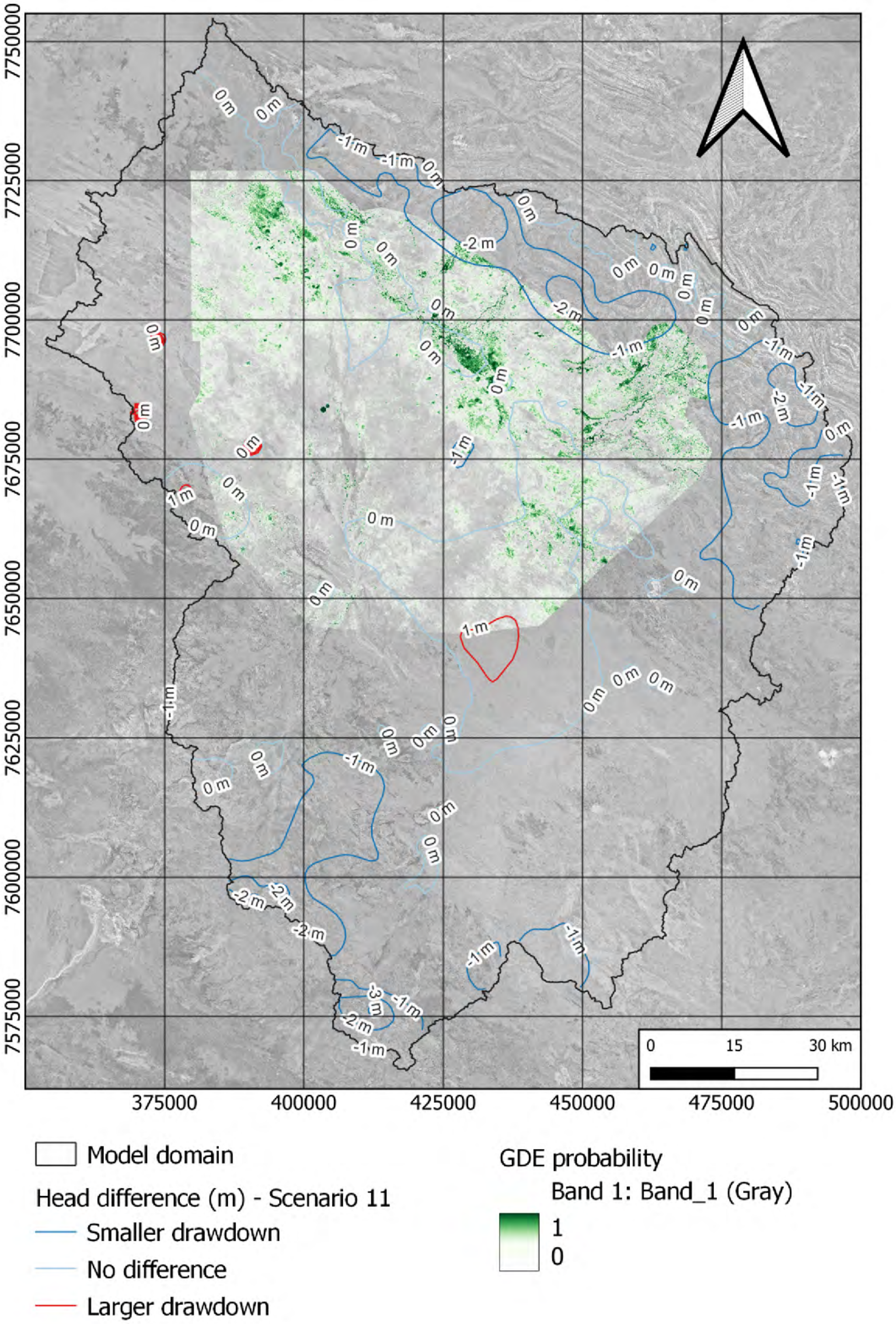

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Head difference (m) - Scenario 11
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GDE probability
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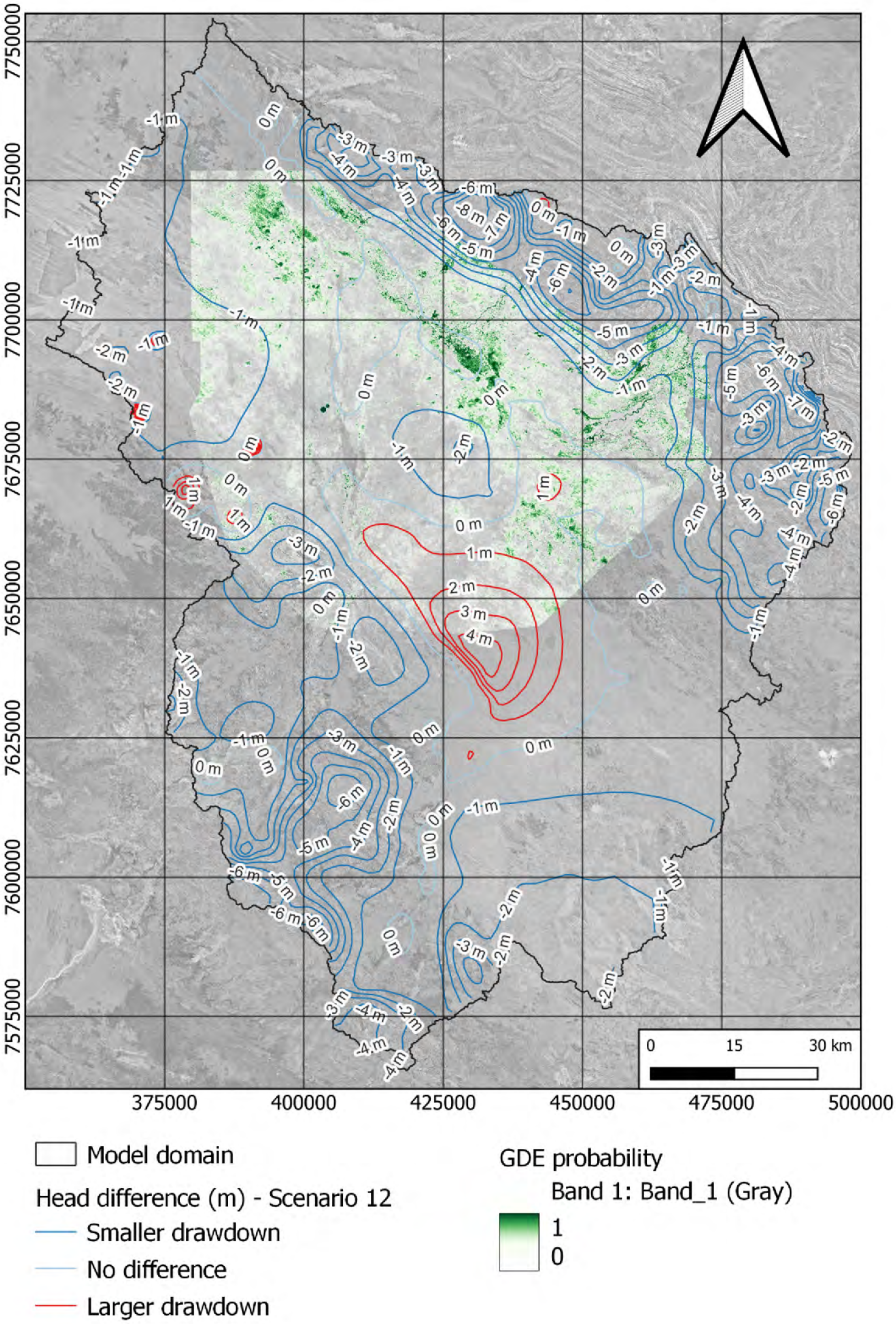

Model domain
Head difference (m) - Scenario 12
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GDE probability
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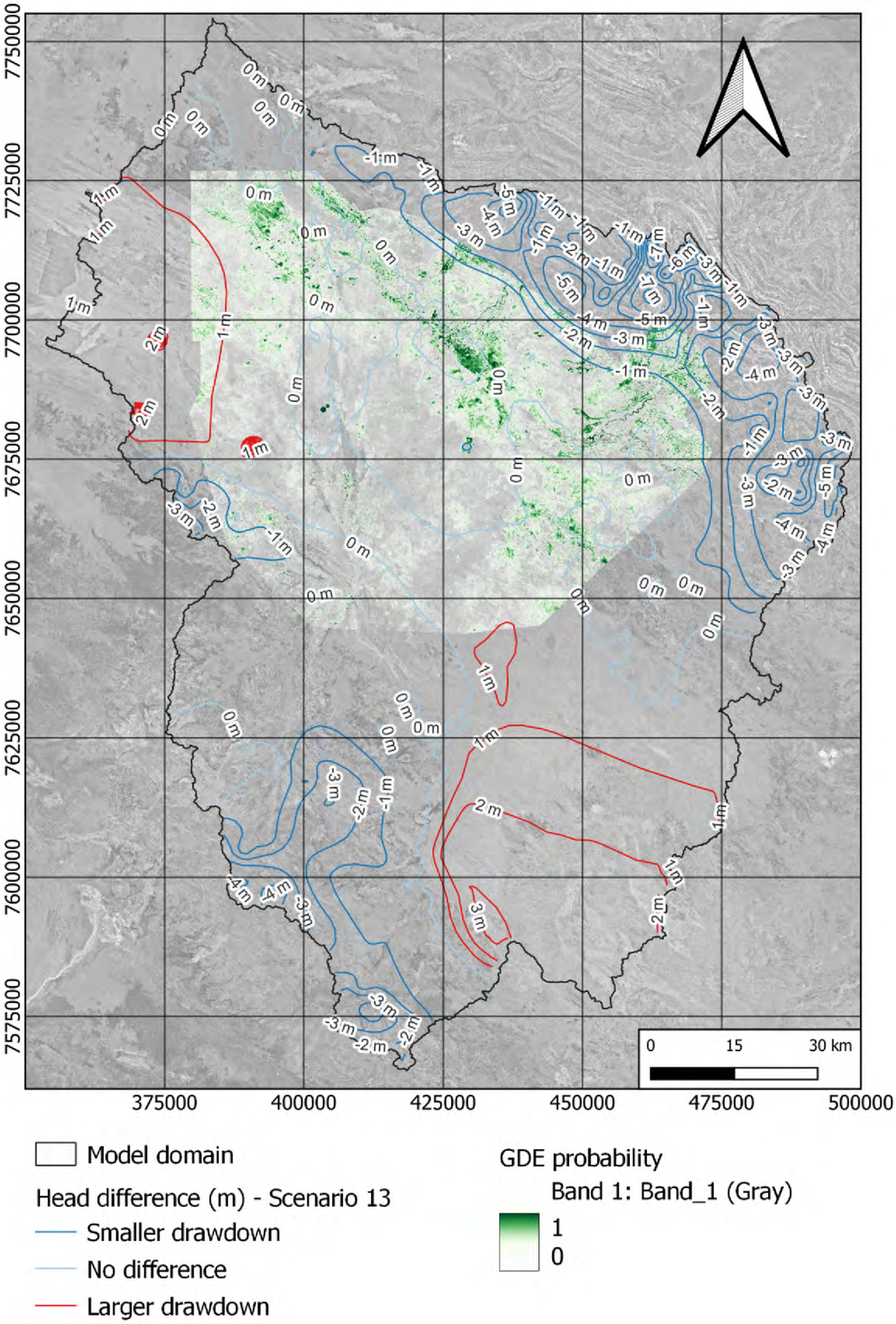
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Model domain
Head difference (m) - Scenario 13
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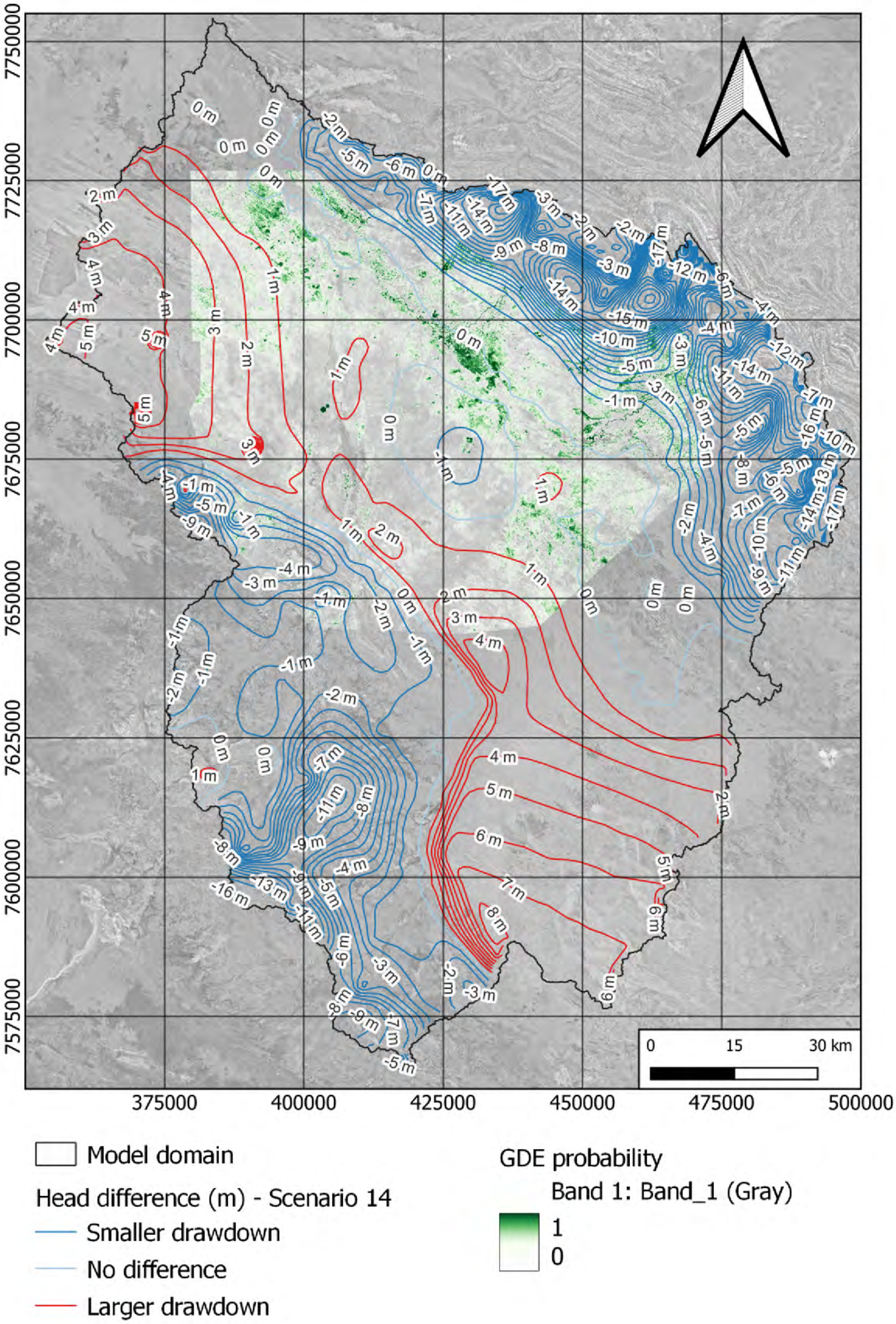
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Model domain
Head difference (m) - Scenario 14
Smaller drawdown
No difference
Larger drawdown
GDE probability
Band 1: Band_1 (Gray)
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Appendix 5 – Curriculum Vitaes

CURRICULUM VITAE

Dr. RYAN I.J. VOGWILL

ABOUT

Ryan's more than 20 years of technical expertise encompass groundwater modelling, water resource planning and recovery of hydrologically impacted ecosystems, with a focus on applying research to sustainable groundwater management and environmental impact/risk assessment

QUALIFICATIONS

BSc (Applied Geology) - Curtin University

First Class Hons (Applied Geology) - Curtin University

Doctor of Philosophy (Applied Geology) - Curtin University

Member Australian Institute of Geoscientists

EXPERIENCE

Ryan has been an influential Hydrogeologist in Western Australia for more than 20 years. He has undertaken project work and provided advice regarding the management of groundwater resources and environmental impacts across most business areas and across all regions of WA, but also with national and international based projects. He played a significant role in establishing and the initial application of the Perth Regional Aquifer System Model, a platform for more responsible and informed management of groundwater resources in the Perth region. He also established, coordinated and was the primary lecturer for the Hydrogeology MSc course at UWA. He has worked in consultancy intermittently throughout his career, but this is now full time as of September 2016.

KEY SKIILS & EXPERTISE

Technical and editorial review

Regional and local scale water allocation planning including drought contingency planning

Water quality and ecology (i.e. effluent discharge and algal blooms)

Sedimentological and geochemical assessment

Land use re-evaluation

Environmental risk assessment

Groundwater Dependent Ecosystems (GDEs) and Environmental Water Requirements (EWRs)

Dryland salinity

Groundwater training and education

Groundwater modelling generally but with a focus on MODFLOW

Surface water/groundwater interaction modelling including water and solute balances

Project and staff supervision

AWARDS

Ocean Seas Ocean Hero Award.

Hydrology and Earth Systems Science - Jim Dooge Award 2020

KEY PROJECT EXPERIENCE

PRAMS development and application - a $5M groundwater model of the Perth (Moora to Mandurah) Region

South West Yarragadee groundwater and impact assessment modelling (SWAMS and local area models) review for the Department of Conservation and Land Management

A member of the modelling technical reference groups for Ord Stage 2 - Weaber Plains and the southern river/Murray River MikeSHE modelling projects by CSIRO

Salt Lake Potash - Water supply and production impact assessment and licensing.

Millennium Minerals Limited - Multiple mine dewatering requirements and GDE impact risk assessment

Supervising Hydrologist for the Natural Diversity Recovery Catchment Program

KEY CAREER HISTORY

Director, Principal Hydrogeologist, Hydro Geo Enviro Pty Ltd, Feb 2018 to date

Principal Hydrogeologist (Sole Trader) September 2016 to Feb 2018

Associate Professor Hydrogeology, The University of Western Australia, December 2011 – September 2016

Supervising Hydrogeologist, Nature Conservation Division, Department of Environment, and Conservation, February 2006 – April 2011

Hydrogeologist, Department of Water, Groundwater Hydrology Section, February 2003 – February 2006

CONTACT

E: ryanv@hydrogeoenviro.com.au
www.hydrogeoenviro.com.au
m: 0427 427 269

PROFESSIONAL EXPERIENCE

DIRECTOR AND PRINCIPAL HYDROGEOLOGIST

HYDRO GEO ENVIRO AND SOLE TRADER SEPTEMBER 2016 – ONGOING

Key clients and project during this time include:

- Salt Lake Potash - water supply and production impact assessment/licensing.
- Millennium Minerals Limited - Multiple mine dewatering requirements, surface water management, GDE mapping and impact risk assessment
- City of Kalamunda - Acid sulphate soil management
- Adelaide Brighton Cement - Inorganic contamination conceptual modelling and remediation
- City of Rockingham - Lake Richmond microbialites, hydrology, chemical risk and weed management
- Rottnest Island Authority - Microbialite monitoring plan and impact criteria

ASSOCIATE PROFESSOR OF HYDROGEOLOGY

THE UNIVERSITY OF WESTERN AUSTRALIA, DECEMBER 2013 – SEPTEMBER 2016

JOINT ASSOCIATE PROFESSOR OF HYDROGEOLOGY

THE UNIVERSITY OF WESTERN AUSTRALIA/CURTIN UNIVERSITY, APRIL 2011 – DECEMBER 2013

SUPERVISING HYDROLOGIST, NATURE CONSERVATION DIVISION

DEPARTMENT OF ENVIRONMENT, AND CONSERVATION, FEBRUARY 2006 – APRIL 2011

Ryan was the key hydrogeologist employed by DEC, providing advice across all business areas. He continued working on GDEs of the Gnangara Mound, dryland salinity and all of the associated issues. Ryan has reviewed, critiqued and presented to the EPA on a number of subjects, including the sustainability of groundwater abstraction from the Gnangara Mound and Southwest Yarragadee project. He has also been heavily involved in many referrals from other government departments and sections of the DEC for many technical reviews of mining applications. Ryan continued to co-ordinate research and projects for the DEC, which involved the interaction of hydrology and biology in the Natural Diversity Recovery Catchments during the first 3 years of his time in academia until the Natural Diversity Recovery Catchment project was shut down.

HYDROGEOLOGIST

DEPARTMENT OF WATER, GROUNDWATER HYDROLOGY SECTION, FEBRUARY 2003 – FEBRUARY 2006

Preparation of modelling scenarios and the associated reporting; Section 46 modelling; Drought Contingency modelling; East Wanneroo Land Use Re-evaluation; graphic presentation of modelling data; database analysis and retrieval for various purposes; development of sampling programs; research proposals; and a large number of modelling/report critiques amongst other duties.

BOOKS AND PUBLISHED REPORTS

Vogwill R., 2017, Western Australia's Tight Gas Industry - A review of groundwater and environmental risks. Conservation Council of Western Australia. ISBN (13): 978-0-9750708-1-9.

Vogwill R. (ed), 2016, Solving the Groundwater Challenges of the 21st Century - IAH - Selected Papers on Hydrogeology. CRC Press, Taylor & Francis. ISBN 9781138027473. https://www.crcpress.com/Solving-the-Groundwater-Challenges-of-the-21st-Century/Vogwill/9781138027473.

Vogwill R., 2015, Water Resources of the Mardoowarra (Fitzroy River) Catchment. Published by The Wilderness Society. ISBN: 978-0-646-94928-4

BOOK CHAPTERS

Doherty J. and Vogwill R., 2016, Models, Decision-Making and Science. In Vogwill R. (ed), 2016, Solving the Groundwater Challenges of the 21st Century - IAH - Selected Papers on Hydrogeology. CRC Press, Taylor & Francis. ISBN 9781138027473. https://www.crcpress.com/Solving-the-Groundwater-Challenges-of-the-21st-Century/Vogwill/9781138027473 (in press).

Vogwill R., 2016, Solutions to the Groundwater Challenges of the 21st Century - Introduction IAH - Selected Papers on Hydrogeology. CRC Press, Taylor & Francis. ISBN 9781138027473. https://www.crcpress.com/Solving-the-Groundwater-Challenges-of-the-21st-Century/Vogwill/9781138027473.

Boulton, A., Brock, M., Robson, B., Ryder, D., Chambers, J., Davis, J., 2014, Australian Freshwater Ecology: processes and management, Wiley and sons. Note Vogwill contribution is a salinity case study on Lake Toolibin. Given this is a published text book, chapters are not attributed specifically but my input has been formally acknowledged in the publication.

THESES

Vogwill, R.I.J., 1996, Aspects of the Hydrogeology and Environmental Geochemistry of Lake Walyungup, Rockingham Western Australia Honours Thesis, Curtin University, Western Australia.

Vogwill, R.I.J, 2003, Hydrogeology and Aspects of the Environmental Geology of the Broome Area Western Australia, PhD Thesis, Curtin University, Western Australia.

JOURNAL PUBLICATIONS

Callow J.N, Hipsey M.R., and Vogwill R.I.J, 2020, Surface water as a cause of land degradation from dryland salinity. Hydrol. Earth Syst. Sci., 24, 717–734, 2020 https://doi.org/10.5194/hess-24-717-2020

Mendes Monteiro J., Vogwill R., Bischoff K. and Gleeson D.B., 2019, Comparative metagenomics of microbial mats from hypersaline lakes at Rottnest Island (WA, Australia), advancing our understanding of the effect of mat community and functional genes on microbialite accretion. Limnol. Oceanogr. 00, 2019, 1–17 doi: 10.1002/lno.11323

Davies C., Vogwill R. and Oldham C., 2017, Urban Subsurface Drainage as an Alternative Water Source in a Drying Climate. Australasian Journal of Water Resources. In Press. http://dx.doi.org/10.1080/13241583.2017.1351130

Coletti J.Z., Vogwill R., Hipsey M.R., 2017, Water management can reinforce plant competition in salt-affected semi-arid wetlands, Journal of Hydrology, doi: http://dx.doi.org/10.1016/j.jhydrol.2017.05.002.

Forbes M. and Vogwill R., 2016, Hydrological change at Lake Clifton, Western Australia – Evidence from hydrographic time series and isotopic data. Journal of the Royal Society of Western Australia, 99(2): 47–60.

Davies, C. Oldham, C. and Vogwill, R., 2016, *Urban Subsoil Drainage as an Alternative Water Source in a Drying Climate.* Peer reviewed paper for Stormwater Australia 2016 National Conference, September 2016, Gold Coast QLD.

Gunaratne GL, Vogwill R, and Hipsey M, 2016, Effect of seasonal flushing on nutrient export characteristics of an urbanising, remote, ungauged coastal catchment. *Hydrological Sciences Journal* http://dx.doi.org/10.1080/02626667.2016.1264585.

Smith, M. J., P. L. Drake, R. Vogwill, and C. A. McCormick. 2015. Managing natural resources for their human values. Ecosphere 6(8):140.

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S. Clohessy , S. Appleyard , R. Vogwill, 2013, Groundwater acidification near the water table of the Superficial Aquifer, Gnangara Mound, Swan Coastal Plain, Western Australia. Applied Geochemistry, V 36, pp 14-152. doi:10.1016/j.apgeochem.2013.06.003.

Mitchell, N., Hipsey, M.R., Arnall, S.G., McGrath, G.S., Tareque, A., Kuchling, G., Vogwill, R.I., Sivapalan, M., Porter, W., Kearney, M. 2013, 'Linking eco-energetics and eco-hydrology to select sites for the assisted colonization of Australia's rarest reptile', Biology, 2, 1, pp. 1-25.

Coletti, J.Z., Hinz, C., Vogwill, R., Hipsey, M.R.,2013, Hydrological controls on carbon metabolism in wetlands, Ecological Modelling, 249, 3-18.

Drake P.L., Coleman B.F. and Vogwill R., 2012, The response of semi-arid ephemeral wetland plants to flooding: linking water use to hydrological processes. Ecohydrology 2012 online.

Forbes M.S., Vogwill, R., 2011. A geochemical investigation of hydrologically derived threats to rare biota: The Drummond Nature Reserve, Western Australia. Hydrogeology Journal Hydrogeology Journal (16 September 2011), pp. 1-17, doi:10.1007/s10040-011-0780-8 Key: citeulike:9818473

Forbes M., Vogwill R and Onton K., 2010, A characterisation of the coastal tufa deposits of south–west Western Australia. Sedimentary Geology Vol. 232, Issues 1-2 pp 52-65.

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I.C. Lau, T.J. Cudahy, C.C.H. Ong, R.J.J. Vogwill, S. L. McHugh, R.D. Hewson and M.S. Caccetta, , 2006, Environmental monitoring of acid sulphate soils in the Swan Coastal Plain, using hyperspectral methods. ASEG Extended Abstracts Volume 2006 Number 1.

NOTABLE "GREY" LITERATURE PUBLICATIONS

Department of Parks and Wildlife (in review). Toolibin Lake Natural Diversity Recovery Catchment: Recovery Plan (2015 to 2035). Department of Parks and Wildlife, Perth, Australia.

Coletti, J.Z, Vogwill, R., Busch, B.D., Callow, N., Hipsey, M.R., (2014) A Decision Support Tool for the Ecohydrological Management of Lake Toolibin Recovery Catchment. Report prepared for the Department of Parks and Wildlife, Government of Western Australia, 127pp.

Coletti, J.Z, Gunaratne, G., Hipsey, M.R., Busch, B.D., Callow, N., Vogwill, R., (2012) BioRisk – Model assessment of wheat-belt biodiversity asset response to ecohydrological dynamics. Report prepared for the Department of Environment and Conservation, Government of Western Australia, 84pp.

Wallace, K., Connell, K., Vogwill, R., Edgely, M., Hearn, R., Huston, R., Lacey, P., Massenbauer, T., Mullan, G., and Nicholson, N., 2011, Natural Diversity Recovery Catchment Program: 2010 Review. Department of Environment and Conservation, Perth, Western Australia.

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Note this is a key report for Western Australian water resources and was copy edited to international publication standards. This report was also peer reviewed by at least 25 people.

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Vogwill, R. I. J., 2004, Section 46 Groundwater Modelling Results - Stage 1, Department of Environment, HR 223 Department of Environment, Government of Western Australia.

Vogwill, R.I.J., McHugh S.L., O'Boy C., Anson B. Yu X., 2007, Section 46 - Sensitivity of the Water Table of Gnangara Mound to Climate Land use and Abstraction, Stage 2. Department of Water, Government of Western Australia, this has been published formally on the Department of Water web page.

McHugh, S.L., and Vogwill, R.I.J., 2005, Investigation of the Sustainability of Shallow Groundwater Systems on Gnangara and Jandakot Mounds, HR 240 Department of Environment, Government of Western Australia.

Buntine-Marchagee Natural Diversity Recovery Catchment, Recovery Plan 2007-2027, DEC, 2007. This report has been copy edited to international publication standards and represents a crucial step in developing a new method of recovery planning to reduce salinisation impacts in the wheatbelt. I was responsible for much of the hydrological content and a key input to planning process and research plan.

CONFERENCE PAPERS, ABSTRACTS AND POSTERS

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Groundwater control and supply for developments on shallow water tables, Swan Coastal Plain, Western Australia - Preliminary results. Stormwater Industry Association of WA, Hydropolis 2015, Perth Western Australia, 22 April 2015 (oral)

Gunaratne GL, Hipsey M and Vogwill R (2015) A model-based decision support tool for managing Lyngbya occurrence in intertidal coastal environments, A poster presentation at Western Australian Marine Science Institution (WAMSI), Perth, Australia. 31-01 April 2015 (abstract)

Gunaratne GL, Hipsey M and Vogwill R (2014) A mechanistic description of Lyngbya algal blooms for inter-tidal coastal embayments, Proceedings of Coast to coast Conference, Mandurah, Australia. 27-31October, 2014. (abstract)

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Vogwill R., Forbes M. and Onton K., 2012, Threats to the coastal tufa deposits of south-west Western Australia. International Association of Hydrogeologists Conference Niagara, Canada. (abstract and oral)

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Zanella Coletti, J., Hinz, C., Vogwill, R.I., Hipsey, M.R. 2011, 'A minimalistic model for carbon cycling in wetlands', 19th International Congress on Modelling and Simulation, Australia, 1, pp. 2219-2225. (oral and reviewed paper)

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Forbes M.S., & Vogwill R.I.J., 2009. Hydrological assessment of the Drummond Nature Reserve. 10th Australasian Environmental Isotope Conference and 3rd Australasian Hydrogeology Research Conference. Perth, Western Australia. (Abstract and oral presentation).

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Forbes M.S., Vogwill R.I.J., Khor, P., Jasper R., 2009. The Drummond Nature Reserve: a dryland biodiversity recovery catchment. 7th International Geomorphology Conference, Melbourne, Victoria. (Abstract and oral presentation).

Forbes M.S., Vogwill R.I.J., Onton K., & Johns J., 2009. The Coastal Tufa communities of south west Western Australia. 7th International Geomorphology Conference, Melbourne, Victoria. (Abstract and oral presentation).

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Mudgway L., Lacey P. and Vogwill R, 2008, Know what you are measuring—a detailed review of groundwater monitoring at Toolibin Lake and Lake Bryde, 2nd International Salinity Forum, Adelaide 31st Mar – 3rd Apr 2008. (Paper)

Noorduijn, S.L., Vogwill, R. O'Sullivan, W., Ghadouani, A., and Smettem, K. R. J., 2008, Multi Frequency monitoring of water table response to Alley Farming, 2nd International Salinity Forum, Adelaide 31st Mar – 3rd Apr 2008 (poster presentation)

Vogwill R, Cook TF, Appleyard, SJ, Watkins R, 2007, Potential for Negative Ecological Impacts of Current Water and Landuse of Gnangara Mound GQ2007, the 6th International IAHS Groundwater Quality Conference, held in Fremantle, Western Australia, 2-7 December 2007. (abstract and oral presentation).

Noorduijn, S.L., Vogwill, R, Ghadouani, A, and Smettem, K. R. J., 2007, Assessing agroforestry as a tool for sustainable water resources management in western Australia, SSEE International Conference on Sustainable Engineering, 31st Oct-2nd Nov 2007 (oral presentation)

Cook TF, Watkins R, Appleyard, SJ, Vogwill R, 2006, Acidification of groundwater caused by a falling water table in a sandy aquifer in the Perth Region, Western Australia. Proceedings of the 18th World Congress of Soil Science, 9-15 July 2006, Philadelphia, USA. (abstract and oral presentation).

Vogwill R, 2004, Groundwater Resources of Western Australia, learning from the past and present with an eye to the future. 175th Anniversary conference. (abstract and oral presentation).

Eduardo De Sousa, PhD

Principal Groundwater Modeller/Business Area Manager

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

Years of Experience: 19

Education:

- PhD, 2021, Hydrogeology, University of Western Australia
- MSc, 2007, Hydrogeology, University of the Free State
- BSc, 2002, Geology, Universidade Federal do Rio Grande do Sul

Professional History:

2021 – Present	Principal Groundwater Modeller/Business Area Manager – INTERA Geosciences Pty Ltd, Perth, Australia
2019 – 2021	Principal Groundwater Modeller/Business Area Manager – DHI Water and Environment, Perth Australia
2012 – 2019	Principal Hydrogeologist – Pells Sullivan Meynink, Perth, Australia
2008 – 2012	Senior Groundwater Modeller – Schlumberger Water Services, Perth, Australia
2007 – 2008	Senior Hydrogeologist – URS Asia Pacific, Perth, Australia
2006 – 2007	Hydrogeologist – Golder Associates, Johannesburg, South Africa
2005 – 2006	Groundwater Modeller – Groundwater Consulting Services, Johannesburg, South Africa
2002 – 2005	Hydrogeologist – AmbiTerra/Essencis remediaco, Porto Alegre, Brazil

Software and Skills

- Proficient in C++, Qt, Python and FORTRAN. Experience in heavy customization of groundwater modelling codes either as external plugins or changes in the original source code.
- SQL Server, SQlite, MS Access. Developed 3Space, an open source database for groundwater and geotechnical data
- Proficient in ArcGIS, Quantum GIS and Global Mapper
- Proficient in Leapfrog Geo, Petrel and SURPAC packages.

Dr. Eduardo de Sousa is a Principal Groundwater Modeller at INTERA. He has nearly two decades of experience working in South America, Africa and Australasia delivering modelling solutions in hydrogeological systems of high complexity, including modelling of geothermal systems, reactive transport modelling, design of dewatering and depressurization systems, environmental impact assessments, ecohydrology and groundwater remediation. Dr. De Sousa's work has included the development of DHI's tool for MODFLOW6 to FEFLOW conversions, dewatering optimization workflows for consulting projects and software product, tools to emulate steam pressures in the unsaturated zones in geothermal sites, software infra structure to allow the use of PEST with FEFLOW models, and high-complexity 3D models in mining environments for operations (dewatering and depressurisation), environmental purposes and dynamic coupling of pit-lake and groundwater models in mine closure projects. His experience also encompasses civil engineering projects, including modelling for underground tunnels, basements, and slope stability purposes as well as experience in contaminated sites, including field activities, and remediation projects (pump and treat and phytoremediation). Additionally, Dr. De Sousa was also an invited keynote speaker for the FEFLOW user conference in Adelaide, 2013, where he presented the importance customization in numerical models of high complexity.

Project Experience – Mining

Liwa Managed Aquifer Recharge, ACC/POSCO E&C, Liwa, United Arab Emirates. 2019. *Principal Groundwater Modeller.* Responsible for calibration, sensitivity analysis and uncertainty quantification of a Managed Aquifer Recharge project.

Office of Groundwater Impact Assessment, Brisbane, Australia. 2020 – Present. *Principal Groundwater Modeller.* Responsible for signal processing works for over 700 boreholes distributed across Brisbane, with the objective to identify and separate influences from rainfall, coal seam gas abstraction and private water users in groundwater level hydrographs. Contributor to design and fault-geology model discretization for the next-gen OGIA model.

Hope Downs, Rio Tinto Iron Ore, Pilbara, Australia. 2020. *Principal Groundwater Modeller.* Conceptualisation and development of a three-dimensional groundwater model of an open pit mine for slope stability purposes. Uncertainty analysis using PESTPP-IES.

Marandoo, Rio Tinto Iron Ore, Pilbara, Australia. 2020. *Principal Groundwater Modeller.* Conceptualisation and development of a three-dimensional groundwater model of an open pit mine for slope stability purposes. Uncertainty analysis using PESTPP-IES.

Koodaideri Solitude, Rio Tinto Iron Ore, Pilbara, Australia. 2019 – 2020. *Principal Groundwater Modeller.* Development of a Goldsim tailings water balance model for estimation of pit seepage rates and environmental impacts on groundwater. Results from Goldsim were used as inputs to a FEFLOW solute transport model.

Solitude, BHP, Arizona, USA. 2020 – 2021. *Principal Groundwater Modeller.* Model review and uncertainty analysis for a tailings dam model, aimed at estimating pore pressures and potential for slope failure.

Antapaccay, Glencore, Yauri district, Peru. 2019 – 2020. *Principal Groundwater Modeller.* Dewatering optimization for an open pit mine, including heavy customization of FEFLOW to allow the use of gradient methods (PESTPP-GLM) in the constrained optimization.

Candelaria, Client, Lundin Mining, Chile. 2020. *Principal Groundwater Modeller.* Responsible for model calibration of a three-dimensional groundwater model of an open pit mine for environmental impact assessments.

Clermont, Glencore, Clermont, Australia. 2018. *Principal Groundwater Modeller.* Groundwater model setup and calibration of an open pit coal mine for slope-stability analysis, and simulation of pore pressure intervention measures including horizontal drains and dewatering wells.

West Canning Basin Model, Department of Water, Perth, Australia. 2017 – 2018. *Principal Groundwater Modeller.* Responsible for conceptualization and development of a three-dimensional groundwater variable-density flow and transport model to be used by the local regulatory agencies (DoW) as a tool for water allocation. Involved the use of highly-parallelised parameter inversion using PEST and cloud computing on Amazon EC2 platform.

Lihir Gold Mine, Newcrest mining, Lihir Island, Papua New Guinea. 2009 – 2018. *Principal Groundwater Modeller.* Responsible for the development of three-dimensional groundwater flow and heat transport model for the site. The model was used to provide pore pressure distributions for slope stability analysis, and estimates on pit floor temperature, inflow rates and dewatering designs.

Collie Basin, Griffin Coal, Collie, Australia. 2015 – 2018. *Principal Groundwater Modeller.* Responsible for the development of several groundwater models for environmental impact assessments and mine closure-studies, including explicit modeling of pit lakes and their interactions with surrounding aquifers.

Cerrejon mine, Glencore, La Guajira, Colombia. 2016. *Principal Groundwater Modeller.* Responsible for the development of cross-section pore pressure models of open-pit mine for slope-stability purposes

Prominent Hill, OzMinerals, Coober Pedy, Australia. 2014 – 2015. *Principal Groundwater Modeller.* Responsible for the hydrogeological conceptualisation and numerical modelling of pore pressures of an open pit and its interaction with the adjacent tailings storage facility.

Pani Gold project, One Asia Resources, Hulawa, Indonesia. 2013. *Associate Groundwater Modeller.* Hydrogeological field investigation, including drilling supervision, packer testing and installation of Vibrating Wire Piezometers. Pore pressure groundwater modelling for slope stability purposes.

Stuart Oil Shale Project, Queensland Energy Resources, Yarwun, Australia. 2013. *Associate Groundwater Modeller.* Hydrogeological review and depressurization assessment for the Stuart oil shale deposit.

Arrow Energy, Brisbane, Australia. 2010. *Senior Groundwater Modeller.* Geological modelling and groundwater flow modelling for the environmental impact assessment of Coal Seam Gas activities.

QGC Energy, Brisbane, Australia. 2010. *Senior Groundwater Modeller.* Geological modelling and groundwater flow modelling for impact assessment of Coal Seam Gas activities.

BHPBIO, Various Locations, Australia. 2009 – 2011. *Senior Groundwater Modeller.* Pore pressure groundwater modelling for slope stability analysis for several sites across the Pilbara region.

Bluewater Ash Co-disposal, Bluewaters, Collie, Australia. 2008. *Senior Groundwater Modeller.* Developed a groundwater flow and transport modelling for the environmental impact assessment of pit backfilling with coal ash materials.

Wesfarmers Premier Coal, Wesfarmers, Collie, Australia. 2008. *Senior Groundwater Modeller.* Dewatering designs and mine water balance with the development of a groundwater flow model.

Bootu Creek Manganese Project, OM Holdings, Tennant Creek, Australia. 2008. *Senior Groundwater Modeller.* Groundwater flow modelling using MODFLOW developed for dewatering designs.

Nooitgedacht Groundwater Impact Assessment, Glencore, Nooitgedacht, South Africa. 2007. *Hydrogeologist.* Developed a groundwater flow model using FEFLOW with the objective of assess drawdown impacts caused by open pit coal mines.

Grootegeluk Groundwater Impact Assessment, Exxaro, Limpopo province, South Africa. 2007. *Hydrogeologist.* Developed a groundwater flow and transport model (MODFLOW-MT3DMS) to assess the impacts of ash co disposal in a coal pit. The model was integrated with geochemical models (PHREEQC) and unsaturated flow models to the define source term water quality and seepage rates.

Capanga Aquifer Characterization, Vale, Moatize, Mozambique. 2006 – 2007. *Hydrogeologist.* Worked in the field program and groundwater modelling activities for the aquifer characterization and impact assessment from river abstraction and open pit mining. Undertaken drilling supervision, groundwater and river level monitoring, groundwater sampling and aquifer tests.

ESKOM UCG Phase 2 Hydrogeological Investigation, ESKOM, Majuba, South Africa. 2006 – 2007. *Groundwater Modeller.* Undertaken field investigations and numerical modelling using FEFLOW for assessing impacts from underground coal gasification in the groundwater environment.

Kalgold Mine, Harmony, Mahikeng, South Africa. 2006. *Groundwater Modeller.* Developed a groundwater model using MODFLOW to assess groundwater impacts in terms of drawdown and baseflow reduction along streams. Undertaken site visit and groundwater monitoring.

Kayelekera Uranium Mine, Paladin, Karonga, Malawi. 2006. *Groundwater Modeller.* Geological modelling and hydrogeology conceptualization for an environmental impact assessment.

Ambatovy Tailings Storage Facility, Knight Piezold, Ambatovy, Madagascar. 2005 – 2006. *Groundwater Modeler.* Conducted field investigations and developed a groundwater flow and transport model using MODFLOW and MT3DMS. Field investigations included drilling supervision, aquifer testing and groundwater monitoring. Undertaken tailings seepage modelling and salt-load calculations in to local streams.

Ambatovy Mine Site Hydrogeological Study, Knight Piezold, Ambatovy, Madagascar. 2005 – 2006. *Groundwater Modeler.* Conducted field investigations and developed a groundwater flow and transport model using MODFLOW and MT3DMS. The model was used to assess groundwater drawdowns, estimate pit inflows and provide salt load estimates along local streams.

Project Experience – Water Resources

M4East Tunnel, Leighton/Samsung C&T/John Holland, Sydney, Australia. 2015 – 2016. *Principal Groundwater Modeler.* responsible for the development of groundwater models for excavation of underground tunnels, aiming at providing predictive estimates of drawdowns, tunnel inflows and pore pressures along the tunnel crown.

Melbourne Metro, CPB, Melbourne, Australia. 2016. *Principal Groundwater Modeler.* responsible for the development of groundwater models aiming at the impact assessment of different excavation methods in terms of drawdown and groundwater inflows.

North West Rail Link, Thiess/John Holland, Sydney, Australia. 2013 – 2014. *Principal Groundwater Modeller.* responsible for the groundwater modelling of the railway tunnel structures, aimed at the simulation of pore pressures above the tunnel crown and inflow estimates.

Lake Muir-Unicup, Department of Parks and Wildlife, City, Australia. 2013 – 2020. *Principal Groundwater Modeler.* Developed integrated surface water-groundwater and ecosystems model couplings using FEFLOW and the University of Western Australia suit of codes to simulate interactions and feedback loops between wetlands, groundwater and vegetation assemblages in semi-arid wetlands of Western Australia.

Phytoremediation site, Undisclosed client, Sao Paulo, Brazil. 2003 – 2007. *Groundwater Modeler.* Developed a groundwater flow model for estimation of evapotranspiration rates and effectiveness of a phytoremediation system. Also conducted field activities, including slug testing, groundwater monitoring and sampling.

Publications, Presentations, and Reports

SOUSA, Eduardo Reckziegel de; Fast Assessment of pore pressures and inflows in open pits using smart models. In: Modflow and More 2017, Proceedings, Golden, United States.

SOUSA, Eduardo Reckziegel de; Simulating open pit transient inflows and pore pressure distributions with variable data availability using FEFLOW and customized plugins: IFMOpenPits and IFMLinearPits. In: Modflow and More, 2015, Proceedings, Golden, United States.

SOUSA, Eduardo Reckziegel de, FOWLER, Mark, SWARBIRCK, Gareth; Importance of monitoring temperature in the improvement of groundwater models – an example from an open pit in Papua New Guinea. In: 9th Symposium of Field Measurements in Geomechanics, Proceedings, Perth, Australia.

SOUSA, Eduardo Reckziegel de; Three-dimensional pore pressure prediction in dual phase conditions for slope stability assessment. In: International Symposium on Slope Stability in Open Pit Mining and Civil Engineering, 2013, Proceedings, Brisbane, Australia.

SOUSA, Eduardo Reckziegel de; When cross section modelling is not enough – Improving pore pressure modelling with use of full 3D models. In: 40th IAH International Congress, 2013, Proceedings, Perth, Australia.

SOUSA, Eduardo Reckziegel de; Improving open pit boundary conditions in FEFLOW with IfmOpenPits. In: 40th IAH International Congress, 2013, Proceedings, Perth, Australia.

SOUSA, Eduardo Reckziegel de; When layering is not enough – Converting geology block models into groundwater models. In: Modflow and More, 2013, Proceedings, Golden, United States.

SOUSA, Eduardo Reckziegel de; Improving recharge representation in FEFLOW with IFMMoveableRecharge. In: Modflow and More, 2013, Proceedings, Golden, United States.

SOUSA, Eduardo Reckziegel de; Myths on spatial discretization, quantification of errors related to geometry and layering misrepresentations. In: Modflow and More, 2013, Proceedings, Golden, United States.

SOUSA, Eduardo Reckziegel de; IFMPHREEQC - Multicomponent reactive transport model coupling Feflow and Phreeqc-2 - Preliminary benchmarking and implementation challenges. In: Modflow and More, 2011, Golden, United States.

SOUSA, Eduardo Reckziegel de; USHER, B; BERNARDES JR., C. Evaluation of the hydraulic effectiveness of a phytoremediation system from southeastern Brazil.In: GSSA Groundwater Conference, 2007, Bloemfontein – South Africa.

SOUSA, Eduardo Reckziegel de. Use of groundwater models to evaluate the effectiveness of Phytoremediation systems: an example from southeastern Brazil. In: IAH Congress – Groundwater and Ecossystems. 2007. Lisbon – Portugal.

SOUSA, Eduardo Reckziegel de; ROSA, A A S; CHEMALE JR, Farid; MAGRO, Francisco Henrique Simões; SCHERER, Claiton Marlon dos Santos. Estudo gravimétrico e magnetométrico da Bacia do Itajaí - SC - Análise preliminar. In: VIII SIMPÓSIO NACIONAL DE ESTUDOS TECTÔNICOS, 2001, Recife. 2001. p. 385-386.

SOUSA, Eduardo Reckziegel de. Avaliação preliminar dos recursos hídricos subterrâneos da região de Lajeado - RS. In: XII CONGRESSO BRASILEIRO DE ÁGUAS SUBTERRÂNEAS, 2002, Florianópolis. Boletim de Resumos. 2002. p. 87-87.

OLIVEIRA, A S; SILVA, M M A; WILD, Felipe; MALLMANN, Guilherme; PRADO, Maurício; SOUSA, Eduardo Reckziegel de. Caracterização Estrutural do Complexo Metamórfico Brusque na região de Camboriú e Tijucas, SC. In: VIII SIMPÓSIO NACIONAL DE ESTUDOS TECTÔNICOS, 2001, Recife. 2001. p. 99-102.

SOUSA, Eduardo Reckziegel de; LISBOA, Nelson Luis Amoretti. Caracterização hidrogeológica da região do Alto Taquari - RS. In: XIII SALÃO DE INICIAÇÃO CIENTÍFICA, 2001, Porto Alegre. Livro de resumos. Porto Alegre: Editora da Unversidade, 2001.

PHILLIP, Ruy Paulo; MALLMANN, Guilherme; PRADO, Maurício; SILVA, M M A; SOUSA, Eduardo Reckziegel de; WILD, Felipe; AREND, Silvana T; LIZ, Joaquim Daniel de; DUARTE, L C. Caracterização litológica e condições metamórficas do Complexo Metamórfico Brusque na região de Camboriú-Tijucas, SC. In: VIII SIMPÓSIO NACIONAL DE ESTUDOS TECTÔNICOS, 2001, Recife. Anais. 2001. p. 93-96.

MALLMANN, Guilherme; SOUSA, Eduardo Reckziegel de; PHILLIP, Ruy Paulo. Correlação entre os padrões de lineamentos mesoscópicos do Complexo Camboriú, Complexo Metamórfico Brusque e granitóides intrusivos na região de Camboriú. In: VIII SIMPÓSIO NACIONAL DE ESTUDOS TECTÔNICOS, 2001, Recife. Anais. 2001. p. 77-80.

WILDNER, Wilson; SOUSA, Eduardo Reckziegel de; NARDI, Lauro Valentim Stoll; LIMA, Evandro Fernandes de; SOMMER, Carlos Augusto. Ancient volcanic successions of Taquarembo Plateau - Brazil - Rio Grande do Sul State. In: IAVCEI GENERAL ASSEMBLY, 2000, Bali. Abstracts. 2000. p. 95-95.

SOUSA, Eduardo Reckziegel de; MORALES, Luiz Fernado Grafulha; PHILLIP, Ruy Paulo. Evolução estrutural e metamórfica do Complexo Metamórfico Brusque na Folha Camboriú (SG-22-2-D-II-2/III-1). In: XIII SALÃO DE INICIAÇÃO CIENTÍFICA, 2000, Porto Alegre. Livro de Resumos. Porto Alegre: Editora da Universidade, 2000.

SOMMER, Carlos Augusto; LIMA, Evandro Fernandes de; NARDI, Lauro Valentim Stoll; SOUSA,Eduardo Reckziegel de. Gênese e Evolução Geoquímica do magmatismo da Sequência Vulcânica Ácida - Dom Pedrito - RS. In: SIMPÓSIO SOBRE VULCANISMO E AMBIENTES ASSOCIADOS, 1999, Gramado. Livro de Resumos. Porto Alegre: Editora da Universidade, 1999. p. 29-29.

WILDNER, Wilson; LIMA, Evandro Fernandes de; SOUSA, Eduardo Reckziegel de. Interpretação de texturas vulcânicas Cambrianas preservadas no Platô do Taquarembó - RS. In: SIMPÓSIO SOBRE VULCANISMO E AMBIENTES ASSOCIADOS, 1999, Gramado. Boletim de resumos. 1999. p. 42.

SOUSA, Eduardo Reckziegel de; WILDNER, Wilson; LIMA, Evandro Fernandes de. Química mineral das lavas comendiíticas do Platô do Taquarembó - Dom Pedrito - RS. In: XI SALÃO DE INICIAÇÃO CIENTÍFICA, 1999, Porto Alegre. Livro de Resumos. Porto Alegre: Editora da Universidade, 1999.

SOUSA, Eduardo Reckziegel de; LIMA, Evandro Fernandes de. O vulcanismo ácido neoproterozóico do Escudo-Sul-Rio-Grandense: Estratigrafia, Ambientação Geotectônica e Evolução Petrogenética. In: X SALÃO DE INICIAÇÃO CIENTÍFICA, 1998, Porto Alegre. Livro de Resumos. Porto Alegre: Editora da Universidade, 1998. p. 73-73.

ATTACHMENT D:

SINGLETON STATION HORTICULTURE PROJECT – EIS AND APPENDICES, FOCUSSED REVIEW

Prepared by Dr Ryan Vogwill of Hydro Geo Enviro Pty Ltd

6 February 2023

SINGLETON STATION HORTICULTURE PROJECT - EIS AND APPENDICES, FOCUSSED REVIEW

PREPARED FOR | Central Land Council - Northern Territory

PREPARED BY | Hydro Geo Enviro Pty Ltd

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Proprietary Information Statement

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Contents

Overall Summary of Review

There is very little new hard data or analysis (if any) presented in my areas (hydrogeology, hydrology, impact assessment modelling and GDE impacts). The salinity assessment is definitely an improvement but is not based much site-specific data. The surface water assessment and management plan are suitable and fit for purpose. The risk of surface water derived impacts is low.

The EIS contains reference to aquatic GDEs but the proponent and their consultants have just applied the terrestrial GDE criteria with no justification of their suitability to an aquatic ecosystem. Aquatic GDEs typically need more stringent criteria than terrestrial vegetation in my experience.

Monitoring and adaptive management plans are generic and have very little actual detail about what will be done when and where. These documents are effectively "a plan to make a plan" after the project is approved, many of the studies proposed to be undertaken after approval should be undertaken before approval to give regulators and stakeholders more confidence in the suitability of the monitoring and adaptive management frameworks.

The existing issues from my previous reviews have not been addressed and in many ways this referral and associated documents contain less information than some of the previous reports. Without good data and analyses underpinning them, the risk assessment presented in the EIS (likelihood verses consequences style) is qualitative and subjective. They have assigned risk ratings but others might assign very different risk rating both before and after proposed management actions. The project team and consultants should not be developing these risk ratings in isolation, they need to include a wider stakeholder group to give these risk ratings any substance.

I would encourage the NT EPA to apply a Tier 3 assessment and require that the proponent addresses these issues prior to approval.

Introduction

The Environmental Impact Statement (EIS) for the NT EPA referral (including some of the appendices) for the Singleton Horticulture Project have been reviewed by HydroGeoEnviro at the request of Central Land Council (CLC). The aim of this review was to assess, at a high level, what new material has been presented and if any conclusions from my previous reviews of the hydrogeology, groundwater modelling and GDE impact potential would change due to the material presented in the EIS. My scientific opinion on the level of assessment was also requested. Points of interest or note resulting from review of the individual document are presented by document below. Where page numbers are referred to, they represent the PDF page number (not the page number in the document headers/footers) to prevent confusion. Given the focus of this review was to assess what additional information is available compared to previous documents produced by the proponent and their consultants, a review of each document is not included however overall comments for some documents are included where I've considered it appropriate.

Individual Document Review Points

Main Referral Document - nt-epa-referral-singleton-horticulture-project.pdf

Page 6 - The Minister declared the Western Davenport Water Allocation Plan (WAP) 2018 - 2021 in December 2018, hence FAFM's application for a Water Extraction Licence was in the context of the declared WAP 2018-2021 (Department of Environment, Parks and Water Security 2021).

> Comment - New WAP is forthcoming and the cited WAP should be referred to as out of date.

Page 8 - 1. Water Extraction Licence (WEL) to access 40,000 ML groundwater per year (Granted)

> Comment - Only stage 1 (12,788ML) has been granted, they have conditions that need to be fulfilled to access more the license entitlement. This should be stated here to not give a false impression of full license approval.

Page 8 - The environmental risk assessment identified 38 risk events in total, and of these no risks were assessed to have a residual risk higher than medium, of which there were 10.

> Comment - Table states 9 not 10 and I would likely disagree with the rankings in Table 1-1. This disagrees with a table later in the document and I counted 13 medium residual risks in Section 6, this should be confirmed. Maybe Table 1-1 didn't include the climate change (CCRA Summary in Table 7-20 which has 3 medium residual risks) but I would think it should?

Page 9 and 10 - Inland water quality Groundwater

> Comment - No mention of herbicides, pesticides and nutrients which all have potential to cause impacts. Mentioned later but should be here also.

Page 10 - Aquatic ecosystems

> Comment - Good that this is finally included but they don't appear to have much data still on this (will confirm later in the review - confirmed just using terrestrial criteria). Wetlands that could be impacted are more diverse than just waterway pools, springs and soaks. This is a very limited definition of aquatic ecosystems and systems other than these can have groundwater dependence. The WAP GDE criteria have not been altered, just expanded to include aquatic GDEs with no additional protection (criteria) for aquatic ecosystems. This

shows a lack of acknowledgement of the heightened sensitivity of aquatic ecosystems to drawdown.

Page 17 - Negative impacts to over 30% of all sandplain **and** alluvial GDEs modelled to occur within Singleton Station and/or the whole Western Davenport Water Control District.

Comment - I think it is 30% impact to either not both combined if I remember the WAP correctly. The **and** should be or. How would the % of GDEs impacted change under a reasonable range of model uncertainty? This is a significant issue in the impact assessment and baseline data collecting processes as previously discussed.

Page 33 - The Review Panel provided its report to the Minister on 15 October 2021. On the 15 November 21, the Minister made the decision to replace the water extraction licence with a new licence that included additional (2) conditions precedent and amended conditions precedent (1).

Comment - Important to note that the minister did not follow the review panel's recommendations on WEL staging volumes (5,000ML/stage?).

Page 39 and 40 - 3.1.1.2 Western Davenport Water Allocation Plan.

The WAP estimates sustainable yield for groundwater for the Western Davenport Water Control District as a whole as 168,405 ML/year, of which 138,405 ML/year is available for extraction for beneficial uses other than environmental and cultural.

Comment - Nothing new here and the sustainable yield is based on 80% depletion of aquifers which are poorly understood. Sustainable yield should be sustainable and not mining 80% groundwater by definition. How does the license compare to annual average recharge as would be used in other jurisdictions to determine sustainable yield? Looking at the WAP (except below) 40,000ML/year is a very high proportion of recharge (40,000/57,000 = 70.1% of average annual recharge). However, they state in the WAP that "Recharge is the portion of rainfall that passes through the unsaturated zone into the saturated zone, less the evapotranspiration loss. This is the volume of water that enters the groundwater system." how much of this is deducted from the recharge? If it is half of it (12,500 ML) then 57,000-12,500 = 44,500 ML per year so 40,000/44,500 = 90%.

WDWAP Management zone	Natural Evapotranspiration	Modelled Recharge
Davenport Ranges	4,000	11,000
Central Plains	25,000	57,000
Southern Ranges	1,000	36,000
TOTAL	**30,000**	**104,000**

Page 51 - Figure 3-4

> Comment - The western bore field is located within the crop plots, but the eastern bore field isn't. If the eastern bore field was located in the cropping area it would reduce clearing substantially. Not sure how this "minimises land clearing required"?
>
> This is their statement on page 62 "Careful micro-siting of bore fields to minimise both initial clearing …" and on page 75 "Co-locate the cropping areas and the bores as far as practical." it is not clear why the eastern bore field couldn't be inside the eastern crop area or better if the proposed eastern cropping area was located on the eastern bore field (i.e. further away from Thring Swamp). Likely to do with soils/land units and flooding but the logic should be briefly stated at this point. Moving the eastern bore field into the eastern plots will move them 1-2 kilometres closer to Thring Swamp (higher impact risk) but will reduce land clearing. This is a difficult trade off given the high uncertainty of impact prediction modelling.

Page 62 - Crops that have a higher water demand located further from identified GDE areas than those with less water demand, thus reducing the GDE impact

> Comment - This makes little sense as the water demand for the crops isn't relevant to impacts to GDEs, the location of the supply bores is. More relevant in terms of contamination (salinity, nutrients etc) but this section is about "configuration of supply".

Page 62 - Pumping tests will be carried out at a more detailed stage of design to confirm the sustainable yield of boreholes on site.

> Comment - This is not directly relevant for sustainable yield it's about calculating hydraulic parameters, and bore efficiency (well loss etc). This would need to be done prior to license approval in many other jurisdictions. More bores will be required if they cannot get their 1ML/day per bore so more clearing etc. This is an example of why the basic investigation work should be done prior to approval.

Page 67 - In addition to the reduction in nutrient and chemical use

> Comment - First mention of "chemical use" in an environmental impact context which I presume would include the herbicides, pesticides etc as previously commented on.

Page 97 - The ephemeral pools that remain are important from a local perspective and provide a surficial water resource (albeit scarce and inconsistent) that is critical to the biodiversity and cultural values of the area (Burgess et al. 2016). <u>They are also an important grazing resource for local pastoralists (Burgess et al. 2016).</u>

> Comment - I'm surprised and concerned that these biodiversity and culturally significant sites are not fenced to exclude stock. Increased weeds and nutrients, physical disturbance of seedlings and small plants in these sensitive wetlands will all be consequences of this. Noit relevant to the review but of concern.

Page 107 - Surface aquatic GDEs within Singleton Station are distributed through alluvial country along the sandy channels of the major creek systems including Wycliffe Creek, Hurst Creek and Skinner Creek

> Comment - As above only mentioned but with not assessment of their sensitivity to drawdown compared to terrestrial.

Page 114 - Figure 5.13 GDE sacred sites within the Singleton Water Licence Area (Donaldson, 2021).

> Comment - First time I've seen this and its very interesting how closely the Dreaming Tracks follow drainages and all converge on Thring Swamp. This is intuitive and further highlights the cultural values and how they are connected to the landscape.

Page 121 - Table 6-5 Environmental risk analysis summary

> Comment - note numbers are slightly different to the summary as peviosuly noted but I'd disagree on their risk ratings. Highly qualitative and subjective.

Page 129 - It is likely that many species have higher vigour and biomass when able to access groundwater but can persist in the environment with moisture obtained during rainfall events.

> Comment - Possibly but if groundwater is removed from the root zone during high water stress periods it may cause species specific vegetation death, particularly for larger trees (which are often the most culturally important) that have greater inherent water requirements hence why they are occurring in areas where groundwater is available in the root zone. Root elongation rates need more consideration in the context of drawdown also.

Page 129 - There will be an adaptive management plan including monitoring and management of GDEs

> Comment - But what about areas currently not inferred to be GDEs due inaccuracies in the GDE mapping and water table elevation maps? If they aren't being identified and monitored it will be not possible to adaptively manage the impacts.

Page 129 - Details for this management plan will be developed and implemented prior to commencement of the Proposal.

> Comment - Should be completed prior to approval as how can the regulators and stakeholders know this plan is suitable?

Page 129 and 130 - The results of the MCAP (multicriteria analysis to determine the likelihood of occurrence of Stygofauna) were limited by the available data, Due to the lack of registered bores with data available close to the proposed bore field, it is difficult to ascertain stygofauna presence closest to the modelled area of intense drawdown.

and

Though the species and community assemblages of stygofauna found within the aquifer will inevitably dictate the extent of the impact on the stygofauna community

> Comment - Stygofauna assessment is desktop only and highly subjective. The extent of impacts also relates to drawdown and the type of aquifer as well as the ability of the species present to move with the water table as it declines. For example, if you have alluvial sediments underlain by low permeability fractured rocks the stygofauna may only be able to migrate as far as the base of the alluvial sediments which would then present a hard criterion for drawdown (i.e. drawdown to the base of the alluvial sediments). In WA stygofauna are often managed by applying a 50% drawdown criterion. This means that drawdown impacts can at most dewater half of their habitat so this would be half the thickness of saturated alluvial sediment in the example I've used.

Page 133 - Climate change - Terrestrial Ecosystems

However, the extent to which is difficult to predict, given the uncertainties around what constitutes negative impacts to GDEs in terms of biological condition.

> Comment - This is why the proponent needs to have pre development monitoring (less than 5 years data will not be sufficient, preferable 10 years or more) to determine an appropriate baseline of vegetation condition relative to rainfall and groundwater levels. There are quantitative measures (sapflow and dendrometry for example) that could be used. Also, no aquatic ecosystem assessment in the Climate Change section. The existing model, as uncertain as it is, could have been used to look at some climate change impacts with and without the project.

Page 141 - and where the features are hydraulically connected to the production aquifer

> Comment - This is simplistic. To be impacted aquatic GDE features do not need to be directly connected to the target aquifer. They could be connected to the alluvial groundwater (not the groundwater in the target aquifer) but if the target aquifer declines underlying the alluvial aquifer this may in turn impact alluvial groundwater levels.

Page 143 - The residual risks associated with the Proposal in relation to aquatic ecosystems do not exceed a residual rating of 'low'.

> Comment - as previously stated I would disagree with this subject and qualitative assessment.

Page 143 - The Salinity Impact Assessment (GHD 2022e) provides a solute transport model based on irrigation drainage in an average climate scenario and presents crop demand estimates (ML/ha/year) for a wet (90th percentile), dry (10th percentile) and average rainfall year (50^{th} percentile).

> Comment - So they can assess the climate variability/uncertainty on the salinity modelling but not in the other areas such as the groundwater model? Salinity present only minor risks compared to drawdown.

Page 143 - The potential to impact offsite receptors during and after completion of the Proposal will be assessed by further modelling after the completion of further onsite investigations.

> Comment - This should be done before approval in my opinion.

Appendix-e-groundwater-extraction-allocation-licence-no-wdcp10358.pdf

Comment - Dated 15/11/2021, no new information.

Appendix-g-singleton-horticulture-project-monitoring-program-and-adaptive-management-plan.pdf

Page 13 - Protection of the aquifer integrity, e.g. avoidance of aquifer compaction

> Comment - This seems like an odd objective for the GMP, possibly they mean aquifer depressurisation and subsidence but it's unclear.

Page 17 - Using the above criteria and the existing groundwater model, FAFM has designed a bore field that is predicted to negatively impact an overall maximum of 10.5% of GDEs on Singleton during the 30 year life of the project. In the 30 years following shutdown of the bores, the impact reaches a maximum of 15.6% (12.7% and 25.3% respectively on the alluvial landform). These are well within the allowable limits (30%).

> Comment - But how do these percentages of GDE's impacted vary under a reasonable range of parameters in the groundwater model? Same issue and question as is previous impact assessments without even beginning to look at conceptual uncertainty.

Page 17 - There are recognised uncertainties with numerical groundwater modelling, however, these are addressed as part of the adaptive management strategy.

> Comment - And what happens if after collecting monitoring and recalibrating the model it predicts that more than 30% of GDEs will be impacted in a particular landform? Active adaptive management necessitates uncertainty analysis prior to approval.

Page 18 - Table 6 Sensitive receptors and their relationship to the FAFM borefield

> Comment - This table could be much more complete based on existing data, for example the location of Neutral Junction is known and post Susan Donaldson's work we know the location of sacred sites, e.g. specific trees, soaks and water holes.

Page 20 - Far from the borefield to establish background conditions. In some cases these would be established in GDE locations which may not be effected for 10 years to 20 years after the commencement of pumping. This is required to obtain background information pre-groundwater disturbance, but also to understand potential variations caused by longer term influences, e.g. climate change

> Comment - What if the potentially impacted GDE's change as the baseline data is collected and the model is updated? How will baseline data be collected for sites that haven't currently been acknowledged as potentially impacted but are then predicted to be impacted in future iterations of the groundwater modelling? This is one of the reasons why the assessment level needs to be higher before commencement of the project and the GDE impact area needs to incorporate the uncertainty in impacts as currently predicted by the groundwater model.

Page 21 - Verification of predictive modelling

> Comment - The modelling is at stage where this is not really a verification (which has a particular meaning in groundwater modelling) it is attaining a minimum sufficient transient calibration which does not currently exist.

Page 22 - This is a common, unavoidable issue with many developments. However, with the staging of the entitlements, and implementation of an adaptive management plan, a long time series of baseline information can be obtained to support the assessment of conditions associated with sensitive receptors.

and

At the time of preparation of this GMP, FAFM have no monitoring or production bores established at the SHP.

> Comment - It is clearly avoidable as they have had ample opportunity (time) to collect the data to have a better assessment now. In many jurisdictions this would be required before approval.

Page 23 - The current NGM predicts that the groundwater drawdown will not reach these areas until after 15 years of pumping. Under these circumstances FAFM will obtain at least 15 years of monitoring information at these sensitive receptors prior to any water level disturbance predicted to be imposed by FAFM.

> Comment - What if the drawdown propagates much quicker than anticipated or in areas that were unanticipated (i.e. drawdown propagates at depth rapidly along preferential flow paths with monitoring focused on the near project/shallow water able? You need to understand the hydraulics of the aquifer before you can predict where impacts will occur, but here there is still significant conceptual uncertainty let alone everything else.

Page 24 - The location of the existing NT network bores is shown in Figure 3, and their construction and formation monitored summarised in Appendix A.

> Comment - Figure 3 has been censored in the document, not very helpful to assess suitability. Likewise, on page 25 Figure 6 has been censored. I know the rough distribution the network from other reports. Why haven't these been monitored for the last 5+ years and the data used to calibrate the groundwater model?

Page 25 - Extensive NGM has been undertaken to determine the staging of the borefield development

> Comment - Extensive is not the term I'd use. Regardless The "extensive NGM" but has little data for model conditioning and calibration. I would argue that the modelling is not extensive and is preliminary, targeted on operational issues not off-site impacts. They have lots of modelling focussed on borefield design.

Page 25 - Bores are installed well before the predicted radius of influence is reached, to provide a minimum of 2 years, and for some sensitive receptors, over 15 years, baseline data prior to water level disturbance.

> Comment - Which receptors are getting 2 years and which are getting 15 years of baseline data? This is important to stakeholders.

Page 29 - Additional monitoring bores will be installed if the measured drawdown in bores outside the borefield exceeds those triggers specified in this plan (refer section 8.4), e.g. water levels in monitoring bores are greater than 20% different from that predicted by the most up to date numerical groundwater model. Monitoring bores will be installed a minimum 2 years in advance of the predicted model extents, so that background water level and water quality can be obtained within the 24 months prior to 'predicted' change.

> Comment - 20% is a strange criterion to use as this works very differently with water levels in mAHD verses meters below ground level (mBGL). What will the 20% be based on? I think an absolute level in meters should be specified. 2 years will likely not be enough to specify a suitable baseline at GDEs and TO sites. Will biological data be collected at GDE sites at the same time and place? In my experience this is critical.

Page 30 - All sites will be assessed at the beginning of the project and then on a five yearly basis.

Comment - 5 years is infrequent, should be sub annual at the start and scale back once (if) they understand how the aquifer actually works and where it is connected to GDEs.

Page 33 - 6.3.3 Soil quality and 6.3.3.1 Method

> Comment - Simplistic monitoring for soil quality, they should consider using tensiometers and other installed soil/unsaturated monitoring equipment rather than repeatedly doing test pits/auger sampling. Nearby sites (extracted samples taken from the same location) may have slightly different soils and structure so may not be directly comparable.

Page 34 - 6.3.4 GDE Health 6.3.4.1 Method

> Comment - This section is vague and generic, more detail required. What does the "formal condition assessment" entail? Quarterly is a good frequency and 5 years is minimum however on page 29 they said 2 years for water monitoring? Biological and hydrogeological monitoring must be undertaken together at the same frequency in the same places.

Page 34 - The predominant sacred sites in the vicinity of SHP are trees, water holes and soaks.

and

However, FAFM plans to consult with the Traditional Owners of this land in order to seek their input to identifying sites that they wish to be monitored and to include these in the monitoring program

> Comment - As I've previously stated this as a limited subset of cultural (wetland) assets. Thring Swamp? Dreaming lines? I think at this late stage the TO consultation needs to be much more complete.

Page 36 - 7. Risk register

> Comment - This should be much more completely developed at this stage. They could have completed most of this but have done almost none.

Page 36 - FAFM propose to undertake a number of site investigations, including exploratory drilling and pumping test investigations, to a) assess the development potential of the aquifer and b) install the monitoring network.

> Comment - By now they should know this for their own security as well as environmental/cultural values.

Page 39 - A <u>comprehensive</u> groundwater model that is used to predict the rate and extent of groundwater drawdown, and subsequently <u>used to predict the impact</u> on GDEs.

Comment - This an overreach of their assessment (modelling and GDEs) to say the least. On page 43 they state "The groundwater model is based on assumptions around aquifer properties that are based on relatively limited data." for example. Contradictory. With this model you should not predict "the" impact you should predict a range of possible impact, i.e. predictive uncertainty.

Page 43 - No site-specific investigations of soaks have been undertaken. The initial hydrogeological conceptualisation of these soaks are that they are fed by water that is less than 2 m depth.

Page 44 - Initial hydrogeological conceptualisations suggest that there may be perched water present which is accessible for GDEs.

> Comment for 43 and 44 - So this is based on basically nothing? Perched water is unlikely to be the case for all of them, this is relatively rare.

Page 49 - Table 15 and Artificial watering of GDEs - If a specific GDE location cannot be protected through this means, re-adjust the pumping regime elsewhere on the project to 'save' others which were 'planned' to be impacted, i.e. an offset process.

> Comment - This is not likely to be successful to protect TO sacred sites (which cannot be "swapped" for another site). Given their lack of understanding, by their own admission, this table is highly speculative. In my experience artificial maintenance (watering) is typically not successful in stopping GDE impacts, I can give some examples. Also you need to know relative value of these cultural assets to be able to offset impacts.

Page 53 - Indigenous Rangers

> Comment - Is there any actual agreement between FABM and CLC?

Page 57 - Recalibration (if required): if large differences between obseCommented and predicted groundwater levels are identified, then a recalibration of the NGM may be necessary.

> Comment - Recalibration will be required as no transient calibration exists for most of the model domain. No model ever matches reality (particularly when the model is so highly uncertain) so this statement is misleading in that it gives a non-specialist in modelling the impression that the model is near perfect when it is in fact highly uncertain and preliminary.

Page 57 - Provide a critical review of uncertainty of the science and technology presented and the conclusions reached

> Comment - This should be done by now not at some unspecified time in the future.

Appendix-l-singleton-horticulture-project-salinity-impact-assessment.pdf

Overall - There is insufficient time to review this in detail but I have completed a high-level review. The assessment looks reasonable. The method is generally suitable and the assumptions over model parameters etc are reasonable. However, there are again issues with a lack of site-specific data as in all of their assessments. They have made the assumption that as the increased salinity water is flushed to the aquifer this does not change the irrigation water's salinity, this feedback could cause moderately worse salinity impacts than currently predicted although this will be predominately an issue for FABM operationally.

Page 14 - Given site-specific information is limited, GHD has assumed values based upon the broader Davenport region, or from correlations with other areas. A sensitivity analysis was completed to address uncertainty attached with the quantification of salt movement within the unsaturated and saturated zone (section 5.4.2). The modelling should be revisited when site specific information becomes available (as proposed by planned additional field investigations described herein).

> Comment - So this is not a site-specific assessment more of a generic/desktop type assessment.

Page 27 - Key to this impact assessment was the identification of additional information required to fully characterise the existing environment, noting that FAFM has scheduled additional field investigations to be undertaken in the second quarter of the 2022-2023 financial year.

> Comment - This time has passed so has this investigation occurred? Again, this assessment is not based on site specific, measured data.

Page 34 - The proposal is at least 5 km east from the Thring Swamp Site of Botanical Significance (SoBs) and is within the area likely to experience drawdown as a result of groundwater extraction.

> Comment - At least they have acknowledged the existence of Thring Swamp and identified that it will experience drawdown. Why is this not noted more in other impact assessments and studies? My understanding is that it is a key cultural asset that is an aquatic GDE surrounded by some areas of terrestrial GDE.

Page 61 - leaching fraction has been used for modelling based on an assumed groundwater salinity of 900 mg/L. If groundwater salinity is significantly lower or higher as verified through intrusive drilling and groundwater sampling, <u>the leaching fraction may require amendment</u>.

Comment - Given there is no site-specific data this (<u>the leaching fraction may require amendment</u>) will likely need to happen, implications of higher salinity water will be significant on this threatening process. Climate obviously important in this also. This will be mostly an operational issue for them to manage and off-site impacts are unlikely, however there will be on site project impacts from this that may impact the on-site GDEs etc.

Appendix-m-gdv-model-validation-figures-extracted.pdf

Overall - highlights the inaccuracy of the GDV model technique but at least they are doing field studies in some areas. This should be coupled with a groundwater assessment as they are using model derived depth to groundwater estimates. Is the inaccuracy in the estimate of GDVs due to the inaccuracy of the NDVI technique or the groundwater modelling/water table elevation mapping? I think a useful additional validation (and one that is independent) would be to look at MODIS derived transpiration estimates which are available (I have checked). Even noting all this yes, the false negatives are few but exist and these represent sites that are GDEs but the model didn't identify them as such. What if the sites assumed to not be GDV have high cultural or biodiversity value? What other GDE sites are being missed?

Page 4 - Most of the areas that were thought to be incorrectly identified as GDV by the NDVI model on alluvial landform were patches of mulga (Acacia sp.), usually with scattered, small Eucalyptus victrix, on sites receiving run-on from the adjacent plain. Typically, these densely vegetated areas occur either at the fringes of the alluvial plain, or fringing localised depressions within the floodplain.

and

These dense areas of persistent woody vegetation were wrongly identified as likely GDV by the model.

> Comment - Just because these receive run-on doesn't mean they aren't groundwater dependant. Measured depth to groundwater or plant ecophysiology are the only conclusive discriminators.

Page 42 - Sandy channels of the major creek systems originating in the Davenport Ranges, such as Sutherland Creek, Wycliffe Creek, and the upper section of Hurst Creek are all high probability GDV in the NDVI model, despite sections of the latter two occurring at DTGW >15 m. These coarse sandy channels are characteristically lined with river red gums (Eucalyptus camaldulensis)(Figure 21), which are likely tapping into a perched aquifer rather than the regional water table as has been obseCommented in the Ti-Tree Basin (Villeneuve et al. 2015). Because of this, suCommentey sites were not included in this vegetation type.

> Comment - Model derived DTGW estimate are not categorical in terms of defining GDV. Just because there are "perched aquifers" in the Ti Tree area doesn't mean they occur here. This needs to be proven not inferred. Not sufficient data to exclude this important vegetation type.

Page 52 - GHD has now conducted an extensive GDV field study to ground-truth the NDVI model and the desktop landform mapping and has found that in most cases the model was reasonably successful in identifying areas of GDV.

> Comment - Is it extensive? I'd say preliminary. It's definitely an improvement. The most important ground truthing is measured depth to groundwater which still hasn't occurred.

Appendix-r-singleton-horticulture-project-gde-mapping.pdf

Overall - Not reviewed as is essentially the same as earlier documents just with a different bore field scenario.

Appendix-s-singleton-horticulture-project-station-baseline-flood-assessment.pdf

Overall - This report is completed to industry standards and is fit for purpose given the low flooding risk at the site. Their validation and reasons why the validation doesn't match the output of their modelling make sense.

Page 6 - Due to the relatively short design life of the project, the flood modelling has not considered long term changes in rainfall, such as climate change.

> Comment - 30 years isn't that short and I would think that some assessment would be prudent as significant climatic changes are predicted by 2050. This is more of an operational issue than an impact issue however.

Appendix-t-singleton-station-horticultural-operation-surface-water-management-plan.pdf

Overall - Reasonable plan and monitoring locations. Low risk to CLC with the exception of impacts to the actual site (including on site natural drainages). These areas are likely to be impacted regardless.

Appendix-w-singleton-horticulture-project-climate-change-risk-assessment.pdf

Overall - good summary of likely (and the range in) climate change impacts but is focussed on operational issues. No investigation of the impact of climate change on groundwater, surface water or the environment. Generic desktop-based risk assessment but a good summary of climate change .

Appendix-y-groundwater-modeling-cloud-gms.pdf

Overall - Very little of note, salinity data map (not FABM - NT government) has significant uncertainty in it as they just contoured up all data regardless of depth. This is not good practise and makes the map of little use.

ATTACHMENT E:

DEVELOPING ADAPTIVE MANAGEMENT GUIDANCE FOR GROUNDWATER PLANNING AND DEVELOPMENT

Thomann, J.A., Werner A. and Irvine D.

Journal of Environmental Management, 322 (2022) 116052

SINGLETON STATION HORTICULTURE PROJECT - ADAPTIVE MANAGEMENT PLAN ASSESSMENT AGAINST THOMANN ADAPTIVE MANAGEMENT REVIEW PAPER

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Proprietary Information Statement

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Contents

Introduction

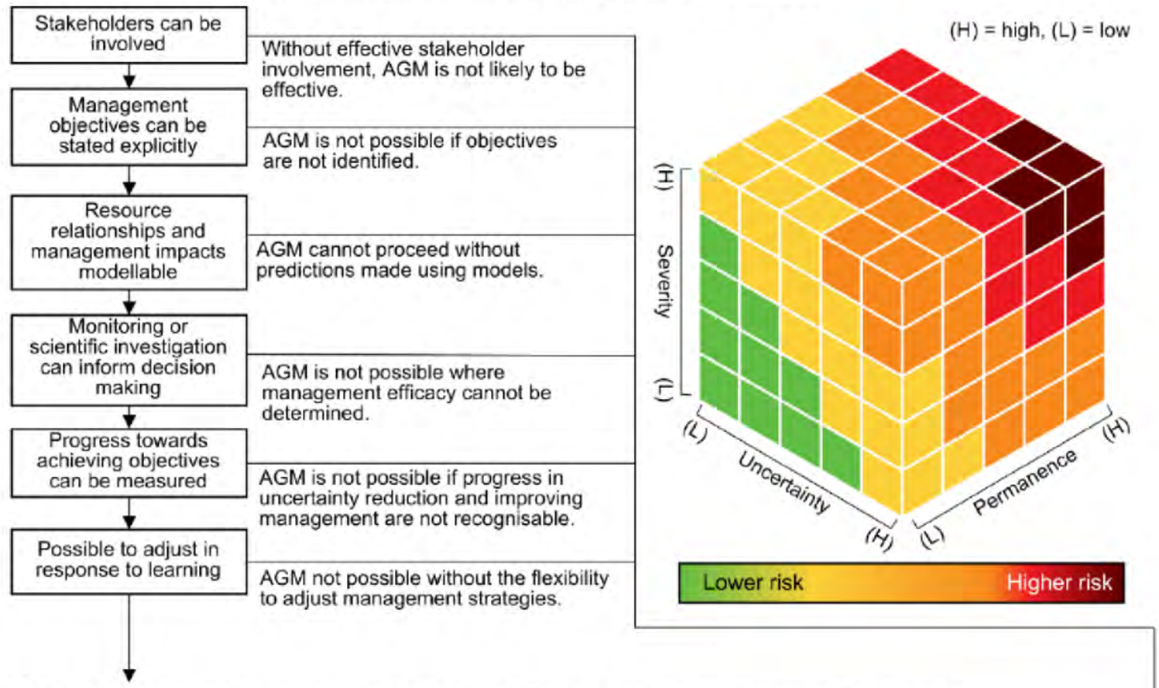
This report is a review of the adaptive management plan (AMP) for the Fortune Agribusiness Funds Management Pty Ltd (FAFM) at the Singleton Horticulture Project (SHP) (appendix-g-singleton-horticulture-project-monitoring-program-and-adaptive-management-plan.pdf). It is based on the Thomann et al. (2022) paper titled - Developing adaptive management guidance for groundwater planning and development.

As an initial comment I found the Thomann et al. (2022) paper to be well-researched, well-considered and a useful framework by which to evaluate the level of adaptative management required for a project (i.e. active, passive or trial and error) and is current (published in 2022). The authors are well respected and experienced from high quality academic institutions with experience in groundwater and adaptive management.

The reader is directed to this paper for a full description of the figures and tables contained herein but some excerpts have been included (Table S2 and Figure S3) to assist the reader and the full paper reference is included immediately below.

> *Thomann, J.A., Werner, A.D. and Irvine, D.J., 2022. Developing adaptive management guidance for groundwater planning and development. Journal of Environmental Management, 322, p.116052.*

1. Assess criteria that preclude AGM (modified from Williams et al., 2009)



2. Evaluate severity, permanence and uncertainty to inform management approach

Factor combination	Influence on management strategy	Groundwater example	Approach
High severity, high permanence, high uncertainty.	Use of AGM may result in failed objectives and long-lasting, severe consequences. Assess stakeholder priorities and risk/reward tolerance to determine if the project should proceed	A greenfield mining project with a nearby environmentally and/or culturally significant GDE	AGM not advised
High severity, high permanence, low uncertainty.	AGM not appropriate due to inability to adapt to permanent impacts. "Make good agreements" may be investigated to offset impacts if the project is approved.	Project where destruction of a significant asset is required.	
High severity, low permanence, high uncertainty.	An investigation plan targeting key uncertainties related to severe impacts should be developed. This plan should be linked to stakeholder re-involvement in a structured way.	Project that may cause temporary loss of access to critical groundwater resources for other users.	Active AGM
Low severity, high permanence, high uncertainty.	An investigation plan should be developed to reduce uncertainty relating to permanent impacts.	An excavation or construction that intersects the water table to a shallow depth.	
Low severity, low permanence, high uncertainty.	Attainment of hydrogeological data for reduction of key uncertainties is recommended due to limited understanding of the site.	Greenfield irrigation site with renewable groundwater and no sensitive assets nearby.	Passive AGM
High severity, low permanence, low uncertainty.	Additional structure in management planning and development may be required due to the potential for severe impacts.	High rate groundwater extraction site, with spatially concentrated wells.	
Low severity, high permanence, low uncertainty.	Ad hoc management may be acceptable due to high confidence in predictions of impact combined with the lack of significant assets.	A mine with no nearby sensitive assets (e.g. GDE and/or other water users).	Trial-and-error
Low severity, low permanence, low uncertainty.	A long history of data collection and hydrogeological investigations combined with the lack sensitive assets, and reversible impacts means ad hoc management may be acceptable.	A brownfield irrigation site with no nearby sensitive assets of significance.	

Figure S3. Influence of severity, permanence and uncertainty on AGM.

Table S2 - Translation of AM elements to AGM elements. Active AGM is taken to include criteria under both active and passive columns. Italicised 28 text in the Passive column denotes where the DOI framework has been translated or extended to apply to groundwater problems. The Active 29 column represents additional management planning and development content required to meet the standard of active AGM.

Element	Passive	Active
Investigation	1. *At the project outset, collect baseline data to determine the prior status of the water resource.* 2. *Identify key knowledge gaps in the understanding of the relevant processes in the hydrogeological system.* 3. *Ensure sufficient data are available to inform/define plausible conceptual hydrogeological models.*	4. *Reduction in hydrological and ecological uncertainty through the targeted collection of data and analyses is demonstrated.*
Stakeholder involvement	1. Stakeholders must be identified and encouraged to participate (1). 2. A process must be implemented that solicits stakeholder input in the design of the *AGM* project and the identification of management objectives and potential management actions (1). 3. Stakeholders must commit to an agreed-upon process of reducing uncertainties and/or disagreements about the effects of management (1). 4. Stakeholder organisations must be encouraged to commit time and energy to adaptively manage the *groundwater system* over the agreed-upon timeframe (1). 5. *Information that underpins management decision-making should be easily accessible to stakeholders and conveyed in a way that enables an understanding of predicted risks and uncertainty associated with these predictions.*	6. *Hydrogeological investigations and the AGM approach should be independently peer-reviewed, and the findings of peer review should be made available to stakeholders and the broader scientific community.* 7. *Stakeholders are re-engaged at agreed-upon timeframes, allowing for revisiting and revision of stakeholder values and concerns in the context of revised uncertainty estimates arising from project progress.*
Objectives	Objectives should (1): 1. Be unambiguous, with specific *hydrogeological variables (e.g. groundwater levels, flow rates, solute concentrations, groundwater-dependent ecosystem health indicators)* and specific target conditions. 2. Contain *hydrological and ecological* elements that can be readily measured, to promote the evaluation of management actions and recognise their contributions to successful management. 3. Be achievable based on the capacities of the *groundwater system* being managed and the political or social system within which management occurs. 4. *Define endpoints for the groundwater system in terms of metrics for quantifying groundwater system health.* 5. Indicate the timeframe for achievement, including where durations exceed that of the project.	6. *Contain measures, timing and target levels of uncertainty reduction.*
Management alternatives	1. Adaptive decision making involves selecting a management action at each decision point, on the basis of the *condition of the groundwater system* at the time (3). 2. Management alternatives in adaptive *groundwater* management often focus on a potential change in *groundwater system* status or the alteration of process rates *(e.g. groundwater abstraction, groundwater recharge/discharge fluxes)* (1). 3. Alternatives should be explicitly documented *and quantitatively assessed* (1).	As per passive AGM

Predictive modelling	1. The models used in adaptive *groundwater* management generally share *the following* certain attributes (1). a. The *groundwater system* is described as changing through time, to allow learning to occur and management to adapt to learning. b. The hydrological system is characterised by key components of interest *(e.g. groundwater level, solute concentration, ecological health indicators)* that are the focus of management and the targets of monitoring. c. Changes often are described in terms of processes *(e.g. drawdown propagation, seawater intrusion, baseflow and/or spring flow)* that are thought to be directly influenced by management. d. Fluctuating environmental conditions *(e.g. seasonal variability in rainfall)* are incorporated as needed to characterise resource dynamics. e. Management impacts are described in terms of costs, benefits, and influences on components *of the groundwater system* or processes that are highlighted in the model. f. Models are calibrated with available data and knowledge, to ensure compatibility with current understanding about resource structures and functions. 2. The suite of models should capture key uncertainties (or disagreements) about resource processes (e.g. source aquifer of GDE water) and management effects (1).	3. *Quantitative modelling should be performed for the range of actions proposed during the "management alternatives" stage under each system conceptualisation.* 4. *Quantitative uncertainty analysis with respect to predictions of interest should be performed. This uncertainty assessment should be repeated over the lifespan of a project to quantify uncertainty reduction achieved through project activities.*
Monitoring and analysis protocols	In general, monitoring *and analysis* provide data for four key purposes (1): 1. To evaluate progress toward achieving objectives. 2. To determine the *state of key indicators of the groundwater system*, in order to identify appropriate management actions. 3. To increase understanding of *groundwater system* dynamics via the comparison of predictions against survey data. 4. To enhance and develop models of *groundwater system* dynamics as needed and appropriate.	5. *To provide additional data required for uncertainty analysis.*
Project approval and regulatory conditions	*Where uncertainty in the functioning of the hydrogeological system is high, AGM may include:* 1. *Approval conditions set (or revised) based on demonstration of uncertainty reduction in hydrogeological system functioning and project impact.* 2. *A range of actions that modify core project activities that are linked to uncertainty reduction outcomes, such that project operations are contingent on the achievement of uncertainty objectives.* 3. *Knowledge gains are assessed against uncertainty reduction objectives to determine the extent of allowable core project activities*	4. *The recommendations for project approval and regulatory conditions listed under passive AGM are a requirement of active AGM.*
Decision-making	1. At each decision point in the timeframe of an adaptive *groundwater* management project, an action is chosen from the set of available management alternatives (1). 2. Management is adjusted in response to both changing *groundwater system conditions* and learning (3).	3. *Analyses are selected based on the condition of the groundwater system and the level of uncertainty reduction that has been achieved.*
Follow-up monitoring and analysis	1. Monitoring is used in adaptive *groundwater* management to track system behaviour, and in particular to track the responses to management through time. 2. In the context of adaptive *groundwater* management, monitoring is seen as an ongoing activity, producing data after each management intervention *(e.g. extraction reduction)* to evaluate the intervention, update the measures of model confidence, and prioritise management options in the next time period (1).	3. *Analyses are undertaken that target the reduction of key uncertainties.*
Assessment	1. Assessment/analysis includes parameter estimation, comparative assessments, and prioritisation of management alternatives (1). 2. Comparison of predicted and actual responses is used to update understanding of management impacts (1). 3. Comparison and ranking of projected outcomes for management alternatives is used in selection of management actions (1). 4. *Assessment is supported by the results of hydrogeological analyses and investigations.*	5. *Reductions in the uncertainty of key groundwater system attributes are assessed.*

DOI framework: (1) Williams et al. (2009); (2) Williams (2011); (3) Williams and Brown (2012); (4) Williams and Brown (2014); (5) Williams and Brown 2016); (6) Williams and Brown (2018).

Methodology

This review will have a 3-stage methodology.

Stage 1 - Initially Figure S3 from Thomann et al. (2022) supporting information document will be used to define the level of adaptive groundwater management (AGM) that is indicated according to their framework based on an assessment of permanence, uncertainty and severity of impacts. Note that this review is focused on GDE impacts, including impacts to dependant cultural values.

Stage 2 - Following on from Stage 1 the current SHP adaptive management plan (AMP) will be evaluated against Table S2 as a checklist, addressing the topics presented in from Thomann et al. (2022) supporting information document.

Stage 3 - Finally, a comparison will be made between key statements from Thomann et al. (2022) and the current SHP AM plan. This section should be read in the context of previous reviews.

Results

Stage 1 - Comparison with Figure S3 from Thomann et al. (2022) supporting information document.

Level of Adaptive Management Recommended.

Part 1 - Assess criteria that preclude AGM

Stakeholders can be involved - Yes but the involvement of some, like the Central Land Council (CLC) has been limited.

Management Objectives can be stated explicitly - Yes but the use of "30% of GDE's in a particular landform can be impacted" is a very loose management objective. The GDE mapping validation report (appendix-m-gdv-model-validation-figures-extracted.pdf) showed that some sites that are GDEs were missed in the remote sensing assessment used to identify them. Also, the depth to groundwater is primarily based on water table elevations from a highly uncertain numerical modelling with no uncertainty presented. There is no data for most (if not all) of the GDE sites so how do stakeholders know that their sites of interest are currently accurately assessed as GDEs? Also, the relative value of sites is important, the current assessment assumes all GDEs are equal in their value. What are the highest value biodiversity and cultural sites? Do any of these need to have a "no impact" criteria? There are also still issues relating to application of the terrestrial GDE criteria to aquatic GDEs as noted in my other reviews.

Resource relationships and management impacts modellable - Yes but with the current model the level of uncertainty in predictions of interest has not been presented and this won't be improved until 5 years into the project, if the right data is being collected FAFM undertakes predictive uncertainty analysis. There is minimal commitment in SHP AMP in terms of what actual data will be collected where and when and no commitment to predictive uncertainty analysis.

Monitoring or scientific investigation can inform decision making - Yes but the proposed scientific investigations are not detailed in the AMP, the AMP has more of a generic commitment to collect data. In this context how do stakeholders know their interests are being taken into account if no firm plan is presented?

Progress towards achieving objectives can be measured - Yes but similar to comments for assessment criteria above. If there is no pre approval monitoring at important GDE sites how can they be identified and protected?

Possible to adjust in response to learning - Yes but there is a significant risk of sites that are GDEs with high cultural value not currently being identified as such and that existing criteria are not suitable to provide protection.

Summary - Although none of these criteria are "no" by my assessment, hence according to Thomann et al. (2022) AGM can occur, there are some that are currently difficult to assess as a definitive yes due to high uncertainty and a lack of basic information of groundwater levels, relative value of GDEs (including cultural assets) and an impact assessment with a groundwater model that has high uncertainty and no uncertainty presented for key predictions.

Part 2 - Severity, permanence and uncertainty to inform management approach

Given these are ranked on a 3-axis diagram on a scale with 5 categories these will be labelled low (1), low-medium (2), medium (3), medium-high (4) and high (5).

Severity of impacts - **High**. GDEs (including cultural values) will be impacted it's only a case of how many, how badly and their value.

Permanence of impacts - **High** but at best **medium-high**. Given the low recharge in the area and the assumption that 80% of aquifer storage can be abstraction in the Water Allocation Plans drawdown impacts will persist for a very long time and recovery of water levels may never fully occur. Impacts to GDEs (including cultural values) may also be permanent if the GDE collapses from lack of groundwater, an individual tree dies or in the case of an aquatic ecosystem the water body disappears and species present cannot recolonise. Even if groundwater drawdown fully recovers these losses may be permanent.

Uncertainty - **High.** Given the lack of baseline data on GDE groundwater levels, lack of drilling, lack of aquifer testing, concerns around GDE impact criteria (particularly aquatic GDEs), the lack of a transient model calibration for most of the model domain and a lack of predictive uncertainty analysis I would rank this as high.

In summary, for this part of the assessment, this interpretation results in a classification of the project as the highest factor combination with Thomann et al. (2022) advising "Use of AGM may result in failed objectives and long-lasting severe consequences. Assess stakeholder priorities and risk/reward tolerance to determine if the project should proceed". Hence their recommendation would be, based on my assessment, that AGM is not advised.

Protecting the CLC's interests necessitate that this particular stakeholder has a low appetite for risk, however other stakeholders may not ascribe the same level of risk to some of these factors. Even if for another stakeholder, two out of the three risk factors were ranked as medium, this would still place the factor combination in the second highest category where the recommendation of Thomann et al. (2022) that "AGM not appropriate due to inability to adapt to permanent impacts. "Make good agreements" may be investigated to offset impacts if the project is approved." Their further recommendation would be based on this assessment would be that AGM is not advised. As a final point with regard to tradition owner values it is unclear how FAFM could make an offset if an irreplaceable cultural site was impacted by GDE collapse/mortality.

Stage 2 - Evaluation of current FAFM AM against Table S2

The recommendation from Stage 1 that AGM is not applied, however if it is to be applied then it should be approached in an active AGM according to Thomann et al. (2022). Table S2 is shown below and has been modified by adding two extra columns with comments from this review and Y/N response for each individual criterion.

Table S2 - Modified form Thomann et al. (2022) with my assessment against these elements and criteria. Note that the active AGM criteria are in grey shaded rows and AGM needs to also included the passive criteria (non-shaded rows). Question marks will be used when the reviewer is unclear if a particular criterion has been met.

Element	Passive/Active Criteria	Comments	Y/N
Investigation	1. At the project outset, collect baseline data to determine the prior status of the water resource.	Lacking, only pre-existing groundwater data has been used.	N
	2. Identify key knowledge gaps in the understanding of the relevant processes in the hydrogeological system.	Knowledge gaps have been acknowledged although they could be more fully considered and should have been addressed prior to approval.	Y
	3. Ensure sufficient data are available to inform/define plausible conceptual hydrogeological models.	Significant gaps exist, many processes not quantified or are poorly understood.	N
	4. Reduction in hydrological and ecological uncertainty through the targeted collection of data and analyses is demonstrated	Only minor amounts of data collected, some verification of GDE status has been undertaken on ground. No collection of groundwater data.	N
Stakeholder involvement	1. Stakeholders must be identified and encouraged to participate	Unclear as I've not been fully involved, I would suspect that CLC would conclude that they have not been as involved as they would have preferred, particularly with GDE/cultural assets identification and management issues.	?
	2. A process must be implemented that solicits stakeholder input in the design of the AGM project and the identification of management objectives and potential management actions	No formal process initiated, some consultation has occurred but it is unclear if CLC issues have been include in AMP management objectives and management actions. FAFM committed to further "further consultation" but this should have happened prior to approval according to Thomann et al. (2022)	N?
	3. Stakeholders must commit to an agreed-upon process of reducing uncertainties and/or disagreements about the effects of management	No process agreed with stakeholders regarding any of these issues.	N
	4. Stakeholder organisations must be encouraged to commit time and energy to adaptively manage the groundwater system over the agreed-upon timeframe	FAFM has stated they are committed to employ TOs in the monitoring program. But no formal agreement reached.	?

	5. Information that underpins management decision-making should be easily accessible to stakeholders and conveyed in a way that enables an understanding of predicted risks and uncertainty associated with these predictions.	Some of the work completed has not been made available to the CLC, it appears as though most has. No measure of predictive uncertainty has been presented although it appears as though some elements of this have been undertaken by FAFM. CLC had to commission their own assessment of model's sensitivity as a proxy for uncertainty. Predictive uncertainty analysis could have been completed if the model was developed in a more amenable modelling platform (MODFLOW) than the chosen platform (MIKESHE).	N
	6. Hydrogeological investigations and the AGM approach should be independently peer-reviewed, and the findings of peer review should be made available to stakeholders and the broader scientific community.	No investigations undertaken yet. Very little formal peer review.	N
	7. Stakeholders are re-engaged at agreed-upon timeframes, allowing for revisiting and revision of stakeholder values and concerns in the context of revised uncertainty estimates arising from project progress.	This hasn't occurred but should have according to Thomann et al. (2022)	N
Objectives	1. Be unambiguous, with specific hydrogeological variables (e.g. groundwater levels, flow rates, solute concentrations, groundwater-dependent ecosystem health indicators) and specific target conditions.	GDE impact criteria as provided by the NT Government are being used. These criteria have issues in my opinion (particularly with aquatic ecosystems) but this is not a FAFMs issue. Ecosystem targets (30% of GDEs in a particular landform can be impacted) are based on a simplistic assumption that all GDEs are of equal biological and cultural value. Again, these criteria are not a FAFM issue.	Y

	2. Contain hydrological and ecological elements that can be readily measured, to promote the evaluation of management actions and recognise their contributions to successful management.	Can be measured but have not been pre-approval, depth to groundwater is inferred from uncertain groundwater modelling of sparse often old data. Ecosystem health indicators (both biological and hydrogeological) at and individual GDE scale have been proposed but will not be fully developed until post approval. For example "10% reduction in GDE condition (health, diversity) based upon mapping" has not been presented on any scientific basis that this is sufficient. By the time impacts are apparent it may be too late to save a particular GDE as there may not be sufficient recharge to cause groundwater level/GDE recovery. Artificial maintenance is very difficult without a very high level of quantitative understanding about plant water sources. Operational triggers have been developed but are focussed on purely groundwater production not impacts.	?N
	3. Be achievable based on the capacities of the groundwater system being managed and the political or social system within which management occurs.	Achievable if sufficient resources are made available. I have concerns that if the aquifer does not have as much water present as assumed, the project is not achievable within the 30% GDE impact criteria but this cannot be assessed due to a lack of predictive uncertainty analysis on their drawdown predictions in the context of GDE impacts.	?
	4. Define endpoints for the groundwater system in terms of metrics for quantifying groundwater system health.	Yes, but high amount of uncertainty	Y
	5. Indicate the timeframe for achievement, including where durations exceed that of the project.	Project timeframes understood, drawdown impacts are likely to persist until well after the active project timeframe. Drawdown may never fully recover in a meaningful timeframe but accepting of 80% decrease in aquifer storage in the Allocation Plan has this inherent in it i.e. is not sustainable.	Y
	6. Contain measures, timing and target levels of uncertainty reduction.	No	N
Management alternatives	1. Adaptive decision making involves selecting a management action at each decision point, on the basis of the condition of the groundwater system at the time	Yes however frequency this will occur with regard to stakeholder involvement is not explicitly included in their trigger breach response.	Y

	2. Management alternatives in adaptive groundwater management often focus on a potential change in groundwater system status or the alteration of process rates (e.g. groundwater abstraction, groundwater recharge/discharge fluxes)	Yes but no "stop pumping" criteria have been proposed only pumping reductions. What would cause them to stop pumping groundwater?	Y?
	3. Alternatives should be explicitly documented and quantitatively assessed	Much of the modelling has been focussed on bore field design to minimise on-site and off-site impacts but regardless without quantitative predictive uncertainty analysis I'd question the veracity of the quantitative assessment. A tier 1 possible management action for GDE impacts is listed as "Implement further ecological investigation" in FAFM AMP. What does this entail? Need to be specific and quantitative.	N
Predictive modelling	1. The models used in adaptive groundwater management generally share the following certain attributes: a. The groundwater system is described as changing through time, to allow learning to occur and management to adapt to learning.	No, recharge is not seasonally modelled and predictive hydrographs for most of the model domain are flat with no seasonal fluctuations. Transient data should have been collected prior to approval and used in impact assessment models to rectify this prior to approval.	N
	b. The hydrological system is characterised by key components of interest (e.g. groundwater level, solute concentration, ecological health indicators) that are the focus of management and the targets of monitoring.	No substantive data collected by FAFM, regional baseline data is often old and few timeseries are available, almost no data near the proposed SHP bore field.	N
	c. Changes often are described in terms of processes (e.g. drawdown propagation, seawater intrusion, baseflow and/or spring flow) that are thought to be directly influenced by management.	Yes, but high uncertainty not presented.	Y
	d. Fluctuating environmental conditions (e.g. seasonal variability in rainfall) are incorporated as needed to characterise resource dynamics.	No	N
	e. Management impacts are described in terms of costs, benefits, and influences on components of the groundwater system or processes that are highlighted in the model.	Investigation and analysis are too preliminary to get to this level of cost benefit analysis. Cost of GDE/cultural value impacts difficult to quantify compared with economic benefits.	?
	f. Models are calibrated with available data and knowledge, to ensure compatibility with current understanding about resource structures and functions.	Although the available data has been used there is very little time series (and none near the SHP). No drilling or aquifer testing done on site so aquifer conditions are highly uncertain.	Y but

	2. The suite of models should capture key uncertainties (or disagreements) about resource processes (e.g. source aquifer of GDE water) and management effects	Not presented.	N
	3. Quantitative modelling should be performed for the range of actions proposed during the "management alternatives" stage under each system conceptualisation.	No	N
	4. Quantitative uncertainty analysis with respect to predictions of interest should be performed. This uncertainty assessment should be repeated over the lifespan of a project to quantify uncertainty reduction achieved through project activities.	No and has been a theme in the CLC discussions with FAFM. Non proposed.	N
Monitoring and analysis protocols	In general, monitoring and analysis provide data for four key purpose 1. To evaluate progress toward achieving objectives.	Proposed monitoring networks and investigations (both groundwater and ecological) are not currently available (redacted EIS maps) or to be developed post approval so it is unclear how suitable they are.	?
	2. To determine the state of key indicators of the groundwater system, in order to identify appropriate management actions.	As above.	?
	3. To increase understanding of groundwater system dynamics via the comparison of predictions against survey data.	This will occur, but will it be sufficient?	Y
	4. To enhance and develop models of groundwater system dynamics as needed and appropriate.	This will occur, but will it be sufficient?	Y
	5. To provide additional data required for uncertainty analysis.	No commitment to predictive uncertainty analysis in the SHP AMP.	?
Project approval and regulatory conditions	Where uncertainty in the functioning of the hydrogeological system is high, AGM may include: 1. Approval conditions set (or revised) based on demonstration of uncertainty reduction in hydrogeological system functioning and project impact.	No approval conditions set for uncertainty reduction (and no commitment to even undertake uncertainty analysis). Also note that SHP decision review panel recommended different (smaller) stage volumes and longer stage times than have been adopted by the regulators.	N
	2. A range of actions that modify core project activities that are linked to uncertainty reduction outcomes, such that project operations are contingent on the achievement of uncertainty objectives.	Collecting and analysing data will reduce uncertainty and there is a commitment to adapt the AMP as more is available.	Y
	3. Knowledge gains are assessed against uncertainty reduction objectives to determine the extent of allowable core project activities	No uncertainty reduction targets proposed.	N

	4. The recommendations for project approval and regulatory conditions listed under passive AGM are a requirement of active AGM.	Noted	NA
Decision-making	1. At each decision point in the timeframe of an adaptive groundwater management project, an action is chosen from the set of available management alternatives	TBC	NA
	2. Management is adjusted in response to both changing groundwater system conditions and learning	Proposed to be adjusted but there is a high amount of uncertainty regarding impacts and proposed mitigation measures. Most of this is to be developed if project is approved.	NA
	3. Analyses are selected based on the condition of the groundwater system and the level of uncertainty reduction that has been achieved.	No uncertainty reduction targets proposed.	N
Follow-up monitoring and analysis	1. Monitoring is used in adaptive groundwater management to track system behaviour, and in particular to track the responses to management through time.	Yes proposed.	Y
	2. In the context of adaptive groundwater management, monitoring is seen as an ongoing activity, producing data after each management intervention (e.g. extraction reduction) to evaluate the intervention, update the measures of model confidence, and prioritise management options in the next time period	Yes proposed.	Y
	3. Analyses are undertaken that target the reduction of key uncertainties.	No uncertainty reduction targets proposed but proposed activities will reduce uncertainty but how much is unclear due to a lack of detail.	N/Y
Assessment	1. Assessment/analysis includes parameter estimation, comparative assessments, and prioritisation of management alternatives	Yes but focussed on bore field design at this stage. There is significant possibility that sites which are GDEs and have not been identified as such, particularly for small sites as GDEs have been identified primarily based on remote sensing data analysis so pixel size (25m?) is the smallest GDE size that can be detected. Springs and sacred trees could occur on a smaller scale than this.	?
	2. Comparison of predicted and actual responses is used to update understanding of management impacts	Proposed to occur	Y
	3. Comparison and ranking of projected outcomes for management alternatives is used in selection of management actions	Unclear	NA

	4. Assessment is supported by the results of hydrogeological analyses and investigations.	Unclear what the scope of these investigations and analyses is. Current investigations and analyses are insufficient.	N but ?
	5. Reductions in the uncertainty of key groundwater system attributes are assessed.	No uncertainty reduction targets proposed.	N

Stage 3 - Comparison between key statements from Thomann et al. (2022) and the current SHP AMP

In this section passages of text (or tables) from Thomann et al. (2022) are presented followed by my comment on how the AMP and other aspects of the SHP EIS meet or fail against these statements. There is subjectivity in some of these comments often due to a lack of data, analysis and detail in the SHP AMP and impact assessment. However, many are not subjective.

Quotes from Thomann et al. (2022)

"Three key factors emerge that are critical in the design of AGM strategies, including:

(1) the severity of groundwater impacts from project operations,

(2) the permanence of groundwater impacts, and

(3) the level of uncertainty in groundwater system responses to project operations.

The above three key factors are integrated into definitions of "active" and "passive" forms of AGM. Passive AGM strategies meet minimum thresholds for structured and iterative management approaches that incorporate uncertainty reduction, while active AGM strategies include additional constraints that place a greater emphasis on uncertainty quantification and reduction."

> Comment - Note the key difference between active and passive AGM, is that active AGM strategies include additional constraints that place a greater emphasis on uncertainty quantification and reduction. Currently no predictive uncertainty quantification let alone reduction proposed.

"However, previous research into AM across various environmental disciplines has shown that AM principles are commonly misinterpreted (Allen and Garmestani, 2015). For example, AM is often considered, erroneously, to refer to a willingness to modify a management approach through ad hoc changes to management practices (Allen and Garmestani, 2015). This has led to management plans being labelled as AM to avoid detailed up-front assessment, despite plans omitting key attributes of AM (Lee and Gardner, 2014; Slattery, 2016)."

> Comment - I would suggest that the AMP for FAFM falls into the "being labelled as AM to avoid detailed up-front assessment" category.

"Typical shortcomings in AM plans included a lack of specific objectives, unclear monitoring approaches, an absence of substantiative mitigation measures, and/or under-developed predictive models for assessing alternative management actions (Ruhl and Fischman, 2010). A subsequent review by Fischman and Ruhl (2015) found that indicator thresholds of system health and the corresponding actions triggered by those thresholds were commonly lacking in purported AM applications. Management plans with poorly defined thresholds lack the explicit structure of rigorous planning and analysis required to meet published guidance on AM (Ruhl and Fischman, 2010;

Fischman and Ruhl, 2015). As such, these approaches can be classified more accurately as trial-and-error management (e.g. Allen and Garmestani, 2015)."

Comment - I would suggest that the AMP for FAFM falls into this category.

Table 1
Conditions that warrant AM and that limit the application of AM, verbatim from Williams et al. (2009).

Type	Condition
Conditions that warrant AM application	1. There must be a mandate to take action in the face of uncertainty. 2. There must be the institutional commitment and capacity to undertake and sustain an adaptive program. 3. A real management choice is to be made. 4. There is an opportunity to apply learning. 5. Clear and measurable management objectives can be defined. 6. The value of information for decision making is high. 7. Uncertainty can be expressed as a set of testable models. 8. A monitoring system can be established to reduce uncertainty.
Conditions that limit AM application	1. Decision making only occurs once. 2. Monitoring cannot provide useful information for decision making. 3. There are irresolvable conflicts in defining explicit and measurable management objectives and alternatives. 4. Decisions that affect resource systems and outcomes cannot be made. 5. Risks associated with learning-based decision making are too high.

Comment - much of the comparison between the AGM proposed and the current SHP AMP is covered elsewhere in this review (and in my other reviews). However to assess the project against the conditions that limit AM application I would conclude for each condition from Table 1:

1- Passed (conditionally) although there are issues with the decision-making process the stage license approach allows the project expansion to be stopped. But the Stage 1 license alone could cause serious impacts.
2- Failed - not enough monitoring data, particularly time series of groundwater, measured groundwater depth for GDE depth to groundwater assessment, understanding of GDE locations, relative biodiversity and cultural values etc.
3- Failed from a CLC perspective - Cultural asset could be destroyed by drawdown from Stage 1.
4- Passed - But I would question if the decision should have been made on the current data and analysis.
5- Failed - CLC could see cultural assets destroyed.

"Consequently, adapted forms of the recommendations from Allen and Gunderson (2011) are offered here, thereby defining three key factors critical to the development of AM strategies for groundwater-affecting activities, given as:

(1) the severity of groundwater impacts from project operations,

(2) the permanence of groundwater impacts from project operations, and

(3) the level of uncertainty in groundwater system responses to project operations."

With respect to severity

"Where potential groundwater impacts are severe, there is a heightened need to develop sound hydrogeological knowledge of the system response to project activities. Also, the need to understand both the reversibility (or conversely the permanence) and uncertainty in more severe impacts is greater. Furthermore, where potential impacts are more severe, the need for clear and effective mitigation and monitoring strategies is heightened, particularly for the purposes of stakeholder involvement, which is likely to be more consequential to AM strategies where threats to critical assets are higher."

> Comment - From a CLC perspective the potential for impacts is severe, impacts are likely non reversable in a meaningful timeframe, mitigation and monitoring strategies are not fully developed (to be complete post approval), stakeholder involvement has been minor for CLC in my experience.

"In general, a more comprehensive characterisation of potential impacts on groundwater systems, along with a clearer demonstration of impact detection and mitigation techniques, is warranted prior to project approval where the plausible range of groundwater impacts includes those that are unacceptably severe."

> Comment - No baseline data or even exploratory drilling and aquifer testing, project stage 1 approved but impacts are potentially unacceptable severe. More investigation and assessment warranted prior to approval.

With respect to Permanence

"Whether or not an impact can be reversed influences the feasibility and efficacy of iterative reassessment, and subsequent improvement, of management practices aimed at protecting critical assets (Williams et al., 2009), thereby limiting the applicability of AM in managing some groundwater-affecting projects. Thus, in accordance with general AM definitions (e.g. Williams et al., 2009), AM is likely unsuitable to protect against permanent or irreversible impacts on groundwater systems."

> Comment - There is potential for permanent impacts from the project (GDE/cultural assets). Drawdown could be greater that predicted and could manifest in locations currently not precited to have any impact so will not necessarily be identified. AM is likely unsuitable to protect against permanent or irreversible impacts on groundwater systems.

"Groundwater-dependent ecosystems (GDEs), particularly those related to springs, are examples of this, whereby the spring ecosystem may decline and recover if aquifer conditions change within a certain threshold range, whereas complete cessation of spring flow may lead to the irreversible loss of aquatic organisms in many cases (e.g. Currell et al., 2017; Devitt et al., 2019)."

> Comment - Note this in the context of impact to aquatic GDEs.

"The long timescales of most hydrogeological processes create major obstacles to learning within the context of groundwater management practices (Currell et al., 2017), in a similar way to the difficulties in addressing permanent impacts within an AM approach.

For example, an assessment should be performed to determine whether substantial, irreversible impacts may occur before managers can reliably assess whether thresholds (i.e. after which impacts are effectively irreversible) have been passed.

The use of AM is also not appropriate where critical thresholds or remedial approaches to possible impacts are poorly understood, because remediation may be precluded by technical barriers, particularly for situations involving long groundwater system timescales and time-lagged impacts (Williams et al., 2009; Nichols et al., 2014; Thomann et al., 2020)."

> Comment - substantial, irreversible impacts may occur and thresholds are not based on a site-specific understanding of ecosystem tolerances and thresholds.

With respect to uncertainty

"Thus, it is critical for project proponents, stakeholders and regulatory authorities to have a clear understanding of both the uncertainty of impacts on groundwater-dependent assets and the methods to lower uncertainty, prior to project approval, where AM is adopted. This is particularly critical when AM is intended to offset the lack of reliable estimates of groundwater impacts at the project outset.

Where uncertainties in groundwater system behaviour are important, clear quantification of the uncertainties of potential impacts and practical and realistic approaches to uncertainty reduction are required before the effectiveness of proposed AM strategies can be known.

Uncertainty in the prediction of groundwater impacts plays a complicated role in project approval. Even where AM can be shown to offset impact risks, it may be necessary to delay approval while critical knowledge gaps are addressed, or at least, uncertainties are quantified and communicated to stakeholders and decision-makers. Approval conditions may additionally include thresholds for uncertainty reduction, notwithstanding the issues of impact permanence, reversibility and time lags, as discussed above.

Strategies for reducing uncertainty within high-uncertainty groundwater-affecting activities are critical in AM plans, because in some cases, data-gathering and other investigative tools may not adequately inform impact predictions, rendering AM largely ineffective (e.g. Williams et al., 2009)."

> Comment - No uncertainty analysis completed and not proposed, let alone targets for reduction therein.

Translation of AM into AGM

"Baseline hydrogeological data are essential for <u>*deliberate phase*</u> *activities, given the complexities of hydrogeological systems. This is especially the case for greenfield sites, which present substantial challenges for the development of AGM strategies because of weaknesses in groundwater system understanding, at least in the context of the anticipated project stresses.*

Initiating hydrogeological investigations early in the <u>*deliberative phase*</u> *provides opportunities to attain time-series datasets, that are essential for developing baseline knowledge of groundwater processes and for building predictive models and devising future monitoring protocols."*

> Comment - very little baseline data on groundwater levels or GDEs. Note that the deliberate phase is prior to project approval in the Thomann et al. (2022) framework.

"Therefore, stakeholder involvement often leads to knowledge exchanges that inform hydrogeological investigations and that assist in prioritising the goals of AGM monitoring and mitigation strategies."

> Comment - The CLC could have helped target investigations prior to approval in terms of cultural assets but no dedicated data collection has occurred.

"The use of trigger levels, whereby exceedance of an objective level of an indicator (e.g. groundwater drawdown, salinity threshold or an ecological health indicator) initiates a pre-defined corrective action, is another example (Evans et al., 2004; Werner et al., 2011).Trigger-level responses within an AGM approach need to be transparent, structured and evidence-based, whereas ad-hoc trigger-level responses are indicative of trial-and-error management (Schultz and Nie, 2012; Fischman and Ruhl, 2015)."

> Comment - Non bore field trigger levels are difficult to set as most GDEs/cultural assets do not have any monitoring data or ranking of importance and no firm plan to address this has been presented in my opinion. The current plan is a primarily plan to make a plan upon approval. This is not supported by my interpretation of the Thomann et al. (2022) framework. Trigger level responses are not transparent, structured and evidence-based, hence the ad-hoc trigger-level responses are indicative of trial-and-error management. According to Thomann et al. (2022) framework this project requires active adaptive management at minimum. My interpretation of the Thomann et al. (2022) framework is that for this project they would recommend not to use adaptive management with the current SHP level of assessment.

"The following four features of active AGM are suggested that add to the minimum requirements for passive AGM: (1) a stronger emphasis on the quantification of uncertainty and its reduction, (2) a broader scope for stakeholder involvement, (3) a staged approval process where project progression is contingent on uncertainty reduction, and (4) independent peer review of the AM strategy and the progress of its operationalisation."

> Comment - (1) no uncertainty analysis and no plan to reduce, (2) stakeholder involvement in AGM minimal, (3) staged approach yes but uncertainty reduction (or even analysis) no and (4) no peer review presented.

"The increased focus on uncertainty quantification and reduction within active AGM necessitates a greater degree of scientific rigour. For example, stochastic representations of key variables (e.g. hydraulic conductivity) in predictive models, rather than deterministic predictions, allows for a more comprehensive quantification of uncertainty."

Comment - has not occurred, currently low scientific rigor.

"Alternatively, multiple conceptual models may be numerically simulated in groundwater flow models, with conceptual models excluded from the set as new data and hydrogeological interpretations are obtained that are sufficient to do so."

Comment - has not occurred, not proposed.

"The development of uncertainty reduction targets is an important stage of active AGM, requiring rigorous uncertainty quantification as part of the predictive modelling element (e.g. Doherty and Moore, 2020). Uncertainty reduction is a key focus of the investigation element (Fig. 2), including during revisitation of this stage after periods of project operations, whereby the collection of data and targeted analysis is explicitly used to reduce hydrogeological and ecological uncertainty, especially in regard to the potential impacts of project operations. This is likely to require drilling and other, non-invasive hydrogeological techniques at locations outside of the region of the project's primary activities."

Comment - has not occurred, what is proposed has no substantive detail prior to approval. Some uncertainty reduction will occur via investigations and subsequent analysis but predictive uncertainty analysis and quantitative reductions targets are not proposed.

Conclusion

Assessing the AGM for SHP against the high-level criteria in Thomann et al. (2022) (Stage 1 on Figure S3) there are some criterion that are currently difficult to assess as yes or no due to high uncertainty. There is a lack of basic information on groundwater levels, relative value of GDEs (including cultural assets) and an impact assessment with a groundwater model that has high uncertainty and no uncertainty presented for key predictions. None are however definitely a no so by that first stage of that Figure AGM could be considered.

However, when the SHP AMP is assessed against the more detailed Stage 2 of Figure S3 in Thomann et al. (2022) (including the risk diagram) AGM is either not recommend or at the very least must be active. A key difference between active and passive AGM is the incorporation of uncertainty analysis and explicit targets for reduction of uncertainty through the adaptive management process. No uncertainty analysis has been provided and none is proposed.

When the detailed assessment against the elements and criteria from Table S2 from Thomann et al. (2022) was undertaken, my interpretation is that there are 13 yes (criteria met), 19 no (criteria failed) and 13 are difficult to assess or are premature to assess at this stage of the project.

I would summarise the current AMP is a primarily plan to make a plan once the project is approved. This is not supported by my interpretation of the Thomann et al. (2022) framework. In my opinion trigger level responses are not transparent, structured and evidence-based, hence the ad-hoc trigger-level responses are indicative of trial-and-error management. According to Thomann et al. (2022) framework this project requires at least active adaptive management. My interpretation of the Thomann et al. (2022) framework is that for this project they would recommend not to use AM with the current SHP level of assessment. Regardless if AGM is to be used predictive uncertainty is required pre approval, at each stage of the reiteration of the AGM plan and an explicit plan must be presented to stakeholders to reduce the uncertainty.

To quote Thomann et al. (2022) “Use of AGM may result in failed objectives and long-lasting severe consequences. Assess stakeholder priorities and risk/reward tolerance to determine if the project should proceed.”

ATTACHMENT F:

REVIEW OF THE SALINITY IMPACT ASSESSMENT REPORT

Report prepared by the CLC based on advice from Peter Cook, Flinders University. The report has been sighted and approved by Peter Cook.

Review of the GHD Salinity Impact Assessment Report (Appendix L) based on advice from Professor Peter Cook, Flinders University

This report was prepared by Evie Rose (Central Land Council) based on expert advice and reviewed by Peter Cook (Professor of Hydrogeology at Flinders University and Director of the National Centre for Groundwater Research and Training (NCGRT)). One of Australia's foremost groundwater scientists, Professor Cook has more than 20 years' experience in groundwater research, spanning the fields of groundwater hydrology, ecohydrology, isotope hydrology, unsaturated zone flow process, and surface water – groundwater interaction.

Review of GHD's 2022 Salinity Impact Assessment Report (**Salinity Report**) found that it **does not:**

1. Adequately model or report maximum potential salinity increases in the water table and groundwater. The model inappropriately and arbitrarily assumes a maximum of 1500mg/L salinity.
    - Due to this arbitrary figure, it does not calculate salinity drainage based on the assumed initial level of 900mg/L and an assumed leaching fraction. If it had done so, the maximum salinity increases would be magnitudes higher than predicted.
2. Consider original soil salinity below 3m, which could greatly increase salinity levels above predictions
3. Report on or model environmental impacts of salinity beyond changes in the groundwater extracted from the pumping bores.

These gaps leave critical questions unanswered and mean the risks of increased salinity are likely much higher than predicted. The Salinity Report does not answer the fundamental concerns raised in Cook and Keane's 2021 report which considered these factors and found that the region is high-risk for salinity impacts after 30 years, especially in areas with shallow groundwater depths. This report, despite being the only previous work on salinity impacts in the region, was not referenced at all by GHD.

1. GHD's Salinity Report fails to calculate and model for the potential maximum increases in salinity levels because it inappropriately and arbitrarily assumes a maximum of 1500mg/L.

The scale GHD uses to model solute transport is misleading and based on inappropriate parameters for the region. The scale goes from 900mg/L TDS[1] to an assumed maximum of 1500mg/L (2022, 15) GHD note they have chosen to cap the salinity increase at 1500mg/L: 'based on the information available, *a salinity of 1500mg/L TDS has been assumed* for the modelling' (2022, 15). This assumed cap is based on an inappropriate and unrelated comparison. While GHD acknowledge that 'the salinity of recharge water is likely to depend on site-specific factors that are difficult to estimate at this stage', they 'deferred to previous experience from projects elsewhere is [sic] regional Australia were the salinity of irrigation drainage has been monitored and data is publicly available' to decide on the maximum of 1500mg/L (2022, 15). The 'projects' referenced are in fact based on one region: the Mallee Catchment Management Authority (north-western Victoria). It is likely that the salinity of water used for irrigation in these areas is much lower than 900 mg/L, were a maximum of 1500mg/L might be more likely. Parameters have been drawn from very different hydrogeological parameters to the Western Davenport region.

[1] 900 mg/L TDS is the initial assumed salinity of groundwater 'based on the limited information currently available' (2022, 16).

This assumed maximum fails to accurately represent potential maximum increases: if the initial level is 900mg/L maximum increases are likely to be magnitudes higher than 1500mg/L. GHD should have calculated what the likely level of salinity of drainage would be based on irrigation with water at 900mg/L, and an assumed leaching fraction (the water that passes through the root zone and carries concentrated salts). Given an initial level of 900mg/L, the salts infiltrating the groundwater would be much more concentrated than 1500mg/L: from at least two to potentially many more thousands of mg/L.

It can be inferred from the modelling (Figure 15, 53) that after 1 year salinity at the water table is already at the maximum level reported on the scale, however there are no figures provided and there is no way of knowing how much higher than 1500mg/L the salts could actually be.

The scale is based on illogical assumptions and inappropriate comparisons, and the resulting modelling suggests salinity impacts far lower than what is likely for the Singleton region.

2. The GHD report only considers the impacts of pumping, and does not consider the naturally occurring levels of salinity in the soils within the unsaturated zone below 3m.

There is no data in the Western Davenports of soil salinity below 2-3m, however Cook and Keane (2021) found that there is likely to be high concentrations of salt below this depth. They found chloride profiles of 6 – 8,000mg/L in soil 5-20m below ground at nearby Rocky Hill and high levels at Ti Tree. Cook and Keane report that the major uncertainty over original soil salinity is ‘the greatest concern’ for determining impacts of irrigated agriculture as some areas contain very high salt stores that could threaten the underlying groundwater system. If there are high levels in the soil, salinity increases could be much greater than predicted. Further sampling and monitoring is required to fill this critical gap in determining the impacts of salinity.

3. GHD’s Salinity Report does not provide a holistic environmental impact assessment, it only models for changes in the salinity of groundwater extracted from the pumping bores.

GHD *identifies* the environmental risks of changes to soil quality, GDE and vegetation ‘loss or death’ (63-64) and ‘damage to cultural heritage’ due to salinity (67), however it rates these risks as low, and fails to provide any modelling on environmental indicators including potential impacts to soil quality, salinity increases at the water table (capped at 1500mg/L) and impacts on the groundwater more broadly.

GHD acknowledges that increases in salinity are likely to be quickest and highest at the water table, yet models changes in salinity of the groundwater drawn from bores 60-140m below ground level (2022, 54). At this depth increases in salinity are likely to occur at a much slower rate, given the time-lag for salts in the recharge front to travel through the aquifer. Salinity increases in this shallow groundwater are critical to understand impacts on the health of aquatic and terrestrial GDEs. The report therefore only models for how salinity increases may impact the Singleton horticultural development, not the environment.

Based on these limitations, the critical questions that remain unanswered by GHD’s salinity report are:

- What is the salinity at the top of the water table?
- What are the potential maximum salinity levels due to the development?
- Why is a salinity concentration of 1500mg/L assumed as the maximum when initial salinity levels are assumed to be 900mg/L?

- What are the soil salinity levels below 2-3m and how might they impact on increased salinity risks?

ATTACHMENT G:

CHANGES IN RICHNESS AND ABUNDANCE OF RODENTS AND NATIVE PREDATORS IN RESPONSE TO EXTREME RAINFALL IN ARID AUSTRALIA

Pavey C.R. and Nano C.E.M.

Austral Ecology (2013) 38, 777–785

Austral ECOLOGY A Journal of ecology in the Southern Hemisphere

Austral Ecology (2013) **38**, 777–785

Changes in richness and abundance of rodents and native predators in response to extreme rainfall in arid Australia

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Abstract The dramatic spatial and temporal variation in rainfall and the resource pulses which these trigger provide a challenge for predicting consumer-primary productivity dynamics especially in arid systems. In particular, understanding is needed of the degree to which boom-bust dynamics drive arid systems. Here, we assess the response of birds (diurnal raptors, nocturnal rodent-specialist raptors) and rodents to a resource pulse in the western Simpson Desert across a 43-month study period that finished in May 2011. Three rainfall pulses in rapid succession from February 2010 to March 2011 underpinned a 'big rain' event. Rodent populations irrupted within 6–9 months of the first of the three rainfall pulses (in February 2010). Two rodent-specialist raptors; the letter-winged kite, *Elanus scriptus*, and eastern barn owl, *Tyto javanica*, appeared in the area within 6–9 months of the start of the rodent irruption. By comparison with the rodents, barn owl and letter-winged kite, diurnal raptors responded rapidly to the February 2010 rainfall event. When comparing surveys carried out the week prior to the February rainfall event with May 2010, raptor richness increased from two to six species and the index of abundance, measured as mean sightings per km, increased from 0.07 to 1.34. These findings emphasize that the 2010–2011 resource pulse was an ecologically significant event. Our results confirmed the link between big rains and rodent irruptions but they also highlighted the occurrence of finer-scale temporal fluctuations that are less easily accounted for by rainfall patterning.

Key words: avian predator, consumer, population dynamics, primary productivity, pulse-hierarchy model.

INTRODUCTION

Key biological resources in natural systems including soil nutrients, water and plant biomass, fluctuate in availability over time often in an unpredictable pattern (Schwinning & Sala 2004). These short periods of high availability are commonly referred to as resource pulses, and are characterized not only by their short duration but also by low frequency and high magnitude (Yang *et al.* 2008). Although resource pulses occur in a wide range of ecosystems (Ostfeld & Keesing 2000), they are particularly dramatic in environments that experience marked spatial and temporal variation in rainfall such as the deserts of northern and central Australia (van Etten 2009; Letnic & Dickman 2010).

The dramatic spatial and temporal variation in rainfall and the resource pulses which these trigger provide a challenge for predicting consumer-primary productivity dynamics in many of the world's deserts. The pulse-hierarchy model (Schwinning & Sala 2004) provides a framework for understanding variability in primary- and higher-order-consumer responses during, and potentially between, high-rainfall phases, but so far direct tests of this model are lacking for Australian arid fauna assemblages. For arid Australia, available evidence shows that community dynamics are the sum total of contrasting responses that fall along a gradient from irruptive dynamism (opportunistic breeding and nomadism) to habitat/resource-mediated residency (Pavey & Nano 2009; Morton *et al.* 2011; Letnic *et al.* 2013; Tischler *et al.* 2013).

The essential aspects of these contrasting responses are encapsulated in the revised framework of Morton *et al.* (2011) for Australian desert functioning as proposition 12 (some consumers exhibit dramatic opportunism in response to irregularity of production) and proposition 13 (consumer assemblages display underpinning stability within their dynamism). Proposition 13 emphasizes that it is overly simplistic to characterize arid environments as being driven by boom and bust dynamics. As a consequence of the stability of certain critical resources, some taxa fluctuate only mildly in abundance in spite of dramatic fluctuations in rainfall. Further, even among taxa with 'extreme' life-histories, there is considerable variability in response both within and between big rain events that is still poorly quantified and understood.

As a generalization, we should expect community composition during resource pulses to reflect

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Accepted for publication May 2013.

doi:10.1111/aec.12062

increased abundance of both resident and nomadic species, but details are still lacking as to the timing of responses and the relative importance of these contrasting life-histories at regional and continental scales (Morton *et al.* 2011). For example, the link between rodent outbreaks and big rains in deserts is well documented (e.g. Previtali *et al.* 2009), but there is still much scope for refining models to more accurately predict when and under what circumstances such outbreaks might occur by directly testing the relationship between primary productivity and primary consumers across wet (boom) and dry (bust) phases (see Greenville *et al.* 2013). Relatedly, the assemblage wide interannual variation in breeding activity of arid zone raptors in response to rainfall variability (e.g. Aumann 2001a), suggests that there are complexities in the relationship between resource-availability and population dynamics of this group that are as poorly understood.

Here, we explore relationships between consumers and rainfall-primary productivity dynamics within a single high rainfall phase (2010–2011). We specifically addressed two questions:

1. How does the timing and magnitude of population responses to a high rainfall phase differ across faunal groups specifically rodents, rodent-specialist raptors and non rodent-specialist raptors?
2. Among the rodent assemblage, does the timing and magnitude of species population responses differ as a result of fine-scale habitat effects? Specifically, do resident rodent species show a different response over time to the introduced house mouse *Mus musculus*, and the nomadic long-haired rat *Rattus villosissimus*, because the former have specialized habitat associations (Proposition 13 of Morton *et al.* 2011) while the latter are opportunistic, tracking resources not habitat parameters (Proposition 12 of Morton *et al.* 2011).

MATERIALS AND METHODS

Study area

The study area of approximately 7000 km^2 is located on Andado Station in the northwest Simpson Desert, southeast of Alice Springs, Australia (fig. 1 of Nano & Pavey 2013). The region's climate features an irregular periodicity and low predictability of rainfall. More details of the climate and rainfall are provided in Nano and Pavey (2013).

Rainfall distribution 2007–2011

The present study was carried out from October 2007 to May 2011. Rainfall data are from Andado Station (25°41′S, 135°29′E) except for May 2007 when rainfall from nearby

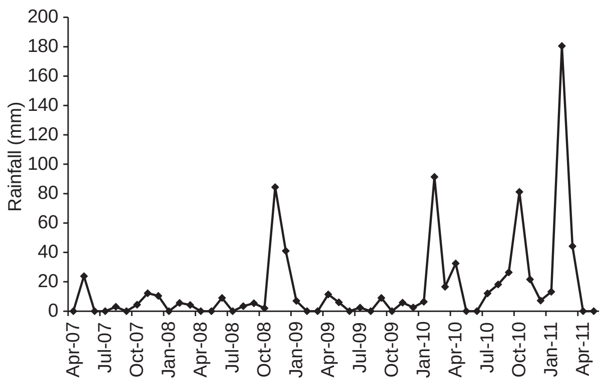

Fig. 1. Monthly rainfall in the study area, recorded at Andado Station (Station Number: 015595) from April 2007 to May 2011.

Mt Dare Station (26°07′S, 135°25′E) was used. During the study, dry conditions prevailed throughout the first phase with 144.2 mm, 155 mm and 44.1 mm in 2007, 2008, and 2009, respectively. In contrast, the final phase was characterized by two years of well above-average rainfall with 313. 6 mm and 307.2 mm in 2010 and 2011, respectively (Bureau of Meteorology 2012). This extended high-rainfall phase translated to a major pulse of plant productivity throughout the region (see Nano & Pavey 2013) and resulted in localized flooding and the creation of ephemeral wetland habitats. This 'big rain' event was underpinned by three large summer pulses in close temporal proximity (Fig. 1). The first comprised 97.4 mm over 6 days in February–March 2010. The second pulse comprised 95.4 mm over 6 weeks in September–October 2010, and the last and largest, comprised 224.7 mm over 6 weeks in February–March 2011. Two isolated rainfall events occurred in the initial dry phase of the study. In 2007, 12.2 mm and 10.4 mm fell in the consecutive summer months of November and December; and then in 2008, 84.4 mm and 41 mm fell in these same months. For the mid-phase year 2009, the low annual rainfall total (44.1 mm) was more or less evenly distributed across the summer and winter seasons and therefore did not occur as a concentrated pulse.

Fauna sampling methods

Sites were sampled on 11 occasions throughout the 2007–2011 study. Sample time 1 (T1) was in October 2007 following a period of very low rainfall (26.8 mm in the past 6 months). Sample time 2 (T2) was in April 2008 about 4 months after the small November–December 2007 rain pulse (see above). Sample times 3 and 4 (T3–4) were in July and October 2008, respectively, when conditions were again very dry (18.8 mm and 17.8 mm over the respective previous 6 months). Sample times 5–7 (T5–7) (March, June, September 2009) were flanked by the November–December 2008 and the February 2010 pulses; and their respective 6-month rainfall totals were 139.8 mm, 65.4 mm and 19.8 mm. The remaining four sample times fell within the 2010–2011 high rainfall phase. Sample time 8 (T8) was in February 2010, but rainfall over the previous 6 months was low (23.7 mm). This

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contrasted with conditions at sample times 9–11 (T9–11) when previous 6-month rainfall totals were 155.2 mm, 159.5 mm and 266.7 mm, respectively. Sample time 9 (May 2010) was 11 weeks after the February 2010 pulse; T10 (December 2010) was 10 months after the initial pulse and 5 weeks after the second pulse concluded in October 2010; and T11 (May 2011) was 9 weeks after the final February–March 2011 pulse.

Rodents

Rodent abundance and composition (captures/100 trap-nights) were assessed by repeatedly sampling permanent grids using collapsible aluminum box traps (Elliott Scientific Co., Upwey, Victoria, Australia). We used 20 permanent grids across the study area with each grid consisting of 25 box traps set in a five-by-five formation with 20 m between adjacent traps. We sampled for a total of 15 350 trap-nights (1 trap-night = 1 trap open for one night). Trapping grids were located in the five main habitat types approximately in proportion to area as follows; gibber plain (eight sites), cracking clay plain (2), swamp (2) sandridge (7), and sand plain (1) (see Pavey *et al.* 2011 for further details). All sites were trapped during each of the 11 sampling times with several exceptions. First, the two cracking clay sites were only set up at T5 but were trapped every session from then on. Second, a swamp site was flooded during sampling from T9 to T11 and the other swamp site was flooded during sampling at T9 and T11 (i.e. it was only trapped during T10). Traps were baited with a mixture of peanut butter and rolled oats and left open for three to four nights per session.

Diurnal raptors

We recorded occurrence and an index of abundance of all diurnal birds of prey (Falconiformes) during diurnal driving transects, and as incidental records. A total of 10 drive transects, ranging in length from 5.2 to 23 km and covering a total of 112.5 km (5.2 km, 9.3 km, 6 × 10.0 km, 15.0 km, 23.0 km) were established in the study area. All the diurnal drive transects overlapped nocturnal transects, although two were longer than the respective nocturnal transects. We aimed to survey each transect during each of the 11 sampling periods; however, this was not possible during T10 and T11 when accessibility to some transects was not possible as a consequence of flooding. Observations were made by an individual sitting in a four-wheel drive vehicle moving at 20–30 km per hour.

We used the drive transect data to calculate an index of abundance for raptors expressed as the number of animals per km of each driving transect. We applied the methodology in a consistent manner throughout the study and therefore it should accurately reflect changes in abundance across the study period.

Nocturnal raptors

We recorded occurrence of two species of nocturnal raptors known to occur in the study area specifically eastern barn owl *Tyto javanica*, and letter-winged kite *Elanus scriptus*. Both species specialize on rodents (Table 1). Barn owls were searched for during spotlight driving transects, whereas both species were searched for during walking transects and as incidental records. A total of nine spotlight transects, ranging in length from 5.2 to 10.0 km and covering a total of 80.5 km (5.2 km, 6.0 km, 9.3 km, 6 × 10.0 km) were established in the study area. We aimed to survey each transect during each of the 11 sampling periods; however, this was not possible during T10 and T11 when accessibility to some transects was not possible as a consequence of flooding. Observations were made by an individual sitting on the roof of a four-wheel drive vehicle moving at 15–20 km per hour. Surveys commenced approximately 1–2 h after sunset.

Table 1. Raptor species present in the study area during each of 11 sampling sessions and the expected main prey groups in the study area based on Marchant and Higgins (1993) and Aumann (2001c)

Species	Main prey	Oct 07	Apr 08	Jul 08	Nov 08	Mar 09	Jun 09	Sep 09	Feb 10	May 10	Dec 10	May 11
Black-shouldered kite	rodents, insects											
Letter-winged kite	rodents											✓
Black kite	carrion, vertebrates, insects	✓										
Whistling kite	vertebrates, insects	✓										✓
Spotted harrier	rodents, rabbit, birds											
Collared sparrowhawk	birds, invertebrates						✓					✓
Wedge-tailed eagle	mammals, birds, lizards, carrion				✓		✓	✓	✓		✓	✓
Black-breasted kite	birds, lizards, carrion			✓			✓					
Brown falcon	reptiles, mammals, birds, insects				✓							
Australian kestrel	reptiles, birds, insects											
Australian hobby	birds, insects							✓		✓	✓	
Grey falcon	birds						✓	✓				
Black falcon	birds								✓	✓		
Eastern barn owl	rodents											✓

All species are diurnal except the letter-winged kite and eastern barn owl. Shading indicates that the species was present on transects; tick indicates the species was recorded incidentally.

doi:10.1111/aec.12062

We walked three transects during each sampling period to search for nesting and roosting nocturnal raptors. The rare and spatially patchy tree cover in the area (see e.g. Nano *et al.* 2012) enabled us to place transects in likely roosting and nesting locations of raptors. Walking transects were 0.5, 1.0 and 6.0 km in length.

We recorded all observations of raptors made during the course of other activities. These observations allowed us to determine whether a species was present during a sampling period despite not being detected during structured surveys.

Analyses

We compared changes in rodent abundance across sampling sessions by calculating the capture rate per 100 trap-nights for each sampling session at each site. Data are shown for each sampling session as the mean capture rate per 100 trap-nights ± SE calculated across all sites sampled.

We then used multivariate models to test hypotheses regarding changes over time at community and species levels. We used PERMANOVA (PRIMER 6 software package with PERMANOVA + add-on, Plymouth Marine Laboratory; Anderson *et al.* 2008) to test for temporal and spatial effects on the rodent assemblage at our study site. For this we used a three-factor design with time (T1–T11) and habitat (gibber/clay plain, sand ridge/plain, and swamp) as fixed factors and site (1–20) as a random factor nested within habitat. This was done to test for generality across space and to control for potential pseudoreplication (Clarke & Gorley 2006). Pair-wise tests were run for the levels of significant fixed factors. For our permutation method, we selected permutation of residuals under a reduced model, with Type III (partial sum of squares) and 9999 permutations.

Data for the raptor index of abundance are presented as means ± SE. We calculated the product moment correlation coefficient to examine the relationship between rodent and raptor abundance across the study period.

RESULTS

Faunal responses during the 2010–2011 high rainfall phase

Rodents

Rodent populations irrupted within 6–9 months of the first of the series of three rainfall pulses in 2010–2011 (Fig. 2). From October 2007 to May 2010, the mean capture rate across all sites was less than five captures per 100 trap-nights for all sessions except April 2008 (T2), when the capture rate was 9.8 ± 1.8 captures per 100 trap-nights (cf 3.4 ± 0.9 at T1). A response to the February 2010 pulse was not detected in May 2010 (T9), but it was clear by the next sampling session T10 (December 2010) with 41.1 ± 6.0 captures per 100 trap-nights. By this time the September–October 2010 rainfall pulse had also occurred (Fig. 1). The capture

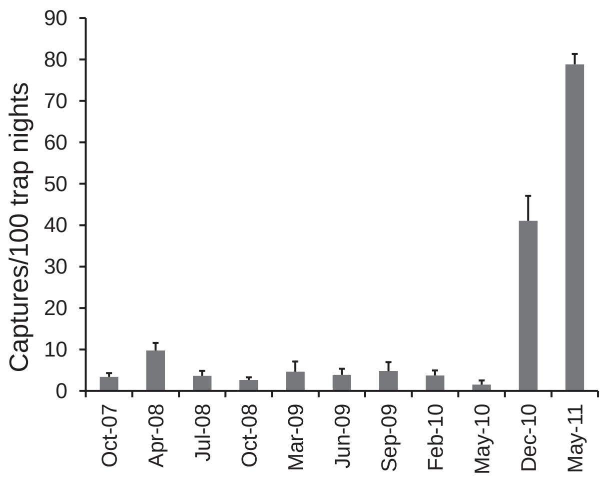

Fig. 2. Capture rate ± SE of all rodents across the 11 sampling sessions from October 2007 to May 2011, at Andado Station, Simpson Desert, Australia.

rate had doubled by T11 (May 2011) at 78.8 ± 2.5 captures per 100 trap-nights.

A total of five species of rodents was captured during the study period; plains mouse *Pseudomys australis*, sandy inland mouse *P. hermannsburgensis*, spinifex hopping mouse *Notomys alexis*, *R. villosissimus* and *M. musculus*. An additional species, short-tailed inland mouse *Leggadina forrresti*, was detected while spotlighting. Rodent species richness during a sampling session ranged from two to five. The low of two species occurred in September 2009 whereas the peak of five occurred during sampling in December 2010 and May 2011, that is, following the two resource pulses in 2010. *Rattus villosissimus* was only captured during T10 and T11 and *M. musculus* was in very low abundance until T10 and T11 (Fig. 3).

PERMANOVA results showed that there were significant main effects of time (Pseudo $F_{10,259} = 15.103$ $P < 0.001$), and habitat (Pseudo $F_{2,259} = 3.1785$ $P < 0.05$), but that there was also significant variability among sites (Pseudo $F_{17,259} = 6.161$ $P < 0.001$), in the structure of the rodent assemblage. Thus, species composition and abundance varied at fine spatial scales, independent of habitat and rainfall (time). The last two sample times (T10, T11), which had dramatic peaks in rodent abundance following the big 2010–2011 rain event, were compositionally different ($P < 0.05$) from each other and from all of the remaining sample times. Notably, T2 which had a minor abundance peak following the small November–December 2007 rain pulse, mostly as a result of increased abundance of *P. hermannsburgensis* (Fig. 3a), was also different from all other sample times. T9 had the lowest recorded capture rate, and it was shown to be compositionally dissimilar to many (seven) of the other sample times. Thus, sample times with the highest and lowest

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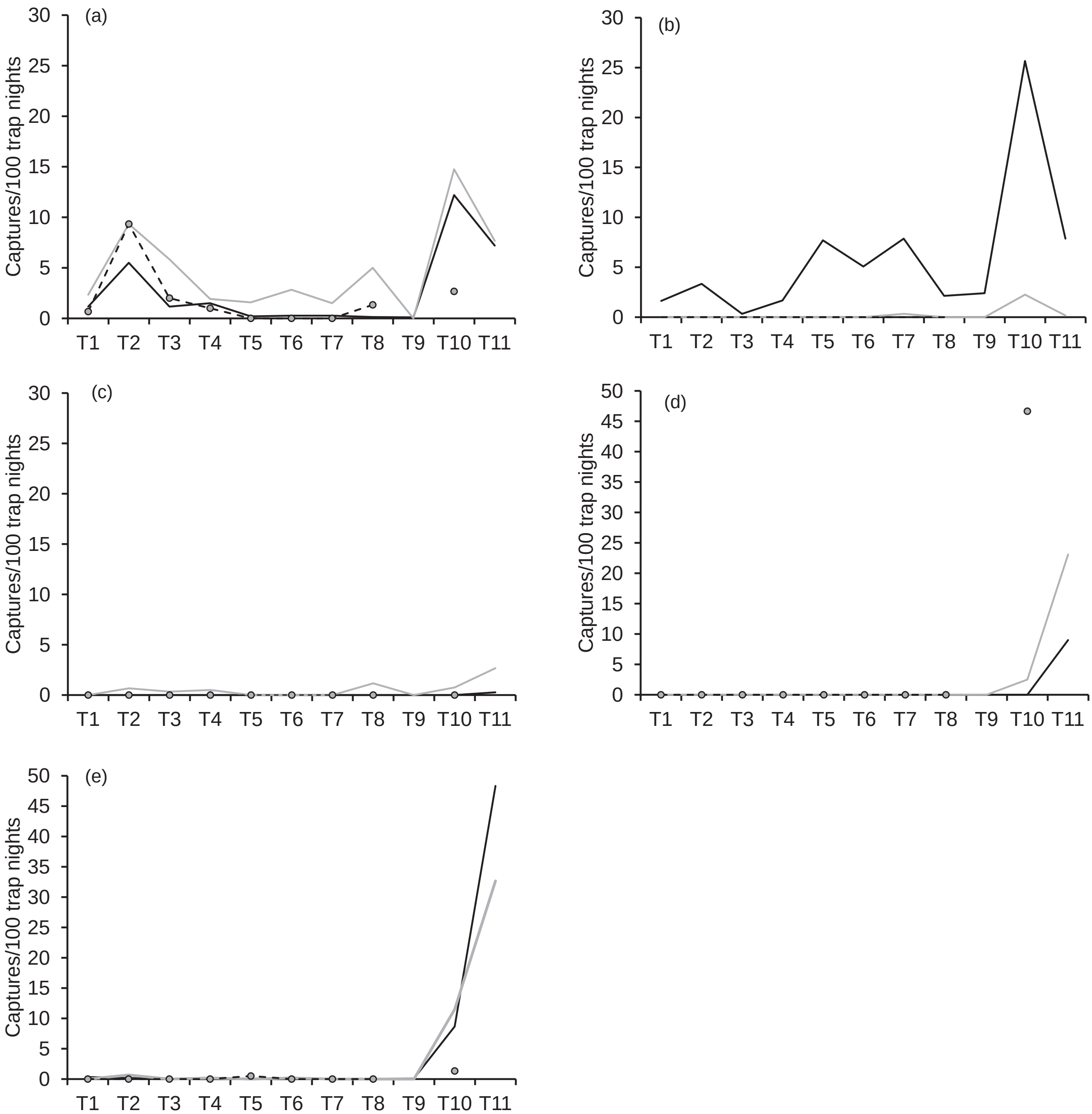

Fig. 3. Capture rate across sampling sessions in gibber/cracking clay (black), sand plain/ridge (grey) and swamp (dashed line) habitat for (a) *Pseudomys hermannsburgensis*, (b) *Pseudomys australis*, (c) *Notomys alexis*, (d) *Rattus villosissimus*, (e) *Mus musculus*.

capture rates were compositionally dissimilar to the remaining samples and, at least in terms of the former (T10, T11), there was a clear link between assemblage changes and rainfall amount. The habitat effect was related to rodent assemblage differences between the gibber/cracking clay and sand ridge/plain sites. In contrast, the swamp sites did not have a distinct assemblage.

Different temporal and spatial patterning was evident in the comparison of native resident rodents *versus* the introduced *M. musculus* and nomadic *R. villosissimus*. Each of the native resident rodents showed an association with the gibber/cracking clay (*P. australis*) or the sand ridge/plain (*P. hermannsburgensis*, *N. alexis*) habitat that was maintained through time. During the high rainfall phase (T10, T11), *P. hermannsburgensis* moved into gibber/cracking clay and *P. australis* into sand environments (Fig. 3). In contrast, *M. musculus* was associated with both the gibber and sand sites (Fig. 3e). *Rattus villosissimus* was

doi:10.1111/aec.12062

associated with both the gibber and sand sites by T11 (Fig. 3d) after being most abundant in a densely vegetated swamp site during the first sampling period it was detected (T10).

Diurnal raptors

A total of 12 species of diurnal raptors was observed within the study area of which nine were recorded on diurnal drive transects (Table 1). Only three species were resident throughout the study; wedge-tailed eagle *Aquila audax*, brown falcon *Falco berigora*, and Australian kestrel *F. cenchroides* (Table 1). In the six sampling sessions to September 2009 (T1–T6), only these species were recorded on transects. A single whistling kite *Haliastur sphenurus*, was recorded in September 2009 (T7). From then on no new species were observed until after the rain event in February 2010. Three new species were detected on transects in May 2010 (T9) and two new species in December 2010 (T10). Species richness on transects was six in May 2010, peaked at eight in December 2010 and fell to seven species by May 2011 (Table 1). Richness, based on both transects and incidental observations, peaked at 10 species in both December 2010 and May 2011 (Table 1).

The mean encounter rate per km per transect for raptors was ≤0.1 individual from October 2007 to February 2010 (T1–T8). Similar to species richness, no response in abundance was shown to the rainfall pulses in November–December 2007 and 2008 (Fig. 4). In contrast to rodents, diurnal raptors had responded to the February 2010 pulse by T9 in May 2010 (Fig. 4). The encounter rate had increased 10 fold to 1.37 ± 0.24 individuals per km. This high encounter rate continued in December 2010 then almost doubled by May 2011 (Fig. 4). Despite the difference in timing of the response to the 2010–2011 rain event, diurnal raptor abundance and rodent abundance were significantly correlated across the 11 sampling sessions ($r = 0.845$; $P = 0.001$).

Although the February 2010 rainfall pulse resulted in a dramatic increase in species richness of diurnal raptors by T9 (Table 1), much of the increase in raptor abundance resulted from an increase in two of the resident species, brown falcon and Australian kestrel. The mean encounter rate per km per transect for brown falcon from October 2007 to February 2010 (T1–T8) was ≤0.04 and then increased 15 fold to 0.62 ± 0.13 by May 2010 (T9) (Fig. 5a). It peaked at 0.80 ± 0.41 by T11 (May 2011). Similarly for Australian kestrel, the mean encounter rate per km per transect prior to T9 was ≤0.07, whereas it peaked at 0.65 ± 0.22 in May 2010 (Fig. 5b).

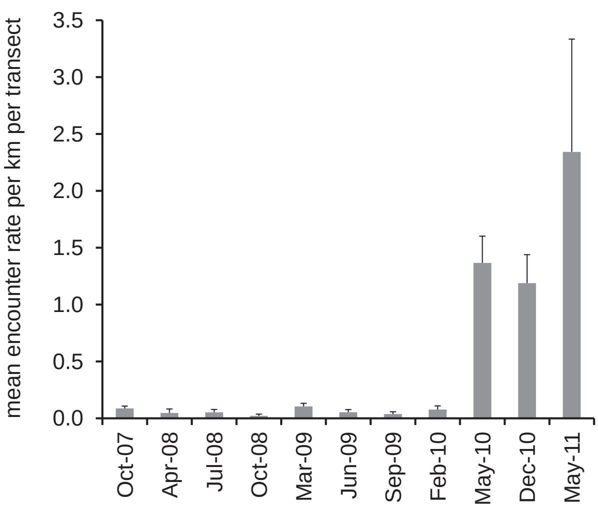

Fig. 4. Index of abundance ± SE of diurnal raptors across the 11 sampling sessions from October 2007 to May 2011, at Andado Station, Simpson Desert, Australia.

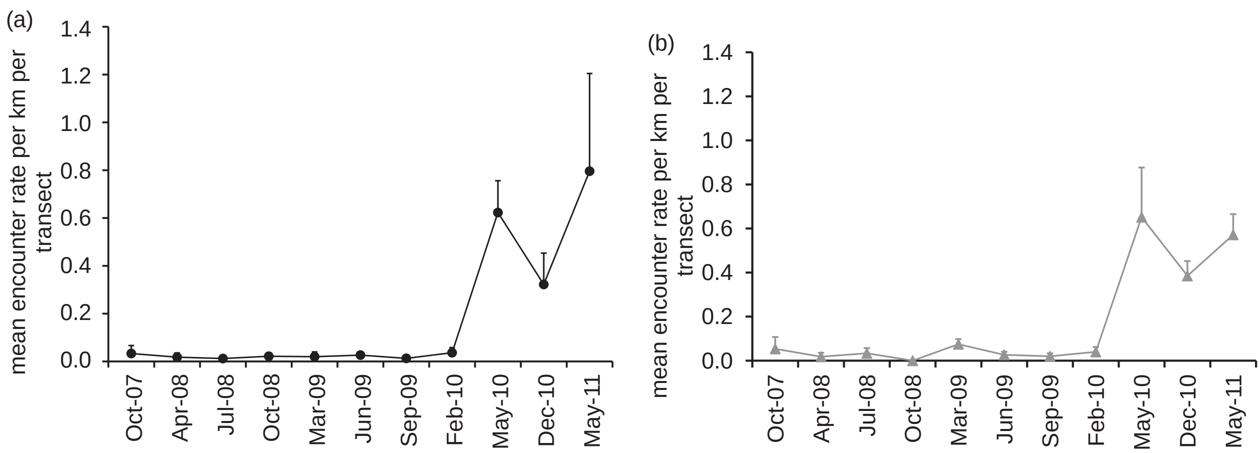

Fig. 5. Index of abundance ± SE of (a) brown falcon and (b) Australian kestrel across the 11 sampling sessions from October 2007 to May 2011, at Andado Station, Simpson Desert, Australia.

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Nocturnal raptors

The two species of nocturnal rodent-specialist raptors, eastern barn owl and letter-winged kite, were not recorded in the study area until T11 (May 2011). It is likely that they appeared in the area by late summer or early autumn 2011 (February–March). The letter-winged kite had not been recorded in the study area since November 2002 and the barn owl since May 2003. Sightings of both species during T11 were incidental records (Table 1). It is not possible to estimate the abundance of eastern barn owl but the count of letter-winged kite was only three birds. This number had risen to nine by December 2011 but contrasts with the previous occurrence in the area in 2001–2002, when median abundance was 66 birds with counts of 100 or more birds in July, August and September 2002.

DISCUSSION

Timing and magnitude of response to high rainfall

The rodent assemblage response was in keeping with expectations of the pulse-hierarchy model (Schwinning & Sala 2004). Specifically, there was a dramatic difference in abundance between the high rainfall samples at the end of the monitoring period and the preceding arid climate samples and, moreover, there was a significant delay (reflecting life-history constraints) between the onset of the high resource phase (T9, capture rate 1.5) and the major peak in primary-consumer abundance (T10–11, capture rates 41.1 and 78.8). PERMANOVA results confirmed that community composition changed through time, and that the timing of significant shifts coincided with rainfall events, and hence plant productivity patterning (see Nano & Pavey 2013 for details of plant productivity patterning). The increase in rodent abundance following high rainfall events in arid Australia has been demonstrated previously in multiple studies (e.g. Masters 1993; Southgate & Masters 1996; Dickman *et al.* 1999, 2010, 2011).

Importantly, while our results confirmed the link between big rains and rodent irruptions for our focal region (Pavey *et al.* 2008a; Dickman *et al.* 2010); they at the same time highlighted the occurrence of finer-scale temporal fluctuations that are less easily accounted for by rainfall patterning. Specifically, we recorded a minor spike in rodent abundance prior to the onset of the high rainfall phase. This occurred in April 2008 (T2), four months after a moderate, isolated rainfall event when the capture rate was 9.8 (compared to 3.4 at T1). The spike was almost entirely the result of an increase in capture rate of *P. hermannsburgensis* (Fig. 3a).

In contrast to the April 2008 spike in response to a moderate rainfall event, the capture rate at T9 (1.52, May 2010) was the lowest for the entire monitoring period despite occurring three months after the major rainfall pulse of 91.4 mm in February 2010. Only three rodent species were captured at T9 and each of these had a very low capture rate (Fig. 3). This result may be of importance in that it is suggestive of a 4-month minimum time-lag for these assemblage responses. In the eastern Simpson Desert, *P. hermannsburgensis* and *N. alexis* reach peak capture rates generally 3–6 months after heavy rainfall although peaks may be reached as long as 12 months after rainfall (Dickman *et al.* 2010).

We have shown that the simple and often used explanatory variable 'cumulative rainfall in the past 6 months' has little explanatory power in relation to these more subtle, but potentially important population dynamics given the contrasting responses at T2 and T9. For arid perennial plants, it has been suggested that low, continuous background recruitment outside of rare above-average rainfall phases may provide a critical buffer against localized extinction (Watson *et al.* 1997). Logically, similar dynamics must occur in relation to primary consumer populations given that intervening drought periods could easily exceed species life-spans. As such, there may in fact be clear fine-scale signals as to the likelihood of local population persistence that can be picked-up through regular monitoring under normal arid conditions. Our results allude to minimum rainfall amount and lag time thresholds, but there is great scope for further refinement of these relationships.

The trigger for the population irruption of rodents is not clear because no increase in numbers was detected in May 2010 (3 months after the February 2010 pulse) and by the time of a 10 fold increase in capture rate in December 2010, the second rainfall pulse occurred in August–October 2010. Overall the lag time in the response of rodents to the rainfall pulses is most likely a consequence of a lag in production of food, specifically plant material. A companion study (Nano & Pavey 2013) showed that the major primary productivity response on the study sites sampled here did not occur until sampling in December 2010.

As detailed above, rodents exhibited a lagged response to the first of the three rain events that occurred in 2010–2011 that was not detectable at T9 (May 2010). In contrast, a strong response was already detectable at T9 for diurnal raptors both in terms of species richness and overall abundance (based on sightings along drive transects). Species richness of raptors jumped from two to six between T8 (February 2010) and T9 (May 2010). The additions between the two sampling periods included three non-resident

doi:10.1111/aec.12062

species (black kite *Milvus* migrans, black-breasted kite *Hanirostra melanosternon*, spotted harrier *Circus assimilis*) that had not previously been recorded on transects. These three species are all generalist predators with prey including birds, mammals, reptiles and carrion (Table 1). A further two species were detected for the first time on transects at T10 (December 2010). Among these was the black-shouldered kite *Elanus axillaris*, the only rodent specialist among the 12 species of diurnal raptors observed in the study area (Table 1).

The increase in the mean encounter rate of raptors by T9 was driven by both the influx of nomadic species and (mostly) by the marked increase in abundance of two resident species, Australian kestrel and brown falcon. The brown falcon is a generalist predator whereas the Australian kestrel is considered a specialist on small reptiles in central Australia (Aumann 2001b, Table 1). Given that the increase in species richness and encounter rate was driven by raptors with generalist diets it is highly likely that the correlation in abundance of raptors and rodents was a response to the rainfall pulse rather than a response by the raptors to increased rodent availability. In the case of insectivorous raptors including the brown falcon and Australian kestrel, a build-up in numbers of spur-throated locust, *Austracris guttulosa*, in the study area from February to May 2010 (C. Pavey, unpubl. data, 2010) may have triggered the increases in abundance.

The response of rodent specialist raptors to the high rainfall phase was the slowest of the three faunal groups examined. Both rodent specialist raptors were not detected in the study area until the final sampling session, T11 (May 2011). Unsurprisingly this occurred after rodent populations had irrupted (T10). This lag in response compared to diurnal raptors is expected given the high degree of specialization by the eastern barn owl and letter-winged kite on native rodents (Pavey *et al.* 2008b).

The response of the letter-winged kite differed between the current study and the previous high rainfall phase in 2001–2002. Specifically, the species occurred in much smaller numbers in the study area in 2011–2012 than in 2001–2002. The reasons for this are unclear. However, this species is an irruptive breeder and is only present in the study area during rodent outbreaks, irrespective of which species are present (Pavey *et al.* 2008a,b). The western Simpson Desert rodent-predator system differs from those in arid–semi-arid environments elsewhere in the world in that none of the specialist rodent predators are resident but rather are themselves irruptive and only occur in the study area during rodent population outbreaks (cf *Previtali et al.* 2009). As a consequence, the response shown by letter-winged kites and barn owls to rodent outbreaks may be related to conditions experienced in the core area of their range during non-outbreak periods. The low numbers of letter-winged kites in our study area during the 2010–2011 resource pulse may be the result of reduced survival and reproduction in the core range during the dry period between the two resource pulses. Alternatively, the lack of response may indicate that conditions were plentiful elsewhere and the species was widely dispersed.

Comparison of rodent responses across habitats and life histories

The examination of species-level patterning lends much weight to the idea that important small-scale population dynamics occur outside of major rainfall episodes in this system. More specifically, we have shown that habitat-related stabilizing mechanisms operate to reduce the differential effect of drought and big rainfall events on the dynamics of resident arid species. We compared responses over time and space between a group of three native resident rodents and a group comprising the introduced *M. musculus* and the highly nomadic and irruptive native *R. villosissimus* (Predavec & Dickman 1994). We found that only the former group showed a strong association with habitat type (either gibber plain/cracking clay or sand ridge/plain). By contrast, the latter group showed no strong link with habitat type, and responded only during the high resource phase at the end of the study. For our study system, we have shown that within the rodent assemblage, there exist contrasting population dynamics that can be related to habitat-life history interactions. Thus we found evidence in support of Propositions 12 (opportunism) and 13 (stability) of Morton *et al.* (2011) for our study region.

ACKNOWLEDGEMENTS

Financial support was provided by the Northern Territory Natural Resource Management Board (now Territory NRM). We thank Donny and Colleen Costello for allowing us access to Andado Station. We thank John and Liz Spencer for hospitality during our early stays at Old Andado. We are grateful for the field assistance provided by Jeff Cole, Peter McDonald, Kathy McConnell, S. Raghu, Robbie Povey, James Ford, Peter Nunn, Greg Fyfe, Ada Nano, Alex James, Andrew Schubert, and Amelia Graham. Ethics approval was obtained from Charles Darwin University Animal Ethics Committee (number A07010). We thank Justin Perry, Leo Joseph, Chris Dickman and two anonymous referees for comments on the manuscript.

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doi:10.1111/aec.12062

<u>ATTACHMENT H:</u>

THE BREEDING AND FORAGING ECOLOGY AND ABUNDANCE OF THE PRINCESS PARROT (*POLYTELIS ALEXANDRAE*) DURING A POPULATION IRRUPTION

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Emu, 2014, 114, 106–115

CSIRO PUBLISHING
Emu, 2014, **114**, 106–115
http://dx.doi.org/10.1071/MU13050

The breeding and foraging ecology and abundance of the Princess Parrot (*Polytelis alexandrae*) during a population irruption

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Abstract. The Princess Parrot (*Polytelis alexandrae*) is an Australian endemic that displays irruptive population dynamics. We studied a breeding event in the southern Northern Territory in 2010–11, which followed a peak in primary productivity stimulated by extended above average rainfall. Birds were present from mid-July 2010 to February 2011, with highest numbers in August–November 2010. The maximum count was 172 birds. Multiple nests, all in mature Marble Gum (*Eucalyptus gongylocarpa*), were detected monthly from August to November 2010 and a single nest in January 2011. Birds fed on flowers, seeds and other material of 11 plant species, both on the ground and within foliage. The decrease in abundance of Parrots over time coincided with a decrease in plant species richness and flower abundance and an increase in availability of seeds and fruit. The area had not been burnt since 2002 indicating that fire-stimulated primary production does not trigger breeding. Despite the time since fire there was evidence of severe effects of past fires. Management of the area now involves efforts to reduce the incidence of high-intensity fires, control of buffel grass (*Cenchrus ciliaris*) and annual monitoring for the presence of Princess Parrots. Our research highlights the importance of ecological information for making effective conservation management recommendations.

Received 6 June 2013, accepted 27 August 2013, published online 25 March 2014

Introduction

A significant proportion of arid Australian bird species have irruptive population dynamics (e.g. Burbidge and Fuller 2007). These species typically retract to, or move between, small, discrete portions of their geographical range – core areas – during extended dry periods, then breed rapidly in response to pulses in the availability of resources. As numbers increase in response to higher resource availability, individuals disperse from core areas into other parts of their range and there is a resultant, often dramatic, increase in population size and area of occupancy (Blyth and Burbidge 1997). The distribution and population dynamics of most of these irruptive species are poorly known and the limits of their core ranges are not well understood. This lack of information makes it difficult to estimate population size accurately during non-irruptive periods and, therefore, to assess conservation status (e.g. Garnett *et al*. 2011). This lack of information has highlighted the importance of understanding the role of population irruptions in the persistence of species. A corollary of this is the importance of researchers being able to respond opportunistically to population irruptions to collect data on ecological and life-history variables.

The Princess Parrot (*Polytelis alexandrae*), is an endemic Australian species restricted to the arid zone of Western Australia, the Northern Territory and South Australia (Fig. 1; Johnstone and Storr 1998; Higgins 1999; Barrett *et al*. 2003). Previously, the pattern of occurrence of the species was referred to as nomadic or migratory (e.g. Johnstone and Storr 1998; Higgins 1999; Pavey 2007). However, there is now general consensus that the Princess Parrot has irruptive population dynamics (Blyth and Burbidge 1997; Baxter and Henderson 2000; Garnett *et al*. 2011). The species is often not present for long periods and then large numbers of birds are seen in an area for a short period of time (e.g. North 1896; Higgins 1999; Cowle in Mulvaney *et al*. 2000). The location of the core range of the Princess Parrot is not well understood (Fig. 1). Some authors suggest that it is centred on the eastern Great Sandy Desert (e.g. Blyth and Burbidge 1997), although recent expeditions suggest that it may be the eastern Gibson Desert and western Great Victoria Desert (Atlas of Australian Birds database (Birdata), 1998–2013, BirdLife Australia, Melbourne, see http://www.birdata.com.au/about_atlas.vm, accessed 15 October 2013). The species is enigmatic and little is known of its biology or ecology (Higgins 1999).

Here we report on a breeding event of the Princess Parrot near Glen Edith on Haasts Bluff Aboriginal Land Trust (ALT) in 2010–11. Our study aimed to collect information on aspects of the ecology and occurrence of Princess Parrots, specifically, the

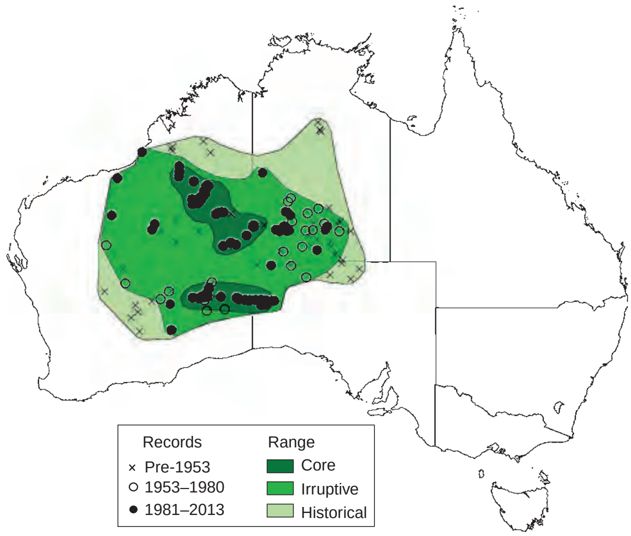

Fig. 1. A map of the geographical range of the Princess Parrot, based on the Atlas of Australian Birds databases showing a division of the range into core, irruptive and historical components. The core range has been derived from records collected between 1981 and 2012 and based on frequency of occurrence. Data were analysed within 1° grids with core attributes being if Princess Parrots were recorded over 2 or more years within the period. To overcome bias from differing survey effort across the area, grids with reporting rates (percentage of sightings compared to number of surveys) of <2% were removed from core range.

period of occurrence in the area, breeding, foraging, group size and overall local population size. A second aim was to understand the components of the environment used for nesting and feeding and to assess whether there were management actions needed to ensure the retention and persistence of important habitat.

Methods

The study was undertaken from August 2010 to August 2011 within the Haasts Bluff ALT (exact location withheld). The vegetation of the area consists of open woodland or woodland of Marble Gum (*Eucalyptus gongylocarpa*) and Desert Oak (*Allocasuarina decaisneana*). The first reports of Princess Parrot in the area came in late July 2010 (I. May, pers. comm.) and our initial field trip (August 2010) was within 4 weeks of this report. During the initial trip observers searched a wide area by driving along 90 km of an access track and searching areas adjacent to the track on foot. Most Princess Parrots located during this search were along a 3-km length of the track that traversed a band of Marble Gum woodland south of Glen Edith. As a consequence of this concentration of Princess Parrots, all subsequent field trips focussed on an area of ~5.0 × 2.0 km (1000 ha) centred on these initial records. This area is hereafter referred to as the main study area.

Eight field trips were made to the location during the study (Table 1), including six trips when nesting was ongoing, one to search for non-breeding birds, and a final trip 12 months after intense breeding had begun (in 2010). The purpose of the final trip was to assess whether the 2010 breeding activity was a singular event or indicative of a more extended irruption (or more regular, previously undetected, breeding) in the region. Field trips were for a minimum of 2 days and included at least two observers, though usually more (Table 1).

Table 1. A summary of field trips to the study area to observe Princess Parrots, including length of visit (in 24-h days), number of observers (dedicated full-time to searching for Princess Parrots and recording data) and observer-days (one observer day is an observer active for a full day)

Dates	Number of days (24-h periods)	Number of observers	Observer days
21–23 Aug. 2010	2	3	6
21–24 Sep. 2010	3	4[A]	12
26–28 Oct. 2010	2	4[A]	8
22–23 Nov. 2010	1	2	2
20–21 Jan. 2011	1	2	2
16–17 Feb. 2011	1	2	2
12–13 May 2011	1	3	3
24–25 Aug. 2011	1	4	4

[A]In addition to full-time observers there was active participation in searches by the Anangu Luritjiku Rangers and their co-ordinator (J. Hulcombe): four rangers in September and three in October.

Annual rainfall at the nearest weather station at Watarrka National Park (Bureau of Meteorology weather station number 015652; 24°17′29.62″S, 131°32′56.00″E, 614 m above sea level, ~50 km from the site) in the year before the irruption and the years of the study was 116.9 mm (2009), 810.3 mm (2010) and 326.5 mm (2011). The annual average for the location is 328.5 mm ($n = 19$ years). The year 2010 featured 4 months with monthly totals of >100 mm in January (114.4 mm), March (139.7 mm), September (104.9 mm) and October (123.7 mm). This was one of only two events of well above-average mean annual rainfall in the area in the past 20 years.

Abundance, group size and behaviour

During the initial field trip, in August 2010, a series of twelve 2-ha searches (a 20-min survey of a 2-ha area using the BirdLife Australia Atlas of Australian Birds methodology, http://www.birdlife.org.au/projects/atlas-and-birdata/become-an-atlasser, accessed 6 November 2013) was undertaken: six in Marble Gum woodland and six in other vegetation associations. These sites were spaced widely along the access track. In September 2010, five 2-ha searches were undertaken within the main study area, each in Marble Gum woodland. These five sites were resurveyed in January 2011.

Another five sites within the main study area were selected for a more detailed assessment of abundance in September 2010. The five sites were each ~1.0 × 0.5 km (50 ha) and were chosen to encompass variation in quality of Marble Gum as potential nesting habitat. The sites ranged from one dominated by large hollow-bearing trees to one consisting mostly of juvenile trees, with the other three sites being intermediate between these two extremes. Each site was surveyed by two observers for 60 min. Observers walked through the site searching for birds, recording the number of Parrots present, and evidence of occupation of hollows.

In addition to the above surveys, observers searched more widely for Princess Parrots within the main study area. Any birds seen were observed and notes taken of behaviour. For each discrete bout of behaviour observers noted: location, time, duration of activity, number of birds including sex and age (if views permitted separation) and activity (separated into flying, perched or feeding). If a bird was observed in flight and perched during a bout, it was scored as 'perched'. For feeding bouts, observers recorded the location as either ground or foliage and the plant species was identified by a botanist (C. Nano) in the field. A feeding bout was defined as an observation of a single bird feeding on a single plant species. Therefore, two birds feeding on the same shrub were classified as two bouts and if a single bird fed on two plant species during an observation this was also classified as two bouts. Observers also noted interactions between two or more birds including the occurrence of calling, preening, begging and feeding.

Habitat and vegetation assessment

Within each of the five 2-ha search sites (described above), we established a 70 × 70-m habitat monitoring plot. These plots were surveyed for vegetation and other habitat variables on three occasions (September 2010, January 2011, May 2011) and for data on Marble Gum demography in September 2010.

In each plot we measured a range of abiotic variables including landform pattern and element, slope (as a percentage), aspect and substrate type. The type and intensity of major disturbances (fire, weeds, introduced herbivores) were also recorded. We characterised vegetation structure (description of dominant species and cover in each stratum: tree layer, upper shrub layer, lower shrub layer and ground layer) and vegetation profile (amount of plant biomass across six different height intervals from 0 to >10 m above the ground). We recorded every plant species and estimated its cover abundance using the classes: 1 (<5% cover, 1–5 individuals), 2 (<5% cover, 6–50 individuals), 3 (<5% cover, >50 individuals), 4 (5–9% cover), 5 (10–30% cover) and 6 (>30% cover). For each species present in the plot we recorded population-level fruiting and flowering using the classes: 0, population sterile; 1, low (<20% of individuals of each species with low levels of flowering or fruiting); 2, moderate (20–100% with low levels of flowering or fruiting or <20% with high levels of flowering or fruiting); and 3, high (20–100% with flowering or fruiting at capacity). For each plot we then multiplied the species cover-class scores by (1) the flower-class score and (2) the fruiting-class score to give a coarse estimate of changes in the abundance of potential food resources over time. This was done to explore patterns of availability of food resources over the monitoring period. For each of the three sample times we calculated plant species richness (averaged over the five plots).

Marble Gum trees were classified into five classes that reflected their age and the availability of hollows: large (diameter at breast height (DBH) usually ≥0.5 m), old trees with multiple apparent hollows (>2 hollows); medium-sized trees (DBH usually <0.5 m) with low availability of hollows (0–1 hollows); saplings (no hollows, pre-reproductive young plant, ≥1 m tall); fire-regrowth (main stem killed, no hollows); and juveniles (pre-reproductive young plant, <1 m tall). We recorded the number of individuals in each class for each of the five plots. For each plot, we obtained height and girth data for one representative individual in each class. We used these data to examine availability of hollows, fire effects, and age structure of Marble Gums across the main study area.

Analysis of data

We carried out analysis on bouts of behaviour. To ensure independence of observations we reviewed the time and location of records to avoid using data from the same birds on the same day more than once. We used a similarity percentage analysis SIMPER (Clarke and Gorley 2006) to identify the plant species that distinguished the September sample period (high Parrot abundance) from the remaining two sample times on the basis of the multiplied species cover by flowering and fruiting scores. This procedure ranks taxa according to their contributions to within-group similarity and between-group dissimilarity.

Data are presented as means ± standard error.

Results

Occurrence and abundance

Princess Parrots were first detected on 23 July 2010 (I. May, pers. comm.; Atlas of Australian Birds database (Birdata), BirdLife Australia) and by mid-August 2010 birds were concentrated in a small area of Marble Gum woodland. This area was used from August 2010 to January 2011 (Table 2). A single bird was heard, but not seen, in February 2011 whereas no individuals were recorded in May 2011 or August 2011. The number of birds present peaked in August–November 2010, with a high sighting rate in September (71 independent observations over 12 observer-days), October (77 observations over 8 observer-days) and November 2010 (34 observations over 2 observer-days). By January 2011 the number of birds had declined dramatically with 14 observations (11 in flight) completed over 2 observer-days.

The population estimate across the 1000-ha main study area, assuming the data in Table 2 represent independent observations, was a minimum of 137 birds in September 2010 and 172 birds in October 2010. In August 2010, a minimum of 36 breeding adults was estimated from within a 200-ha area within the 1000-ha main study area. The maximum flock size observed during the study period was 20 birds on 27 October 2010 (Table 2).

In August 2010, when surveys were covering a wide area of Haasts Bluff ALT, Princess Parrots were recorded at four of six

Table 2. Group size of Princess Parrots in the south-western Northern Territory from September 2010 to January 2011

Group size data are given separately for perched (including feeding) birds and those in flight

Month	Activity	Mean size of groups (birds)	Median size of groups (birds)	Maximum size of groups (birds)	*n* (groups)
September	Flight	1.58	1	4	25
	Perch	2.13	2	7	46
October	Flight	2.30	1	20	40
	Perch	2.16	2	5	37
November	Flight	1.74	1	7	12
	Perch	2.64	2.5	6	22
January	Flight	1.55	2	2	11
	Perch	1.67	2	2	3

2-ha search sites in Marble Gum woodland (14 birds, estimated density of 1.17 individuals ha^{-1}) and one of six 2-ha search sites in other vegetation associations (3 birds, estimated density of 0.25 individuals ha^{-1}). Princess Parrots were present on each of the five 2-ha search sites established within the main study area in September 2010 (34 birds, estimated density of 3.4 individuals ha^{-1}). However, when the five sites were resurveyed in January 2011, Princess Parrots were present at only two of the sites (3 birds, estimated density of 0.3 individuals ha^{-1}).

Princess Parrots were present on each of the five 50-ha sites, representing a gradation in habitat quality of Marble Gum woodland, in September 2010. The minimum estimate for the five sites combined was 38 adult birds (mean 7.6 ± 5.12, range 1–14). If these data are used to extrapolate to the 1000-ha main study area then the minimum estimate is 152 birds in September 2010.

Reproduction

Active nests were detected in August (15 nests), September (8), October (7) and November 2010 (3) and January 2011 (1) (Table 3). No more than one active nest was detected in a single tree, although at several sites nests were located in adjacent trees. In these instances, nest-trees were 40–60 m apart. The nest-hollow used in January was also occupied in September 2010 indicating the possibility that some pairs laid two clutches.

The first evidence of fledglings came in September 2010 (Table 3), when one juvenile bird was positively identified, and the number of fledglings peaked in October–November 2010. No fledglings were detected in August 2010 or January 2011. The last observation of fledglings at the site was on 3 December 2010 (A. Stafford, pers. comm.).

Our observations on group size in October and November suggest that the average pair fledged one or two young with a maximum of five (Fig. 2*a*). Not all groups, especially those in flight, could be inspected for the presence of young. However, most groups that were observed closely contained juvenile birds. When considering all sightings, the percentage of groups that had three or more birds (i.e. potentially consisting of a pair and offspring) increased substantially from September (14%) through October (27%) to November (38%). This pattern indicates an increase in the presence of fledglings from September to November and suggests that group size in October and November is a reliable indicator of the number of young fledged.

Table 3. The breeding phenology of Princess Parrots in the south-western Northern Territory from August 2010 to August 2011

	August 2010	September 2010	October 2010	November 2010	January 2011
Courtship feeding	✓	✓		✓	✓
Inspection of nests	✓	✓			
Incubation or brooding	✓	✓	✓	✓	✓
Fledgling being fed		✓	✓	✓	✓

Characteristics of nests

At least 22 active Princess Parrot nests were observed, although there may have been more nests. All nesting took place in hollows in large Marble Gums. The mean height of 15 nesting trees in August 2010 was 14.06 ± 0.70 m (range 7.85–18.06 m) and the mean height of entrances to the nesting hollow 6.76 ± 0.37 m (range 4.40–9.88 m). The mean height of entrances to the nesting hollows of six nests in October 2010 was 6.52 ± 0.64 m (range 4.40–8.35 m).

Feeding

We observed foraging Princess Parrots in August ($n = 14$), September ($n = 15$), October ($n = 7$) and November ($n = 2$). A total of 38 independent foraging records were obtained, of which five were birds flushed from the ground, in which case feeding was not observed but inferred. The longest continuous observation of a foraging bird was 35 min. Princess Parrots frequently foraged on the ground and in the foliage of shrubs and trees (Fig. 2*b*).

Princess Parrots were observed feeding on at least 11 plant species. Parrots were observed feeding on grass seeds (2 observations: *Digitaria ammophila*, *Eragrostis eriopoda*), Acacia seed pods (2 observations: *Acacia maitlandii*), flowers (21 observations: Mulga (*Acacia aneura*), *Grevillea juncifolia*, *Leptosema*

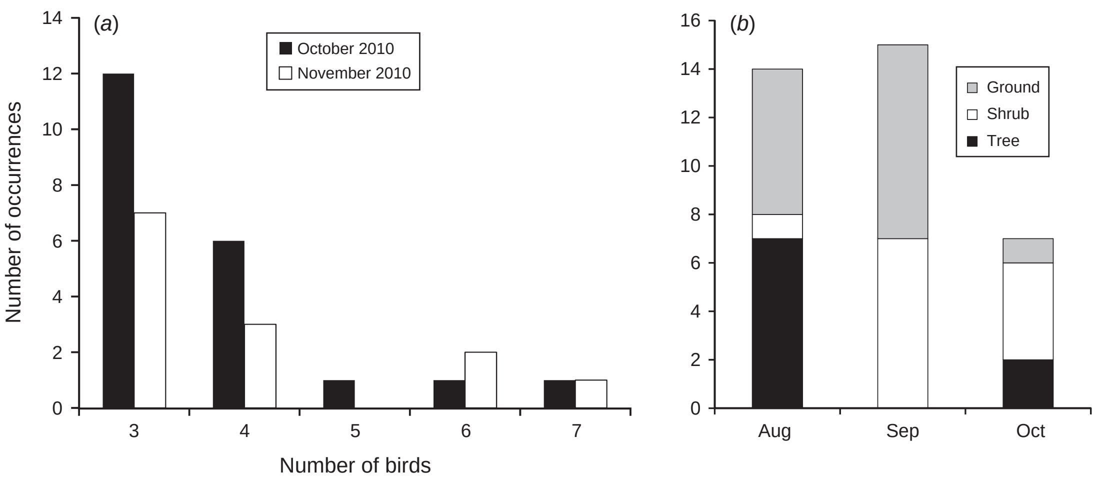

Fig. 2. (*a*) Summary of group size (perched and flight combined) for all groups of three or more Princess Parrots in October and November 2010; and (*b*) strata occupied by foraging Princess Parrots over 3 months in 2010.

chambersii, *Hakea lorea*, *Eremophila* spp.), leaf stems (2 observations: *Euphorbia ferdinandii*, *Amyema miquelii*), lerps (2 observations: *Eucalyptus* sp.) and unidentified plant material (four observations: *Ptilotus polystachyus*). The composition of feeding records changed across the 3 months of intensive sampling from August to October 2010. The red-flowering subshrub, *L. chambersii* was important in August ($n = 5$ feeding records) but was seen to be eaten only once in September and not at all in October. In contrast, flowers of the shrub *Grevillea juncifolia* were observed to be eaten during only one observation in August whereas these were the main food source in September ($n = 7$) and October ($n = 3$). Although birds frequently fed on flowers we have no direct evidence that nectar was consumed.

Habitat and vegetation assessment

The Marble Gum woodland in which the Princess Parrots nested was located on an undulating sandplain (aeolian sand) with sandy loam soil. Plant species richness in September 2010 ranged from 48 to 69 species (mean 60.6 ± 8.08) across the five habitat plots and 59% of the plant-species records ($n = 300$) included some level of flowering, with 27% of these being scored as high (class 3). Further, all plots had 50% or more species with some level of flowering (range 50–65%). By contrast, the incidence of fruiting at this time was 20% and none of the species was given a high fruiting score. In January 2011, plant species richness was marginally lower than the previous sample, ranging from 44 to 66 species (mean 55 ± 8.4). The incidence of flowering at this time was also lower (50.5%) whereas that of fruiting had increased to 56% ($n = 275$ total species records across the plots). No species was recorded as having high flowering or fruiting (class 3) in January 2011. Finally, by May 2011, species richness was at its lowest, ranging from 40 to 51 species (mean 45.6 ± 5.0) across the five plots. At this time, flowering incidence was at its lowest (28%), and fruiting was intermediate at 46% ($n = 228$ species records across the plots). Again, no species had high fruiting or flowering levels in this last sample.

The September sample period was characterised by higher flowering in more shrub (9 species) and subshrub species (3 species) compared with the January sample (0 shrub species; 0 subshrub species) (SIMPER analysis: 70% cumulative between-group dissimilarity). The same pattern was apparent in the comparison of the September (6 shrub species, 3 subshrub species) and May samples (0 shrub species, 0 subshrub species). Abundance of flowers was notably higher in the September sample for *Grevillea juncifolia*, *Leptosema chambersii*, *Acacia murrayana*, *Bonamia erecta* and *Aluta maisonneuvei* subsp. *maisonneuvei* (Appendix 1).

The September sample period was not characterised by high availability of fruit or seeds compared with the following two sample periods. Only four species – *Euphorbia ferdinandii*, *Bonamia erecta*, *Ptilotus polystachyus* and *Lawrencella davenportii* – had a comparatively high fruiting index in September *v.* January (22 species) and May (14 species) (SIMPER analysis: 70% cumulative between-group dissimilarity).

The site was last burnt in 2002. The presence of One-humped Camel (*Camelus dromedarius*) was detected in two of the five plots and there was moderate indications of presence of Camels throughout the main study area. We did not detect indications of any other introduced herbivores. No weeds were detected on the plots, although we noted several small patches of the introduced and invasive buffel grass *Cenchrus ciliaris* within the study area.

The average height of the Marble Gum overstory ranged from 12 to 17 m. The mid-layer of the Marble Gum woodland consisted of mallee eucalypts (*Eucalyptus gamophylla*, *E. mannensis*, *E. oxymitra*), shrubs (*Eremophila longifolia*, *Eremophila glabra*, *Senna artemisioides*, *Acacia maitlandii*) and Marble Gum saplings. The ground cover was dominated by hummock grass (*Triodia schinzii*) and short-lived tussock grasses (*Aristida holathera*, *Enneapogon polyphyllus*) with the subshrub, *Leptosema chambersii* subdominant on one plot. Across all plots, the bulk of the live vegetation biomass was concentrated in the upper and lower height-classes: >10 m (range of biomass across the five plots 5–12%), 0.5–1 m (range 6–12%) and 0–0.5 m (range 30–40%). Thus, medium to tall shrubs were found to contribute relatively little to the biomass of the sites.

The distribution of size-classes of Marble Gums in the 70×70-m plots varied (Fig. 3). Three of the plots (at sites 1, 3 and 5) had three or more large old trees with multiple apparent hollows and it was at these sites that Princess Parrot activity was concentrated. The number of large trees per plot in the five sites ranged from 6 (site 3) to 1 (site 4). Medium-sized trees (no or few hollows available) formed the dominant component of the plots at sites 1 and 2. The occurrence and density of Princess Parrots was relatively low at site 2 compared to other sites. Site 4 differed most in that it was the only site with juvenile Marble Gums, and it also had the lowest number of mature adult Marble Gums (n = 1) across the site. Activity of Parrots was similarly relatively low here compared with other sites. Like the distribution of juvenile Marble Gums, the distribution of sapling Marble Gums was not uniform across the study area, with individuals occurring in only two of the five plots. Resprouting adults were recorded from two sites that otherwise had a good representation of large and

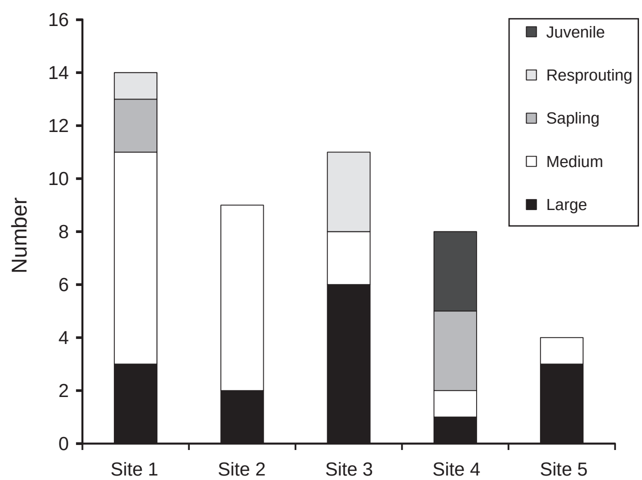

Fig. 3. Frequency distribution of size-classes of Marble Gums in five vegetation monitoring plots (70×70 m) in the study area. Classes were: large old trees with multiple apparent hollows (>2 hollows); medium trees with low availability of hollows (0–1 hollows); saplings (no hollows, no roosting sites); fire-resprouting (main stem killed, no hollows, no roosting sites); and juveniles (small trees <1 m tall).

medium trees (sites 1 and 3). Thus, there was no evidence that fire was resulting in a decline in the availability of key resources under the present fire regime.

Discussion

The pulse in primary productivity that likely triggered the Princess Parrot breeding event was driven by high rainfall early in 2010. Specifically, at Watarrka National Park, 50 km from the study site, monthly rainfall events of 100 mm or more occurred in January and March 2010, following a dry year in 2009 (annual rainfall of 116.9 mm). This spike in rainfall was widespread across the southern Northern Territory and adjacent areas of arid Australia (Pavey and Nano 2013; Wardle *et al*. 2013). The response time of Princess Parrots to the summer rainfall seems to have been rather brief; significant numbers were present by the time of the first visit to the site in late July 2010. During the Princess Parrot breeding event other parrots present in the study area were Major Mitchell's Cockatoo (*Lophochroa leadbeateri*), Cockatiel (*Nymphicus hollandicus*), Australian Ringneck (*Barnardius zonarius*), Mulga Parrot (*Psephotus varius*) and Budgerigar (*Melopsittacus undulatus*) (C. R. Pavey, C. E. M. Nano, J. R. Cole, P. J. McDonald, P. Nunn, A. Silcocks and R. H. Clarke, unpubl. data). Follow-up monthly rainfall events of >100 mm also occurred during the peak of breeding activity in September and October 2010. This resulted in temporary pools of water being present in the study area, although the nearest permanent water is likely to be >50 km from the study area.

The study area had remained unburnt for 8 years at the time of the vegetation and habitat assessments in September 2010. However, all five habitat monitoring plots had evidence of severe effects of fire. Fine-scale fire-scar mapping of the study area (Northern Territory Government, unpubl. data) together with broader satellite imagery analysis (Turner *et al*. 2008) reveal that Haasts Bluff ALT is subject to large wildfires following wet years. These fires can damage or kill Marble Gums thus reducing breeding habitat quality for Princess Parrots. The last such fire event was in 2002. The fire threat in the area may increase in future if invasive buffel grass, which we located in several small patches, becomes established. Buffel grass is known to alter fuel-load characteristics, increasing the frequency and intensity of fires and negatively affecting native trees and shrubs (Miller *et al*. 2010). Establishment of buffel grass in the study area is highly likely to lead to increased mortality of hollow-bearing Marble Gums as is happening with River Red Gums (*Eucalyptus camuldensis*) after buffel grass invasion of river channels in the MacDonnell Ranges bioregion (C. R. Pavey, pers. obs.).

Occupancy of the site and the breeding event of Princess Parrots was prolonged in comparison with previous records based on the limited existing information available. Specifically, the breeding event continued for 6 months, with active nests observed from August to November 2010 and in January 2011, although the peak in nesting activity was from August to November. As recently fledged juvenile Parrots were present from September and Princess Parrot incubation and nestling stages average a total of ~56 days (Higgins 1999), some Princess Parrot breeding must have begun in July 2010 at this site. The breeding period is usually given as September–November or September–December in the wild (Higgins 1999) and September–December in captivity (Shephard 1989). We recorded a peak of fledglings in the population in October and November 2010. Our data on group size indicate that most pairs fledged one or two young with a maximum of five (Fig. 2*a*). These data match estimates of clutch-size of 3–6 eggs for wild birds (Higgins 1999) and typical clutch-sizes of 4–5 eggs in captivity (Shephard 1989).

We have several sources of data to estimate the minimum number of Princess Parrots present within the ~1000-ha main study area (see Methods). The data on group size (Table 2) indicate a minimum number of 137 birds in September 2010 and 172 in October 2010. The alternative method of estimating abundance, based on the five 50-ha search areas, minimised the likelihood of re-counting birds because two observers spent 60 min in the area familiarising themselves with the movements and activities of all Princess Parrots. If the September 2010 data (38 adult birds with a mean of 7.6 per site) are used to extrapolate to the 1000-ha study area then the minimum estimate is 152 birds. As an alternative, searches for nests in August 2010 in an area of ~200 ha within the study area located a minimum of 36 breeding adults. If extrapolated to the 1000-ha study area this gives a total of 180 adults. That these estimates are congruent is encouraging.

Whether the number of birds present at Haast's Bluff ALT in late 2010 is a significant portion of the global population of the Princess Parrot is not clear. However, if the estimate of 1200 mature individuals given, albeit with low confidence, by Garnett *et al*. (2011) as a potential population size at its lowest point is accepted, then the estimate of a minimum of 172 birds in our study area in October 2010 is almost 15% of the global population of the species.

The current knowledge of the geographical distribution of the Princess Parrot indicates that Haasts Bluff ALT does not form part of its core range (Fig. 1). The species does not appear to be resident there (or in the general area) as no individuals were present in May or August 2011 despite food and nesting resources being available. However, four birds were sighted on 23 May 2012 (C. Nano and P. Hodgens, unpubl. data) indicating that the area may not be unoccupied for long during wet periods. A potential explanation of the use of the area by Princess Parrots is that it is significant for breeding during population irruptions and, therefore, is occupied only periodically. Before 2010 the area was infrequently visited by observers so the pattern of occupation by Princess Parrots is not clear. Nevertheless, large numbers were observed in this general vicinity in 1894 (North 1896) with 15 specimens taken (Spencer 1896, p. 101). The site of North's observation is given as 'between Glen Edith and Deering Creek'. Although this description does not enable an exact location to be specified, the furthest of the two locations is within 30 km of our study area. Further, the stand of Marble Gums in which breeding occurred during our study was previously identified as being significant on a regional scale and a survey for Princess Parrots was done in the area in the early 1980s, albeit without detecting Parrots (Fleming and Piercey 1982). Our work showed that the stand is characterised by a high proportion of medium-sized and large hollow-bearing trees, a feature which makes it a high-quality breeding location for parrots and other hollow-nesting fauna.

Our observations provide new insights into, and clarify other aspects of, the diet and foraging behaviour of the Princess Parrot.

Specifically, we show that the species feeds on flowers, seeds and other material of a wide range of plants and that it frequently forages on both the ground and in foliage. At the species level, most food plants that we observed being consumed by Princess Parrots have not been recorded previously (Higgins 1999). However, all the food plants were common in the study area during our observations (C. Nano, unpubl. data) and a significant portion of plants were flowering. Further, many of the species are common and widely distributed throughout the arid zone. The study area had remained unburnt since 2002, demonstrating that fire-stimulated primary production is not a trigger and is not necessary for reproduction in this species.

The decrease in numbers of Parrots over time coincided with a gradual decrease in plant species richness and in abundance of flowers. By contrast, the results did not indicate that the birds have a strong reliance on overall high seed availability for breeding or persistence at a site, given that population numbers were dramatically reduced by January when the availability of seeds and fruit was at its highest level.

All confirmed nesting observed during this breeding event was in mature Marble Gums, which was the dominant tree within the main study area. Although Marble Gum has previously been identified as a nesting tree for the Princess Parrot (Johnstone and Storr 1998; Garnett *et al*. 2011), most reports of nesting are from River Red Gums and other eucalypts along drainage lines (Higgins 1999). Although Desert Oak has been listed as a nesting tree (Higgins 1999), it does not readily form hollows and Princess Parrots were not recorded nesting in Desert Oak despite it being common in the study area. Marble Gum typically grows on sandy substrates, often at considerable distance from watercourses, so it may have been overlooked as a nesting tree in the past. It is a tree that readily forms hollows (Fleming and Piercey 1982) and is distributed across the eastern and southern portions of the range of the Princess Parrot (Brooker and Kleinig 1994; Garnett *et al*. 2011). Although its distribution in the southern Northern Territory is patchy (Fleming and Piercey 1982) it appears likely to be an important nesting tree for Princess Parrots in these parts of its range.

Management issues and actions

Several important management issues have emerged from this Princess Parrot breeding event. The first set of issues relate to the logistics of carrying out this type of opportunistic study. The project would not have been possible without the positive attitude and approach of the organisation responsible for management of the land, the Central Land Council, and the traditional owners of the land who facilitated access to the area and enabled the study to proceed collaboratively. Specifically, the Anangu Luritjiku Rangers responsible for management of this area assisted with collection of data for the duration of the two longest and most intense field trips in September and October 2012. The value of such collaboration for obtaining information on Princess Parrots has been noted previously (Brennan *et al*. 2012). The Anangu Luritjiku Rangers have subsequently undertaken fire management (see below) and control of buffel grass in the study area. Further, the ability of the organisations involved in the study (Northern Territory Government, Monash University, BirdLife Australia (Birds Australia at the time), Central Land Council) to dedicate staff to the project at short notice was vital to its successful completion. Without this ability the work could not have been undertaken.

In terms of on-ground management, the protection of stands of Marble Gum as a critical nesting resource has emerged as the key management focus. Although the frequency of use of the area by Princess Parrots is not known, the occurrence of two significant known irruptions (1894, 2010–11) and the reappearance of birds in May 2012 suggest that the Glen Edith area is an important location for the species. Because the years including and immediately following significant rainfall have a heightened risk of large-scale wildfires (Letnic and Dickman 2006), particular attention was given to the risk of fire affecting the stand of Marble Gums in mid- to late 2011. This period encompassed a series of significant fire events in the southern Northern Territory (Bastin and Allan 2012), affecting several bioregions: MacDonnell Ranges, 34.9% of the bioregion burnt; Burt Plain, 31.6%; Finke, 25.1%; and Great Sandy Desert, 35.4% (Australian Collaborative Rangelands Information System (ACRIS), unpubl. data). A fire burnt the periphery of our 1000-ha study area in August 2011, but the effect on individual Marble Gums was negligible. As a consequence of the fire risk, a fuel-reduction burn to mitigate any potential effect from wildfire was undertaken by the Central Land Council in spring 2011 (B. Kaethner, pers. comm.).

Acknowledgements

We are grateful to traditional owner Douglas Multa who gave us access to the study area. We greatly appreciate the efforts of Central Land Council staff, particularly Sam Rando, Richie Brittingham and Ben Kaethner, in facilitating many aspects of this work and for visiting the study area with us. We are grateful for the field assistance provided by Andrew Schubert, Pat Hodgens, Justin Paech, Brian Johnston and the Anangu Luritjiku Rangers from Warumpi (Papunya) and Ikuntji (Haasts Bluff), specifically Dennis Minor, Sylvester Jugadai, Willy Raggett, Terrence Abbott, and Gerrard Anderson. We thank Jeff Hulcombe, the Anangu Luritjiku Ranger co-ordinator, for his support and guidance. We also thank Ian May, Don Hadden and Andrew Stafford for providing us with details of their observations of the birds. Gary Bastin generously provided the fire data which was supplied by ACRIS. Comments on the manuscript were provided by Tony Grice, Leo Joseph and Hugh Ford. C. Pavey wishes to thank John Woinarski for his support of this work and Andrew Stafford for his thoughtful insights on this breeding event and its implications.

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Appendix 1. Diagnostic species for the September 2010 sample period and species contributing up to 70% of the average Bray–Curtis between-sample–time dissimilarity (defined by SIMPER analysis) based on the generated flowering and fruiting indices (cover class × flowering ÷ fruiting class)

Numbers in bold indicate diagnostic species for the September sample. Italicised numbers indicate discriminating species for pairwise comparisons between the September and the January and May 2011 sample times. Growth-form codes: f, forb; ss, subshrub; s, shrub; t, tree; tg, tussock grass; ms, mallee shrub; hg, hummock grass

Species	Growth-form	Flowering			Fruiting		
		Sep	Jan	May	Sep	Jan	May
Abutilon fraseri subsp. *fraseri*	f	0	0.2	0	0	0.2	0.2
Abutilon otocarpum	ss	0	0.6	1			
Acacia kempeana	s	0	0.2	0			
Acacia maitlandii	s	0.4	0	1.2	*0*	*1.2*	0
Acacia murrayana	s	***2.4***	*0*	0			
Allocasuarina decaisneana	t	0	0.2	0			
Aluta maisonneuvei subsp. *maisonneuvei*	s	***4.2***	*1.2*	2.4			
Amphipogon caricinus	tg	***4.6***	*0.4*	0	*1*	*2*	*1.6*
Aristida holathera	tg	***3***	*4.6*	*1.4*	***1.2***	*3.2*	*3.8*
Aristida inaequiglumis	tg	0	0.6	1.6	***1.2***	1.2	*3.8*
Bonamia erecta	ss	***5.4***	*0*	*0*	***1.8***	*0*	*0*
Brachyscome ciliaris var. indeterminate	f	0.2	0.4	0	0	0.4	0
Brunonia australis	f	1	1.4	0.8	*0*	*1.8*	*1.2*
Calandrinia balonensis	f	*1.4*	1.2	*0*	*0*	*1.2*	0
Calandrinia remota	f	0	0.8	0	0	0.4	0
Calandrinia reticulata	f	***1.6***	*3.2*	1.6	*0*	*1.8*	*1.2*
Calotis hispidula	f	0.2	0	0			
Calytrix carinata	s	0.6	0.2	0			
Chenopodium desertorum	ss	0.2	0.4	1.2	0	0.4	0.4
Chrysocephalum apiculatum	f	*0*	*3.4*	*5.2*	*0*	*1.8*	*2.6*
Chrysocephalum eremaeum	ss	0.6	1.4	0.8	0.2	1	0.8
Cymbopogon obtectus	tg	0.6	2	1.4	*0.2*	*2*	*2.8*
Digitaria ammophila	tg	1.4	1.8	1.2	*1*	*3.6*	*4.2*
Digitaria brownii	tg	0.4	0.8	0.4	*0.4*	*1.6*	0.8
Einadia nutans subsp. *eremaea*	f				0	0	0.4
Enneapogon polyphyllus	tg	***4.2***	*5.4*	*2.4*	***3.2***	*5.6*	*4.4*
Eragrostis eriopoda	tg	*0*	0.4	*2.2*	***1.2***	2	*2.8*
Eremophila glabra subsp. *glabra*	s	***1.8***	*0.2*	*0*	*0*	*1.2*	0
Eremophila latrobei subsp. *latrobei*	s	0.2	0	0			
Eremophila longifolia	s	0	1.2	0.4	*0*	*1.2*	1
Eremophila platythamnos	s	**1.4**	1.2	0	0	1	0.8
Eriachne aristidea	tg	0	0.4	0	*0*	*1.2*	0
Eriachne helmsii	tg	0.2	0	0	0.2	0.4	0.4
Eucalyptus gongylocarpa	t	0	1.6	0			
Eucalyptus oxymitra	ms	0	0.4	0	0	0	0.4
Euphorbia ferdinandii	f	***4***	*0.8*	*0*	***1.2***	*1*	*0*
Euphorbia tannensis	f	0.8	0.4	0	0.4	0.2	0
Exocarpos sparteus	s	0.6	0	0			
Glischrocaryon aureum	ss	0.2	0.2	0.2			
Gompholobium simplicifolium	s	0	0.2	0			
Goodenia glabra	f	***2.4***	*1.4*	*0*	0	0.4	0
Goodenia mueckeana	f	***2***	*0.6*	*0*	0	0.6	0
Grevillea juncifolia subsp. *juncifolia*	s	***3.6***	*1.6*	*0.4*	*0*	*2*	0.6
Jasminum calcareum	s	0	0.2	0			
Lawrencella davenportii	f	***3***	*0*	*0*	***1.6***	*0*	*0*
Lepidium phlebopetalum	f	0.2	0	0	0.4	0	0
Leptosema chambersii	ss	***3.6***	*0*	*0.6*	0	0	0.6
Leucochrysum sp.	f	0.4	0	0			
Leucochrysum stipitatum	f	***3***	*1*	*0*	0	0.8	0
Lobelia heterophylla subsp. *centralis*	f	0	1.2	0	*0*	*3.2*	0.4
Logania centralis	ss	0.2	0	0			
Micromyrtus flaviflora	s	***2.4***	*0*	*0*			
Minuria leptophylla	f	***2.8***	*1.8*	*0.4*	*0.8*	*1.6*	*2.2*
Monachather paradoxus	tg	1.2	0	0	0.8	0.4	0.2

Appendix 1. (*continued*)

Species	Growth-form	Flowering			Fruiting		
		Sep	Jan	May	Sep	Jan	May
Olearia subspicata	s	*1.8*	*0*	0	0.2	0.2	0
Panicum effusum	tg	*0.6*	*1.6*	0.4	*0.2*	*1.6*	0.8
Paraneurachne muelleri	tg	**1.4**	0.2	0.4	**1**	0.6	1.2
Paspalidium reflexum	tg	*0.6*	*2.2*	0.8	*1*	*2.8*	*3*
Pimelea trichostachya	f	1.2	0.8	0			
Podolepis canescens	f	***2.8***	*2.2*	*0.2*	*0*	*2.2*	0.2
Prostanthera althoferi subsp. *longifolia*	s	0.4	0	0	0	0.2	0.4
Prostanthera striatiflora	s	***2.2***	*0*	*0*	*0*	*1.4*	0
Ptilotus nobilis subsp. *nobilis*	f	0.6	0	0			
Ptilotus obovatus var. indeterminate	ss	1.2	0	0.4	0.4	0	0
Ptilotus polystachyus	f	***5.6***	*1.6*	*0.2*	***3.4***	*1.6*	*0.2*
Ptilotus sessilifolius	ss	***2.4***	*1.6*	*0.8*	**0.8**	1.2	0.6
Salsola tragus subsp. *tragus*	f	0	0.6	0.2	0	0.2	0.2
Scaevola basedowii	ss	0	0.8	0.4	0	0.4	0
Sclerolaena johnsonii	f	**1.8**	2	1.2	***1.6***	*3*	*2.6*
Senecio gregorii[A]	f	0.2	0	0			
Senna artemisioides subsp. *artemisioides*	s	1.6	0	0	0	0	0.4
Senna artemisioides subsp. *petiolaris*	s	***2.2***	*1.2*	*0*	0	0.2	0
Senna pleurocarpa var. *pleurocarpa*	s	***2.2***	*0*	*0*	0	0.6	0
Sida sp. Pindan	ss				0	0.4	0
Sida ammophila	f	0	0.4	0	0.2	0.8	0
Solanum centrale	ss	0.6	0	0			
Solanum coactiliferum	ss	0	0	0.4			
Solanum ferocissimum	ss	0.2	0	0	0	0	0.8
Solanum orbiculatum subsp. *orbiculatum*	ss	0.2	0	0			
Solanum quadriloculatum	ss	0.4	0	0			
Stackhousia megaloptera	ss	0.2	0.6	0	0	0.6	0
Stenopetalum lineare var. *lineare*	f	0.2	0	0	0.2	0	0
Swainsona affinis	f	*2.2*	*0.4*	*0*	0.6	0.4	0
Synaptantha tillaeacea var. indeterminate	f	0.2	0	0			
Triodia schinzii	hg	*0*	*6.4*	0	*0*	0.8	*4.8*
Vittadinia sp.	f	0	0	0.2	0	0.8	0.4
Wahlenbergia tumidifructa	f	0	0.2	0	0	0.2	0
Xerochrysum bracteatum	f	0.6	0.6	0	0	1	0

[A]Note: this taxon was previously recognised as *Othonna gregorii*; that name is no longer current.

ATTACHMENT I:

POPULATION DYNAMICS OF DASYURID MARSUPIALS IN DRYLAND AUSTRALIA: VARIATION ACROSS HABITAT AND TIME

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Austral Ecology (2020) 45, 283–290

Austral
ECOLOGY A Journal of ecology in the Southern Hemisphere

Austral Ecology (2020) **45**, 283–290

Population dynamics of dasyurid marsupials in dryland Australia: Variation across habitat and time

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Abstract The irruptive population dynamics of rodents are a globally renowned wildlife phenomenon; however, the dynamics of other small mammals with which rodents are sympatric are poorly understood. Dryland Australia supports a high diversity of small (<200 g) arthropod-eating marsupials (Dasyuridae). Here, we test the hypothesis that dasyurid marsupials do not exhibit the same degree of irruptive population dynamics that are shown by rodents. We addressed this question by sampling small mammal assemblages on 20 permanent trapping sites in the Simpson Desert on 20 occasions from 2007 to 2017. Sampling was stratified across three broad habitat types: sandridge, gibber plain and clay plain. We captured 478 dasyurid marsupials of nine species, ranging in mean body mass from 5.75 to 93.50 g, at a capture rate of 1.71 per 100 trap-nights. Capture rate varied across habitat and over time and the interaction between these two effects was also significant. Capture rate was highest on clay plain (3.35 captures/100 trap-nights), followed by gibber plain (2.16 captures/100 trap-nights) and lowest on sand habitat (0.54 captures/100 trap-nights). Each species had a clear preference for one of the dominant habitat types. Dasyurid assemblages responded to high rainfall pulses in November–December 2008 and January 2015; however, the largest rainfall period in 2010–2011 resulted in very low captures. Likewise, a peak in abundance occurred in April 2008 although it was not preceded by high rainfall. We conclude that, although dasyurid marsupial capture rates varied up to 34 fold during the study period, population changes are not strongly tied to rainfall. Heterothermic physiology in this family, in particular the ability to use daily torpor to save energy, may be central to the decoupling of population dynamics from rainfall-driven primary productivity.

Key words: clay, Dasyuridae, gibber, heterothermy, rainfall.

INTRODUCTION

The population fluctuations of herbivorous rodents, featuring cycles with peaks in abundance interspersed with longer periods of low population size, are a widely known and intensively researched phenomenon especially in northern temperate ecosystems (Blair 1953; Krebs 1988, 2013). In contrast, the population dynamics of the insectivorous and carnivorous small mammals with which rodents are sympatric are poorly understood (e.g. Boonstra *et al.* 2001). Rodents are sympatric with members of the Insectivora across the globe except in Australia and Papua New Guinea where the Dasyuromorphia (so-called 'carnivorous marsupials', although most species predominantly consume invertebrates) occur and species of Insectivora are absent. There is some evidence that these groups can undergo population irruptions that are similar to sympatric rodent populations. For example, the abundance of shrews (Soricidae) from 1999 to 2010 in the Serengeti savanna ecosystem showed moderate population peaks, synchronous with but with a lower magnitude than that of sympatric rodents, in three of the years of sampling (Byrom *et al.* 2014).

In dryland Australia, rodents with irruptive dynamics (Newsome & Corbett 1975; Dickman *et al.* 1999; Pavey *et al.* 2017) occur in sympatry with a high diversity of arthropod-eating marsupials (Dasyuridae) all the extant species of which are <200 g in body mass (van Dyck & Strahan 2008). Some of these species also consume small vertebrates including frogs, reptiles (mostly small lizards), birds and mammals; however, vertebrates typically make up less than 10% of the diet (Dickman 2014). These assemblages represent the most species rich-mammal insectivore–carnivore assemblages in drylands globally (Dickman 2003). The reproductive capacity of dasyuromorph marsupials is relatively fixed and has been hypothesised to limit immediate responses to resource pulses (Dickman *et al.* 2001). However, several species of Dasyuridae occurring in sandridge desert in central

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Accepted for publication November 2019.

doi:10.1111/aec.12854

Australia exhibit population fluctuations that, as with the shrews in the Serengeti, are relatively muted by comparison with sympatric rodents (Dickman *et al.* 2001; Greenville *et al.* 2016; Bennison *et al.* 2018). Larger species (>100 g) of dryland dasyurids, including two species included in the current study, are more likely to show responses to peaks in resource availability than smaller species (<100 g). Larger species eat a high number of rodents during resource pulses and their numbers increase in response to rodent population irruptions (Greenville *et al.* 2016).

Whether the population dynamics of dasyurid marsupials in dryland Australia varies among habitats has not been examined. In addition to the environments dominated by sand substrates (sandridge and sand plains), the drylands of Australia also feature extensive areas of gibber plain (desert pavement) and clay plains (Mabbutt 1977; Isbell 1996; Fujioka *et al.* 2005). Among these three environments, the two that show the greatest vegetative response to pulses of rainfall are clay plain and gibber plain. In comparison, sandridges show greater compositional stability of vegetation (less differentiation within and between the pre- and high rainfall phases) and higher productivity (plant species richness, diversity and abundance) through time (Nano & Pavey 2013). The rodent species that occupy gibber and clay plains demonstrate dramatic population fluctuations over time (Letnic & Dickman 2010; Pavey & Nano 2013; Pavey *et al.* 2014). The greater variation in resource availability in these environments suggests that the resident dasyurid species on gibber and clay plain may be more likely to exhibit peaks and troughs in population size in response to resource variation than those on sand environments.

The aim of this research was to examine variation in the population dynamics of an assemblage of dasyurid marsupials across three major environments at a regional scale in the Simpson Desert, central Australia. We sought to determine whether population dynamics changed over time and among habitats. We did this by collecting a long-term (10 year) data set and examining changes in populations of a diverse assemblage across the three major regional environments: sandridges, gibber plain and clay plain. We predicted that population fluctuations, if they did occur, would be greatest on gibber and clay plains, the two environments with the highest vegetative response to pulses of rainfall.

METHODS

Study area

The study area of approximately 7000 km^2 is located on Andado Station in the Simpson Desert, south-east of Alice Springs, Australia. This environment is dominated by long periods with low resource availability and daily extremes in temperature ranging from summer maximums of >40°C and winter minimums <5°C. The region's climate features an irregular periodicity and low predictability of rainfall. More details of the climate and rainfall are provided in Pavey *et al.* (2014).

Trapping

The abundance and composition of the dasyurid marsupial assemblage were assessed by repeatedly sampling permanent sites using collapsible aluminium box traps (Elliott Scientific Co., Upwey, Vic., Australia). We used 20 permanent sites across the study area with each site consisting of 25 box traps set in a 5 × 5 formation with 20 m between adjacent traps.

Trapping was carried out from October 2007 to July 2017 on 20 separate occasions. However, no trapping was carried out from May 2011 to March 2013 except for one occasion (December 2012) when only 10 sites were trapped. During May 2011, we discovered that an irruptive rodent the long-haired rat (*Rattus villosissimus*) was breaking into our traps and consuming animals (C. Pavey, unpubl. data, 2011); therefore, we discontinued trapping for ethical reasons. When we recommenced trapping in December 2012, we found that *R. villosissimus* was still present so we waited till 2013, when *R. villosissimus* was no longer present, to recommence the trapping programme.

Trapping sites were set-up in two blocks, each consisting of 10 sites, to ensure spatial replication. The two blocks were separated by a distance (at the closest point) of 30 km. Within each block, three habitat types were sampled: sandridge (four trapping sites), gibber plain (four sites) and clay plain (two sites). All sites were trapped during each of the 20 sampling periods with several exceptions as a consequence of site inaccessibility after flooding.

Traps were baited with a mixture of peanut butter and rolled oats and left open for two to four nights per session. In total over the entire study, we sampled for 27 991 trap-nights (1 trap-night = 1 trap open for one night).

Analyses

We compared changes in the relative abundance of dasyurid marsupials across sampling sessions by calculating the capture rate per 100 trap-nights for each sampling session at each site. Data are shown as the mean capture rate per 100 trap-nights ± SE (standard error).

We used multivariate models to test hypotheses regarding changes over time at assemblage and species levels. We used PERMANOVA (PRIMER 7 software package with PERMANOVA + add-on, Anderson *et al.* 2008) to test for temporal and spatial effects on dasyurid marsupials. For this analysis, we initially used a four-factor design with habitat (sand/gibber/clay) as a fixed factor and time (T1–T20) as a random factor. Block was also a random factor. To account for the repeated sampling of our trapping sites, site (1–20) was included as a random factor in the model nested within

doi:10.1111/aec.12854

habitat and block. After running the initial model, the variable block was found to have a large P value ($P > 0.5$); therefore, we pooled this variable and re-ran the model. As a result, the final model was a three-factor design with habitat as a fixed factor, time as a random factor and site as a random factor nested within habitat. The dependent variable was capture rate per 100 trap-nights per site per sampling session.

A resemblance matrix was constructed using the zero-adjusted Bray–Curtis similarity measure (i.e. a dummy variable with a value of 1 was added prior to computing similarities in Bray–Curtis; Clarke & Gorley 2015). The data were forth root transformed prior to analysis. For our permutation method, we selected permutation of residuals under a reduced model, with Type I (partial sum of squares) and 9999 permutations. Type I sum of squares was used because the design was unbalanced featuring unequal replication across habitats. Because the sampling design involved no replication at the level of site, the most complex interaction term (time × site (habitat)) was excluded from the analysis. Pairwise tests were run for the levels of significant fixed factors.

We used a chi-square test of independence to examine, for each of the species of dasyurid with 10 or more captures, whether there was a significant relationship between number of captures and capture effort (measured as the number of trap-nights) across the three habitat types. For this analysis, we used total number of captures of the species in the specific habitat and total number of trap-nights of effort in that habitat (as given in Table 1). We examined the correlation between capture rate for a given sampling period and rainfall in the previous (i) 6 months and (ii) 12 months using the Spearman rank order correlation coefficient.

RESULTS

During the study, we captured a total of 478 dasyurid marsupials from nine species (Table 1). Given that there were 27 993 trap-nights over the duration of the study period this represented a capture rate of 1.71 animals per 100 trap-nights. The species ranged in mean body mass from the 5.75 g Giles' planigale (*Planigale gilesi*) to the 93.50 g crest-tailed mulgara (*Dasycercus cristicauda*). Four of these species were captured less than 10 times whereas the most commonly captured marsupials were the fat-tailed dunnart (*Sminthopsis crassicaudata*) (170 captures) and the kultarr (*Antechinomys laniger*; 120 captures).

The capture rate of dasyurid marsupials varied across the study period as did monthly rainfall (Fig. 1). However, capture rate was not correlated with rainfall over the previous 6 months or 12 months (Spearman rank order correlation, $P = 0.127$ and $P = 0.461$ for 6 and 12 months, respectively). Overall capture rate showed a 34-fold variation from lowest (0.15 captures/100 trap-nights, June 2013) to highest (5.11 captures/100 trap-nights, September 2015). The peak in September 2015 followed high rainfall in January of that year and represented the capture of 73 individuals; 15% of captures for the entire study. The second highest peak in capture rate was in April 2008 (3.11 captures/100 trap-nights); a period that did not follow a high rainfall pulse (Fig. 1). Capture rate was also high in June 2009 at 3.00 captures/100 trap-nights; this followed high rainfall in late 2008.

Capture rates of less than 1 animal per 100 trap-nights occurred on four occasions including a sequence of three consecutive sampling periods in December 2010 (0.75 captures/100 trap-nights), May 2011 (0.36 captures/100 trap-nights) and June 2013 (Fig. 1). The trend for low captures during this period was confirmed in December 2012 when we trapped only one block (10 trapping sites) and captured a single *A. laniger* over 633 trap-nights (capture rate of 0.16 per 100 trap-nights). The capture rate was also <1 in March 2015 (0.94 captures/100 trap-nights).

Capture rate varied across each of the three habitats sampled being highest on clay plain (3.35 captures/100 trap-nights), followed by gibber plain (2.16 captures/100 trap-nights) and lowest on sand habitat (0.54 captures/100 trap-nights). In contrast, species richness was highest on sand (eight species) with four species on each of gibber and clay plain (Table 1). The largest fluctuations in capture rate over time occurred on clay plain followed by gibber plain (Fig. 2). Captures on sand remained consistently low over time.

Each of the five species that was captured >10 times had a clear preference for one of the three dominant habitat types (Table 1) and was not captured in similar proportion to trapping effort across the three habitats (chi-square test of independence, $P < 0.001$ for each species). *Dasycercus cristicauda* was only captured on sandridges. The brush-tailed mulgara (*D. blythi*) occurred predominantly on gibber plain with 14 of 86 captures on sand and two captures on clay plain. *Antechinomys laniger* was also captured predominantly on gibber plain with 7% of captures on sand but none on clay plain. In contrast, *S. crassicaudata* occurred predominantly on clay plain with a smaller number of captures (22%) on gibber plain and only two captures on sandridges. Only the stripe-faced dunnart (*S. macroura*) had a similar number of captures on clay plain and gibber plain; however, its capture rate was much higher on clay plain because of the lower trapping effort there (0.679 and 0.237 captures/100 trap-nights on clay and gibber plain, respectively).

PERMANOVA results using the capture rate of all species combined showed that both main effects of habitat and time were significant (Table 2). Given that the unbalanced design of sampling necessitated the

 doi:10.1111/aec.12854

Table 1. A list of each species of carnivorous marsupial captured at Andado Station in the Simpson Desert, Australia, from 2007 to 2017 including mean body mass, total number of captures, and captures in each of the three habitats sampled and overall capture rate. Data on body mass are for the study populations

Species	Mean body mass (g)	Number of captures	Captures by habitat (number of trap-nights) Sandridge (11 572)	Gibber plain (11 409)	Clay plain (5 010)	Overall capture rate (captures/100 trap-nights)
Dasycercus blythi	68.61	86	14	70	2	0.31
D. cristicauda	93.50	25	25	0	0	0.09
Planigale gilesi	5.75	2	0	0	2	0.01
Antechinomys laniger	20.11	120	8	112	0	0.43
Sminthopsis crassicaudata	12.34	170	2	38	130	0.61
S. hirtipes	14.00	5	5	0	0	0.02
S. macroura	13.14	62	1	27	34	0.22
S. ooldea	12.00	1	1	0	0	<0.01
S. youngsoni	8.90	7	7	0	0	0.03
Total		478	63	247	168	1.71

use of type I (i.e. sequential) sums of squares, the sequence of the main effects may have influenced the results. As a consequence, we repeated the analysis and changed the order of the main effects. However, the results did not change.

The main effect of site nested within habitat was also significant. In addition, the interaction of habitat and time was significant (Table 2). Pairwise tests showed that each of the three pairs of habitat types was significantly different.

At the species level, the commonest species, *S. crassicaudata* (Table 1), had a peak in capture rate on clay plain in September 2015 at 14.90 captures/100 trap-nights ($N = 40$). Captures of this species drove the peak in dasyurid abundance in September 2015; 54 of the 73 dasyurid captures in September 2015 were of *S. crassicaudata* with 40 of these captures occurring at the four sites on clay plain (Fig. 3). Because of this strong effect of *S. crassicaudata*, the PERMANOVA analysis was repeated but with *S. crassicaudata* removed. In this case, the time by habitat interaction was no longer present but the direction and strength of other effects remained.

DISCUSSION

The assemblage of dasyurid marsupials assessed in the Simpson Desert, Australia, showed variation in abundance through time with an inconsistent response across environments. Abundance showed a 34-fold variation across the 20 sampling sessions from a low of 0.15 captures/100 trap-nights in June 2013 to a peak of 5.11 captures/100 trap-nights in September 2015. However, the capture rate of carnivorous marsupials did not show a clear relationship with rainfall (Fig. 1). Some large rainfall events (defined as at least 1 month with >100 mm of rainfall) resulted in a lagged increase in numbers, such as when a large rainfall event in November-December 2008 was correlated with a peak in captures in June 2009 and another such event in January 2015 was correlated with the highest peak of captures in September 2015. However, at other times there was asynchrony between rainfall and capture rate, most notably during and after the widespread, high rainfall of 2010 and 2011 (Wardle *et al.* 2013). The capture rate was less than 1 capture per 100 trap-nights between May 2010 and September 2014. Asynchrony between rainfall and dasyurid marsupial abundance also occurred in April 2008 with the second highest capture rate of the study being recorded in the absence of a large rainfall event (Fig. 1). A similar peak in abundance of a sympatric small rodent, *Pseudomys hermannsburgensis*, also occurred in April 2008 (Pavey & Nano 2013). Previous research in dryland Australia has generally failed to find evidence of a strong positive relationship between capture rate of dasyurid marsupials and antecedent rainfall, rather it has indicated the presence of more subtle or local-scale factors influencing population dynamics (Dickman *et al.* 2001; Greenville *et al.* 2016). Local-scale factors potentially operating include site-specific temporal differences in prey availability and availability of shelter and foraging sites (Kwok *et al.* 2016; Molyneux et al. 2018a,b).

Our research revealed that the assemblage of dasyurid marsupials consisted of species each with a clear preference for one of the three major environments sampled. No species was captured in similar proportion to trapping effort across the three environments. The largest species in the assemblage, *D. cristicauda*, was captured only on sandridges. The majority of captures of *D. blythi* (81%) and *A. laniger*

doi:10.1111/aec.12854

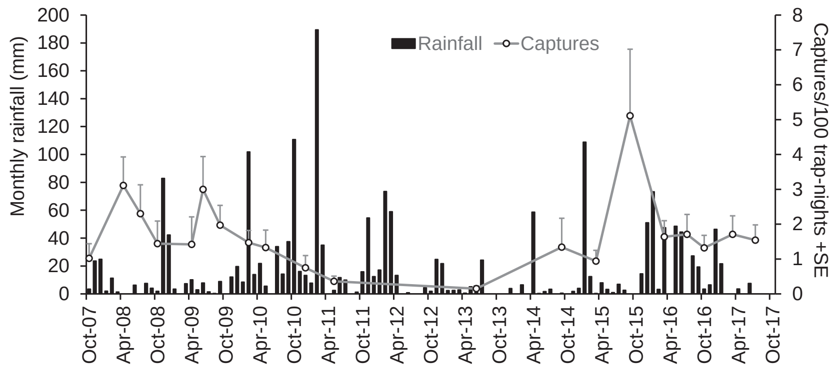

Fig. 1. Time series of fluctuations in monthly rainfall (mm) and relative abundance (capture rate per 100 trap-nights, mean across all sites trapped during a given sampling period) of dasyurid marsupials at Andado Station, Simpson Desert, Australia, from 2007 to 2017.

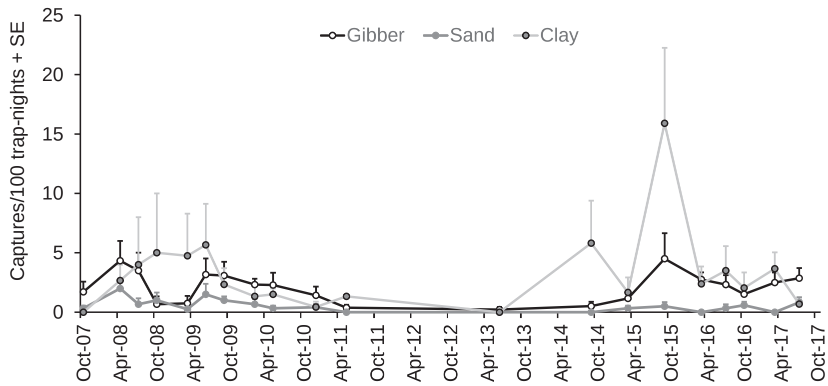

Fig. 2. Capture rate of dasyurid marsupials at Andado Station, Simpson Desert, Australia, from 2007 to 2017, showing the relative contribution of captures (capture rate per 100 trap-nights, mean across all sites trapped in a given habitat during a given sampling period) in each of gibber plain, sandridge and clay plain.

Table 2. Results of PERMANOVA analysis of variation in capture rate of dasyurid marsupials at Andado Station in the Simpson Desert, Australia, from 2007 to 2017, with main effects of habitat, time and site (nested within habitat)

Source	d.f.	SS	MS	Pseudo-*F*	*P* (permuted)
Habitat	2	34 651	17 326	7.21	0.001
Time	19	18 000	947	1.86	0.001
Site (habitat)	17	27 640	1625	3.19	0.001
Time × habitat	38	33 278	875	1.73	0.001

(93%) were on gibber plain, whereas most captures of *S. crassicaudata* (76%) were on clay plain. Only one species, *S. macroura*, was captured in similar numbers on gibber and clay plain; however, capture rate was over double on clay plain (Table 1). In addition, all four of the rare (<10 captures) species were trapped in a single environment; three species of *Sminthopsis* in sand and *P. gilesi* on clay plain (Table 1). These preferences are consistent with published information on habitat use in each species (e.g. Dickman *et al.* 2001; Haythornthwaite 2005; van Dyck & Strahan 2008; Pavey *et al.* 2011; Waudby & Petit 2017; Molyneux *et al.* 2018a).

The effect of habitat on capture rate of dasyurid marsupials was inconsistent through time and space. As predicted at the outset of the study, of the three environments we assessed, it was those that show the greatest vegetative response to high rainfall events, that is clay plain and gibber plain (Nano & Pavey 2013) that had the highest capture rates and experienced the greatest fluctuations in capture rates over time (Fig. 2). Sandridges, the most stable habitat in

doi:10.1111/aec.12854

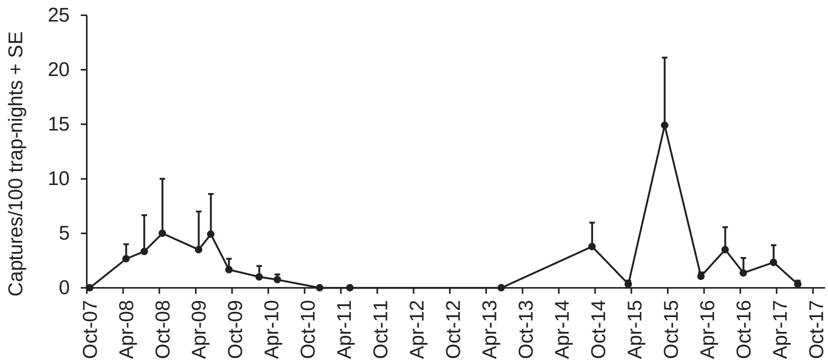

Fig. 3. Time series of relative abundance (capture rate per 100 trap-nights, mean across all sites trapped during a given sampling period) of fat-tailed dunnart, *Sminthopsis crassicaudata* on clay plain at Andado Station, Simpson Desert, Australia, from 2007 to 2017.

terms of composition of vegetation, had a relatively low capture rate over time. The more dramatic population fluctuations by dasyurid marsupials on gibber and clay (especially *S. crassicaudata*) are likely to have resulted from increases in reproductive output and survival rates following the significant increases in resource availability after high rainfall events.

Our study also demonstrated significant variability among sites in capture rate of dasyurid marsupials; the main effect of site nested within habitat was highly significant. This result points to variation in species abundance at fine spatial scales across the study area as a result of site effects irrespective of habitat or time. Our finding is in agreement with the work of Greenville *et al.* (2016) who reported that drivers for sub-populations of three dasyurid species were acting on a local rather than a regional scale.

As noted above, the response of the dasyurid assemblage to rainfall was inconsistent across time and habitat. The most notable mismatch occurred between May 2010 and September 2014 when capture rate was very low despite the high rainfall. A number of potential explanations may account for this trend. First, we note that the high rainfall period of 2010–2011 was at the upper extreme of recorded rainfall in dryland Australia (Wardle *et al.* 2013; Harris *et al.* 2018) and may have represented a challenge for local-scale persistence of populations even for species adapted to ecosystems that experience high natural variability in rainfall and resource availability. For example, populations, especially on clay and gibber plains, may have been flooded and subsequently had to recolonise from outside the area. In addition, the area experienced an irruption of *R. villosissimus*, from December 2010 to December 2012 (Pavey & Nano 2013) which was part of an irruptive event of the species across the Simpson Desert and into south-west Queensland (D'Souza *et al.* 2013; Greenville *et al.* 2013). The occurrence of the *R. villosissimus* irruption on Andado Station encompassed the sampling periods with a very low capture rate of carnivorous marsupials. *Rattus villosissimus* is a large (body mass to 280 g), burrowing species that occupied most of our trapping sites by May 2011 (C. Pavey, unpubl. data, 2011). The low capture rate of dasyurid marsupials may have resulted from competition with and/or predation from *R. villosissimus* as dispersing individuals attempted to recolonise gibber and clay plains. Negative impacts from the two large predatory *Dasycercus* species (*D. blythi* and *D. cristicaudata*), which are known to suppress populations of lesser hairy-footed dunnart (*S. youngsoni*; Dickman 2014) may also be an important factor explaining the low number of captures of smaller species of dasyurid marsupial in the current study. As an alternative explanation, the low capture rate may be an artefact of high food availability following high rainfall which could have resulted in a reduction in trapability of all species of carnivorous marsupial.

All dasyurid species captured in our study are known to use torpor to save energy during periods of low food availability especially during cooler weather (Geiser 2004; Warnecke & Geiser 2009; Körtner & Geiser 2011; Körtner *et al.* 2016). It has been estimated that a combination of daily torpor and basking during rewarming can reduce the daily energy expenditure of arid zone dasyurids by about 50% (Geiser & Pavey 2007). The ability to decouple from a direct reliance on primary productivity driven by rainfall is an important adaptation in dryland environments with unpredictable rainfall. It is a plausible explanation for the absence of a tight relationship between capture rate and rainfall in the dasyurid marsupials of the Simpson Desert. The ability to use torpor enables individuals to persist when food availability is limited during prolonged dry periods and contributes, along with reproductive constraints, to populations showing a more muted response to resource pulses.

In contrast, rodents in dryland Australia have not been recorded using torpor (Geiser 2004) and appear

doi:10.1111/aec.12854

unable to decouple from a direct reliance on primary productivity. Although rodents elsewhere in the world do undertake torpor, there appears to be a consistent difference in thermal physiology between rodents and sympatric insectivorous species of small mammal (Lovegrove 2012; Hoole *et al.* 2018). Understanding the role of thermal physiology in enabling persistence of carnivorous marsupials in environments with unpredictable resource availability is a topic requiring further investigation.

ACKNOWLEDGEMENTS

Financial support was provided by Northern Territory Resource Management/Territory Natural Resource Management (project numbers: CFOC 2007/132, NTRM 00139, NTRM 00241, TNRM00432, TNRM 00528). We are grateful to Raquel, Peter, Colleen and Donny Costello for allowing us access to Andado Station. We thank John and Liz Spencer, Bob Stewart, and a number of other caretakers for hospitality during our stays at Old Andado and to Meegan Sullivan for facilitating out stays there. We are grateful for the field assistance provided by many dedicated people over the 10 years of research in particular Jeff Cole, Peter McDonald, Lauren Young and Alistair Stewart. Marti Anderson provided statistical advice. Ethics approval was obtained from Charles Darwin University Animal Ethics Committee (number A07010) and CSIRO (numbers 2012-03 and 2015-18).

AUTHOR CONTRIBUTIONS

Conceptualization-lead, data curation-lead, formal analysis-lead, funding acquisition-lead, investigation-lead, methodology-lead, project administration-lead, resources-lead, writing-original draft-lead, writing-review & editing-equal: C.P. Conceptualization-supporting, data curation-supporting, formal analysis-supporting, investigation-supporting, project administration-supporting, writing-original draft-supporting, writing-review & editing-equal: C.N. Project administration-supporting, resources-supporting, supervision-supporting, writing-original draft-supporting, writing-review & editing-supporting: M.W.

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doi:10.1111/aec.12854

ATTACHMENT J:

THE ROLE OF REFUGES IN THE PERSISTENCE OF AUSTRALIAN DRYLAND MAMMALS

Pavey, C.R., Addison J., Brandle R., Dickman C.R., McDonald P.J., Moseby K.E. and Young L.I.

Biological Reviews (2017), 92, pp. 647–664.

BIOLOGICAL REVIEWS

Cambridge Philosophical Society

Biol. Rev. (2017), **92**, pp. 647–664.
doi: 10.1111/brv.12247

The role of refuges in the persistence of Australian dryland mammals

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ABSTRACT

Irruptive population dynamics are characteristic of a wide range of fauna in the world's arid (dryland) regions. Recent evidence indicates that regional persistence of irruptive species, particularly small mammals, during the extensive dry periods of unpredictable length that occur between resource pulses in drylands occurs as a result of the presence of refuge habitats or refuge patches into which populations contract during dry (bust) periods. These small dry-period populations act as a source of animals when recolonisation of the surrounding habitat occurs during and after subsequent resource pulses (booms). The refuges used by irruptive dryland fauna differ in temporal and spatial scale from the refugia to which species contract in response to changing climate. Refuges of dryland fauna operate over timescales of months and years, whereas refugia operate on timescales of millennia over which evolutionary divergence may occur. Protection and management of refuge patches and refuge habitats should be a priority for the conservation of dryland-dwelling fauna. This urgency is driven by recognition that disturbance to refuges can lead to the extinction of local populations and, if disturbance is widespread, entire species. Despite the apparent significance of dryland refuges for conservation management, these sites remain poorly understood ecologically. Here, we synthesise available information on the refuges of dryland-dwelling fauna, using Australian mammals as a case study to provide focus, and document a research agenda for increasing this knowledge base. We develop a typology of refuges that recognises two main types of refuge: fixed and shifting. We outline a suite of models of fixed refuges on the basis of stability in occupancy between and within successive bust phases of population cycles. To illustrate the breadth of refuge types we provide case studies of refuge use in three species of dryland mammal: plains mouse (*Pseudomys australis*), central rock-rat (*Zyzomys pedunculatus*), and spinifex hopping-mouse (*Notomys alexis*). We suggest that future research should focus on understanding the species-specific nature of refuge use and the spatial ecology of refuges with a focus on connectivity and potential metapopulation dynamics. Assessing refuge quality and understanding the threats to high-quality refuge patches and habitat should also be a priority. To facilitate this understanding we develop a three-step methodology for determining species-specific refuge location and habitat attributes. This review is necessarily focussed on dryland mammals in continental Australia where most refuge-based research has been undertaken. The applicability of the refuge concept and the importance of refuges for dryland fauna conservation elsewhere in the world should be investigated. We predict that refuge-using mammals will be widespread particularly among dryland areas with unpredictable rainfall patterns.

Key words: refugia, mammal, rodent, dasyurid marsupial, irruptive dynamics, arid, dryland.

CONTENTS

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I. INTRODUCTION

Arid or dryland environments comprise just over 37% of the world's land mass (Warner, 2004) with much of this area characterised by unpredictable precipitation patterns. This unpredictable precipitation produces unpredictability in cycles of resource availability which in turn have profound impacts on dryland biota (Ostfeld & Keesing, 2000; Yang *et al.*, 2008, 2010). As a consequence, a significant component of dryland-dwelling fauna is characterised by irruptive population dynamics, with population abundance tracking changes in the availability of key resources (Jaksic *et al.*, 1997; Letnic & Dickman, 2010; Meserve *et al.*, 2011). Irruptive population dynamics are driven by periods of high precipitation that lead to increased germination and growth of ephemeral, annual and perennial plant species (Ostfeld & Keesing, 2000). These pulses in primary productivity result in increases in both reproduction and survivorship of folivorous, granivorous and omnivorous fauna and lead to population irruptions in these species after time lags of several months to a year (Previtali *et al.*, 2009; Letnic & Dickman, 2010; Shenbrot, 2014).

Irruptive population dynamics are characteristic of a wide range of dryland-dwelling fauna (e.g. Yang *et al.*, 2008; Atkinson *et al.*, 2014) and may arise in several ways. For example, periods of prolonged precipitation may break dormancy in animals with resting stages in their life history (e.g. many invertebrates; Crawford, 1981) or elevate the metabolic rates of animals that are aestivating (e.g. burrowing frogs; Hillman *et al.*, 2009), in turn providing opportunities for population growth *via in situ* reproduction. By contrast, more-mobile fauna such as birds may move into dryland areas following heavy precipitation events, achieving irruptions over local or regional areas initially by immigration and then by reproduction (Dean, 2004). Other animals may irrupt if widespread precipitation events improve conditions over large regional areas, allowing them to move from discrete refuge sites into the broader dryland environment (Newsome & Corbett, 1975; Morton, 1990). This latter strategy has perhaps been used most often to explain the irruptive dynamics of dryland mammals (Letnic & Dickman, 2010; Pavey *et al.*, 2014*b*), although many other taxa with local dispersal abilities appear to exhibit similar dynamical patterns.

Among mammals, population irruptions are best known among rodents in many of the world's drylands (e.g. Newsome & Corbett, 1975; Fichet-Calvet *et al.*, 1999). Other dryland mammal groups that undergo irruptive dynamics include some lagomorphs, eulipotyphlans (e.g. Chung-MacCoubrey, Bateman & Finch, 2009) and several orders of marsupials (Dasyuromorphia, Didelphimorphia, Diprotodontia) (e.g. Dickman *et al.*, 2001; Lima *et al.*, 2001). Population irruptions of mammals and other vertebrates are often referred to as 'booms' or 'ratadas'.

Recent attention has focussed on the mechanisms by which irruptive species, particularly small mammals, are able to persist during the extensive dry periods of unpredictable length that occur between resource pulses in drylands. These periods are of considerable importance as resource pulses may occur as infrequently as once per decade. In the western Simpson Desert of central Australia, for example, it is estimated that the low (or bust) phase of mammal population cycles occupies 8.5 out of every 10 years (Pavey *et al.*, 2014*a*). In this region, as well as the drylands of southern Africa, India and South America where prolonged dry periods are punctuated by occasional high-precipitation events, many species drop to low population abundance or become locally extinct during these dry periods (Griffin, 1990; Tripathi, 2005; Moseby *et al.*, 2006). However, recolonisation occurs after heavy precipitation and the subsequent resource pulse, and the pattern of occurrence of a given species within the landscape is often one of local extinction and recolonisation events (Milstead *et al.*, 2007; Dickman *et al.*, 2011).

There is growing evidence that regional persistence of small mammal populations occurs as a result of the presence of refuge habitats or refuge patches into which populations contract during dry periods (Milstead *et al.*, 2007; Letnic & Dickman, 2010; Greenville, Wardle & Dickman, 2013; Pavey *et al.*, 2014*a*). These refuge areas act as a source of animals when recolonisation occurs during and after subsequent resource pulses (Naumov, 1975; Brandle & Moseby, 1999; Dickman *et al.*, 2011). Such refuge areas appear to occupy only a small portion of the landscape that is occupied during population outbreaks. For example, refuge habitats for the rodents *Oligoryzomys longicaudatus* and *Abrothrix longipilis* in north-central Chile occupied only about 2% of the study area (Milstead *et al.*, 2007). The term refuge is hereafter used to refer to these refuge habitats and patches, with drought used interchangeably with bust and low phase of population cycles.

Protection and management of refuges is increasingly recognised as a priority for the conservation of dryland-dwelling mammals and other fauna (Letnic & Dickman, 2010; Pavey *et al.*, 2014*a*). There is growing evidence that disturbance to refuges can lead to the extinction even of species that are abundant during population outbreaks (e.g. see Lockwood & DeBrey, 1990). In dryland Australia, for example, refuges can experience high levels of predation from introduced predators, such as the feral cat (*Felis catus*) and red fox (*Vulpes vulpes*), because they represent significant concentrations of biomass in a dry and resource-poor environment (Pavey *et al.*, 2014*a*). In dryland regions generally, refuge habitat is threatened by a range of other disturbances including farming, pastoralism and tourism (Bahre, 1979; Ayyad & Ghabbour, 1986; Seely & Pallett, 2008).

Despite the likely significance of refuges for the persistence of dryland fauna, there are few published empirical data on their characteristics or locations. Also of concern is that the term refuge is used frequently in the literature but is often not defined, or is poorly defined, and there is regular conflation between the terms 'refuge' and 'refugium' (e.g. Nekola, 1999; Davis *et al.*, 2013). With these shortcomings in mind, herein we aim to synthesise available scientific information on the refuges of dryland-dwelling fauna, using Australian mammals as a case study to provide focus, and to document a research agenda for increasing this knowledge base.

We begin this review by examining the use of the terms 'refuge' and 'refugium' in the literature and setting the refuges used by dryland fauna within this terminology. Next we provide a definition of, and develop a typology of, refuges. We then present three case studies of dryland-dwelling mammal species that illustrate the breadth of refuge types used and the variability in the level of ecological understanding across species.

We next present a three-step approach to locating refuges. The inclusion of a methodology section is driven by the lack of available information on refuge location and usage and the knowledge that all published descriptions of refuge habitats and/or patches indicate that these comprise a small proportion of the landscapes that they occupy (Brandle & Moseby, 1999; Milstead *et al.*, 2007; Pavey *et al.*, 2014*a*). Next, we assess potential threats faced by the different refuge types and consider how present-day refuge location may be influenced by the actions of threatening processes such as introduced predators in the recent past. Thus we consider the possibility that refuges may now be located in relatively threat-free habitats or habitat patches. We conclude this review by developing an ongoing research agenda for refuges. This agenda details the information that is needed to further our understanding of these important features of drylands.

II. USE OF THE TERM 'REFUGE' IN THE LITERATURE

(1) Concepts of refuge

The term 'refuge' is widely used in biology, but the term encompasses a range of divergent phenomena (Berryman & Hawkins, 2006). Various concepts based on the term are used in theories of ecology, biogeography, evolution and speciation. However, in many cases the term refuge is used erroneously when actually referring to refugia/refugium (see Section II.2 for clarification on the distinction of the two concepts).

In ecology, the term 'refuge' refers to the life history of species and how individuals within a population are able to survive despite the presence of predators and parasites (e.g. Elton, 1939). This view has been developed further within the discipline of population ecology so that refuge is an important aspect of predator–prey population dynamics (Berryman & Hawkins, 2006; Owen-Smith, 2008). The concept is also widely applied in insect pest management. In recent years, refuge has been applied in conservation science with potential refuges being important sites in conservation planning and in decision-science approaches. The term is also in common conservation parlance where it is sometimes used to denote areas that are legally protected from anthropogenic disturbance, especially hunting (Keppel *et al.*, 2012).

(2) Refuge *versus* refugium

The term 'refuge' is often used interchangeably with 'refugium' (or its plural 'refugia') in the literature (Keppel *et al.*, 2012). This conflation has created confusion about what each term refers to and is exacerbated by various definitions which mix process, pattern and mechanisms when defining and applying these terms. Several recent reviews have recognised these issues and sought to separate the two concepts.

A unifying feature in separating the two terms is that refugia are seen to operate at broader temporal and/or spatial scales than refuges. Specifically, a refuge is seen to operate over timescales of minutes to decades. By contrast, refugia operate on longer timescales of millennia (Keppel *et al.*, 2012). This separation of the two terms on the basis of time and the understanding that speciation in many taxa occurs over time frames of >100000 years (Lister, 2004) also enables a separation of the two concepts on the basis of the evolutionary processes that may operate. Therefore, refugia are locations where organisms can adapt to changing conditions in order to persist over time. Davis *et al.* (2013) extended these ideas to develop the complementary terms of ecological refuge and evolutionary refugia and went on to apply the terminology to aquatic habitats in arid Australia. Aquatic habitats with the greatest degree of decoupling of microclimate from regional climate were the most likely to function as evolutionary refugia (Davis *et al.*, 2013).

Keppel *et al.* (2012) developed a definition of refugia as sites to which organisms retreat, persist in and potentially expand from under changing environmental conditions. As indicated above, refugia have been identified as sites where the local climate is decoupled from the regional climate (Dobrowski, 2011) and, therefore, sites where a species can persist if the regional climate changes in an unfavourable direction. Thus the term refugia should be used when referring to range dynamics and climate change (Keppel *et al.*, 2012; Mackey *et al.*, 2012).

III. DEFINITIONS AND TYPOLOGY OF REFUGES

(1) Previous definitions

Refuges have been variously defined, but definitions have been poorly tested, are not scaled, or mix processes and patterns. For example, Morton & Baynes (1985) defined refuges as places where animal species can persist through drought owing to the existence of relatively dependable supplies of moisture and nutrients. Such a definition conflicts with those that emphasise structural elements that minimise predation risk (e.g. Morton *et al.*, 1995; Burbidge & Manly, 2002) or provide relief from fire effects (e.g. McDonald *et al.*, 2013). Definitions have largely precluded considerations of species-specific requirements (i.e. autecology), making it difficult to identify potential refuge-using species.

Some recent usage defines refuges at very fine spatial and temporal scales that are applicable to individual animals. Under this concept, a refuge is a location where an individual can escape from difficult circumstances, particularly predation, such as under a rock, into a burrow or an area of dense vegetation (e.g. Li *et al.*, 2014). Den sites, where an animal rests for the day or night or where it aestivates or hibernates, are also considered to be refuges. In the context of fire, refuges are defined as habitat features within a landscape that in the short term facilitate the survival or persistence of organisms in the face of a fire event that would otherwise result in their mortality, displacement or local population extinction (Robinson *et al.*, 2013).

(2) Definition of refuge used by irruptive mammals

Here we develop a definition of refuge that is based on Keppel *et al.*'s (2012) approach to defining and classifying refugia. Specifically, the approach involves a process-based definition, centred on species-specific requirements in a multidimensional domain of environmental variables, space and time. In the temporal dimension, we consider that refuges operate on timescales of decades or less. In the spatial dimension we consider that a refuge must be of sufficient area to support a local population of a species. Thus we do not consider refuges at the scale of the individual. Specifically, refuges are not only sites that provide protection from predation (see Berryman & Hawkins, 2006) but also enable a local population to persist.

We recognise that species with irruptive population dynamics are likely to be obligate refuge users, with the use of refuges between population irruptions analogous to species distributional changes over much longer timescales, such as during glacial cycles. These species are considered to be obligate refuge users because populations outside refuges during dry periods are expected to go extinct in a similar manner to populations outside refugia during times of climate change (Stewart *et al.*, 2010).

We define a refuge as a subset of the potential range of a species with irruptive population dynamics where a viable population persists during the low phase of the population cycle (i.e. the bust phase). We refer to a species with irruptive population dynamics as an irruptive species. An irruptive species is one that experiences population outbreaks that result in significant increases in both the area of occupancy and population size before contracting back to spatially restricted areas with specific habitat attributes.

In all documented cases, irruptions have been triggered by a pulse in primary productivity. Such pulses are often driven by precipitation but can also be driven by food moving in from outside the range of the irruptive species (e.g. desert locusts; Atkinson *et al.*, 2014).

(3) Refuge typology

Below we present a typology of refuge types. The aim is not to present a taxonomy of refuges but rather to show the variation that is currently understood in refuge types and to illustrate that refuges can have different temporal and spatial dynamics. As the refuge concept is more widely tested in the future it is probable that other refuge models will become apparent.

We recognise two main types of refuge: a shifting refuge and a fixed refuge. In addition, four potential types of fixed refuge are recognised. A shifting refuge has a set of intrinsic properties that make it more suitable than the surrounding landscape for limited periods of time (typically at a scale of weeks or months) for any one particular species. A fixed refuge has a set of intrinsic properties that make it consistently more suitable (typically on a scale of years or decades) than the surrounding landscape for any one particular species. Models of shifting and fixed refuges are given in Fig. 1 and are expanded upon below.

(*a*) *Shifting refuge*

Refuges are most commonly assumed to occur in fixed or predictable locations. In drylands, however, where moisture is critically important for life, refuges may shift from place to place over short time periods depending on the spatial variability of precipitation (Fig. 1, model 1). A species that exploits shifting refuges uses a large number of small and highly localised refuges, moving from one to another in rapid succession. In introducing the concept of shifting refuges, Newsome & Corbett (1975) recognised that these could be exploited only by animals that are both able to track ephemeral flushes of resources, as they are created by local precipitation events, and have the ability to access them by directed movement. Mobile organisms such as birds could be expected to exploit such spatially and temporally variable resources most effectively (e.g. Tischler, Dickman & Wardle, 2013), although Newsome & Corbett (1975) argued that some species of rodents could disperse sufficiently long distances to exploit temporary resource patches. This was confirmed by Dickman, Predavec & Downey (1995), who showed that three species of rodents and three species of dasyurid marsupials increased their movements during or just after rainfall, with most movements (74%) being directed to where rain had recently fallen.

(*b*) *Fixed refuge*

Fixed refuges are those that occur in predictable locations and that are used consistently over time. We describe four models of fixed refuge use. These differ on the basis of whether the species' use of the refuges is stable between and/or within busts (Fig. 1, models 2A–D). A species that uses fixed refuges that are stable between busts uses the same refuge patches across consecutive bust periods and also typically continues to occupy the same refuges during the intervening boom phase. A species that uses fixed refuges that are unstable between busts uses a different set of refuge patches from one bust period to the next bust period. Some of the refuge patches may be the same across busts, but not all. A species that uses fixed refuges that are stable within a bust occupies each of the refuge patches for the duration of the bust period, while a species with fixed refuges that are unstable within a bust period uses one or more of the refuge patches for only part of a bust period.

Based on these criteria, the four models of irruptive species usage of fixed refuges (Fig. 1, models 2A–D) are those that are: (A) stable within and between busts (model 2A); (B) unstable within busts and stable between busts (model 2B); (C) stable within busts and unstable between busts (model 2C); (D) unstable within and between busts (model 2D). Note that models 2A and 2B are based on the use of specific refuge patches (i.e. refuges are stable between busts), whereas models 2C and 2D rely on the importance of broad refuge habitat rather than patches (i.e. refuges change between busts).

The stability criteria for fixed refuge models (A) and (C) defined above do not preclude the possibility that individuals move from one occupied refuge to another within a bust. However, the movement of individuals is predicted to be bi-directional and a population continues to occupy each fixed refuge patch. If such movement does occur, then the refuges in a local area may function as a meta-population.

IV. CASE STUDIES OF REFUGE USE

Below we present three case studies of refuge use in small mammals. These species were chosen because of the significant amount of information available and the range of refuge types that they represent.

(1) Plains mouse, *Pseudomys australis*

(*a*) *Species characteristics*

The plains mouse (*Pseudomys australis*) is a rodent (Muridae) (body mass 30–65 g) endemic to a 700 km north–south band of stony desert habitat and interdunal plains within the Simpson and Strzelecki Deserts, Australia (Brandle, Moseby & Adams, 1999). It is listed globally as Vulnerable (Woinarski, Burbidge & Harrison, 2014). Females have four nipples, can suckle up to four young and may produce successive litters every 2–3 months (Breed, 1990), thus enabling an irruptive population response to increased resource abundance. Dramatic increases in abundance and area of occupancy have been documented in response to rare, large-magnitude climate-driven resource pulses (Brandle & Moseby, 1999; Pavey *et al.*, 2014*a*). Plains mouse populations and area of occupancy are large while resource availability remains high, but fall rapidly as resources decline (Brandle & Moseby, 1999; Pavey, Eldridge & Heywood, 2008*a*). Brandle & Moseby (1999) detected an 80-fold decrease in estimated population size during their 3-year

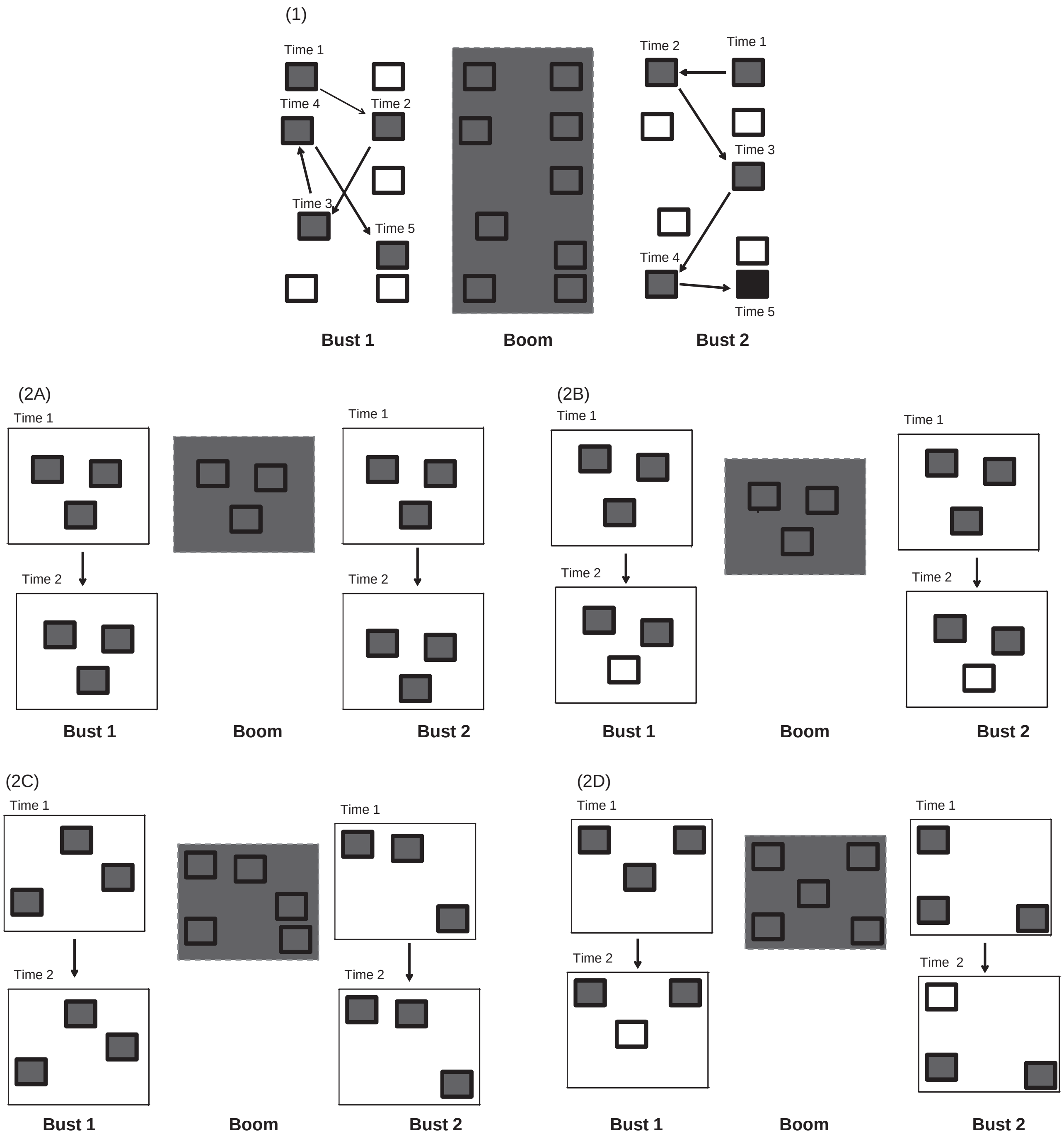

Fig. 1. Models of refuge types showing changes in the pattern of occupancy of an irruptive mammal species across boom and bust cycles. Boxes represent refuges. Shaded areas are occupied by the irruptive species, unshaded areas are not occupied. Movement of individuals from one refuge to another within busts is expected to occur for the fixed refuges and is not indicated in the diagrams. Model 1 is for shifting refuges; models 2A–D are for fixed refuges: 2A, stable within and between busts; 2B, unstable within busts and stable between busts; 2C, stable within and unstable between busts; 2D, unstable within and between busts.

study of this species within a favoured habitat patch. The area of occupancy during busts declined to 17% of the boom areas in the western Simpson Desert (Pavey *et al.*, 2014*a*). The range of habitats occupied is greater during population outbreaks than during the low phase of the cycle (Pavey & Nano, 2013).

(*b*) *Habitat preferences*

The plains mouse occurs primarily on cracking clay and gibber plains within stony desert. Occurrence is often associated with areas receiving moisture from the surrounding landscape (hereafter referred to as 'run-on' areas) and minor drainage features, but not with areas receiving large water flows and prolonged ponding such as major drainage channels, floodplains and swamps (Brandle *et al.*, 1999). Friable cracking clay soils supporting little or no perennial vegetation are characteristic of the preferred habitat (Brandle *et al.*, 1999).

(*c*) *Refuge use and type*

Run-on patches within stony desert are considered to be refuge habitat for the plains mouse (Brandle & Moseby, 1999; Pavey *et al.*, 2014*a*). Minor localised rainfall events that produce limited run-off provide moisture to these run-on patches which then produce flushes of grasses and forbs. This vegetation is an important food resource for the plains mouse (Brandle & Moseby, 1999; Pavey *et al.*, 2014*a*).

The occurrence of plains mouse refuges is associated with topographic position and soil type, which are fixed in the landscape and unlikely to change substantially over ecological timeframes, except where significant landscape modification occurs through accelerated erosion or deposition. Plains mouse refuges therefore fit the fixed refuge concept (see Fig. 1, models 2A–D). There is evidence that the species' use of refuges fits both model 2A – fixed refuges with stability in refuges within and between busts (R. Brandle, unpublished data) –and model 2B – fixed refuges with instability in refuge location within busts but stability between busts (Pavey *et al.*, 2014*a*; C. R. Pavey, unpublished data). Empirical support for the species fitting model 2B comes from populations in both South Australia and the Northern Territory. Specifically, a regularly sampled refuge in northern South Australia was occupied for 2 years during the early phase of a bust in 1993–1995 and then had no animals during the remainder of the sampling period (Brandle & Moseby, 1999). Plains mice in a study area in the western Simpson Desert, Northern Territory, used a series of four fixed refuges from 2007 to 2014. One of these was occupied for only part of a bust (from October 2007 to March 2009) and then abandoned (Pavey *et al.*, 2014*a*). The other refuges were occupied during the two bust phases and the intervening boom (C. R. Pavey, unpublished data). Individually marked plains mice in this study were recorded moving between refuges during a bust phase (C. R. Pavey, unpublished data).

(*d*) *Drivers of population and occupancy dynamics*

The primary driver of population increase in the plains mouse is precipitation. Rainfall triggers primary productivity and the subsequent increase in food availability drives reproduction (Brandle & Moseby, 1999). In captivity, plains mice will continue to breed throughout the year and a gestation period of 30–35 days gives the species the capacity for a rapid increase in population size (Smith, Watts & Crichton, 1972). Such reproduction appears to occur only during times of high resource availability in the wild (Watts & Aslin, 1981).

In plains mouse habitat in the western Simpson Desert, summer bias in rainfall is more marked in high-precipitation years and it typically occurs as discrete, short pulses of 5–6 weeks duration. This summer bias in rainfall favours extensive plant growth (Nano & Pavey, 2013). Increased food availability likely increases plains mouse reproductive activity and survivorship, leading to increases in population density and eventual dispersal from refuges. A summer rainfall event of 75 mm led to significant breeding and a within-refuge population increase of the species, but did not produce a population outbreak. By comparison, summer rainfall events of >100 mm do produce population irruptions (Pavey *et al.*, 2014*a*), with the species moving into a range of habitats not occupied during dry periods (Pavey & Nano, 2013). Populations of plains mouse show marked increases 4–9 months after heavy summer rain (Pavey & Nano, 2013) with dispersing individuals appearing outside of refuge habitat within 4 months (C. R. Pavey, unpublished data).

The rate of population increase is likely to be slowed by declining food resources and increased levels of predation from mammalian carnivores [dingo (*Canis dingo*), feral cat, red fox] and native birds of prey [eastern barn owl (*Tyto javanica*), southern boobook (*Ninox novaeseelandiae*), letter-winged kite (*Elanus scriptus*) (Pavey *et al.*, 2008*a*; Pavey, Gorman & Heywood, 2008*b*; McDonald & Pavey, 2014)]. Predation may also contribute to dramatic post-resource pulse population declines. The impact of predation by mammalian carnivores may be further increased in the presence of the European rabbit (*Oryctolagus cuniculus*) as this species supports high predator densities.

Other potential drivers of plains mouse population dynamics may be important. Disease may act to cause declines at high population densities when individuals are stressed as resources become depleted. High levels of use of refuge habitat by livestock [cattle (*Bos taurus*), sheep (*Ovis aries*)] and other ungulates [feral horse (*Equus caballus*), feral one-humped camel (*Camelus dromedarius*)] may impact refuges and reduce the size of refuge populations, thus muting the response to resource pulses. The combination of grazing and trampling removes ground cover and seed sources, and can also damage burrows. Finally, competition for food and shelter may be a factor, especially from the larger, native, long-haired rat (*Rattus villosissimus*) which invaded plains mouse habitat during a resource pulse in 2010–2011 (Pavey & Nano, 2013).

(*e*) *Persistence in refuges*

Some refuges appear to be occupied for the entire duration of the bust phase of the population cycle. Pavey *et al.* (2014*a*) recorded capture rates in refuges during the low phase of the population cycle equal to or higher than those in outbreak sites during the population peak, indicating that these refuges are important for the persistence of the plains mouse during dry periods. Refuge populations remain in good condition and plains mice continue to breed in refuges throughout the dry period (Brandle & Moseby, 1999; Pavey *et al.*, 2014*a*). By contrast, populations outside refuges appear to go extinct during dry periods. A number of key resources are present in refuges that enable persistence of the plains mouse. Shelter is present in the form of protected burrow systems (dug in sandy soil under shrubs) and deep soil cracks (that provide protection from predators and environmental extremes). Food is available as a result of the landscape characteristics of these areas that enable a regular supply of green food and seed accumulation.

(2) Central rock-rat, *Zyzomys pedunculatus*

(*a*) *Species characteristics*

The central rock-rat (*Zyzomys pedunculatus*) is a medium-sized (body mass 70–150 g) rodent (Muridae) endemic to mountain ranges and adjacent foothills in central Australia. The species is listed globally as Endangered, with a recommendation that this be upgraded to Critically Endangered as it is undergoing declines and is little known (Woinarski *et al.*, 2014). In captivity, central rock-rats live to a maximum of 7 years and breed between the ages of 2 and 5 years. Females can produce multiple litters during a year and show the capacity to breed year-round, with young recorded in all months except June and September. Average litter size is three. This reproductive capacity means that the species can respond to periods of resource abundance by rapidly increasing in population size. Dramatic increases in abundance and area of occupancy have been documented in response to a large-magnitude climate-driven resource pulse (Edwards, 2013*b*).

(*b*) *Habitat preferences*

The species was recorded from several mountain range systems in central Australia until 1960 but then remained undetected until 1996 when it was rediscovered in a remote part of the mountainous MacDonnell Ranges (Nano, 2008). Over the following 7 years the central rock-rat was recorded at 13 sites across a 600 km^2 area of the West MacDonnell National Park (NP) and a nearby cattle station (Nano, 2008). In this period the species was recorded from tussock and hummock grasslands and tall open shrublands on a range of rocky substrates (Nano, 2008). It underwent a population irruption in 2000–2001. In 2002, when drought conditions prevailed and wildfires burnt a large proportion of the region (Turner, Ostendorf & Lewis, 2008), central rock-rats disappeared from monitoring sites near Ormiston Gorge and the species has not been captured there since (Edwards, 2013*a*). Targeted surveys in 2009–2010 located an extant population near the summit of Mt Sonder (at 1380 m above sea level), and the species has since been recorded from a further two locations in the West MacDonnell NP and at a single location 70 km west of there (McDonald *et al.*, 2013, 2015*a*; Fig. 2). All these recent locations are on high-elevation (>1100 m) quartzite ridges and mountain peaks, despite substantial survey effort at lower elevations and on other geologies throughout the region (McDonald *et al.*, 2013). This landform type is now considered core refuge habitat (McDonald *et al.*, 2013, 2015*a*). Vegetation on these landforms is characterised by a ground layer dominated by either hummock grasses or a mixture of forbs and sub-shrubs with the upper strata comprised of scattered low shrubs or mallee-form eucalypts.

(*c*) *Refuge use and type*

High-elevation quartzite ridges and mountain peaks are considered to be core refuge habitat of the central rock-rat. The factors defining the refuge quality of this habitat are poorly understood, although protection from both predation by feral cats and disturbance from wildfires have been suggested as hypotheses (McDonald *et al.*, 2013, 2015*b*). Recent research on Australian small mammals shows that declines in population size after fire occur as a result of fire-induced loss in vegetation cover which increases the vulnerability of individuals to predation; that is, individuals survive the fire but are subsequently depredated in the more open habitat (Körtner, Pavey & Geiser, 2007; McGregor *et al.*, 2014). The tendency for wildfire extent to be patchy on high-elevation ridges and peaks in the MacDonnell Ranges may contribute to these acting as refuges, particularly from feral cat predation. Food resources are not thought to be a major limiting factor as the central rock-rat feeds on the seeds and stems of a range of widespread grass, forb and shrub species, including many that are fire-encouraged (Nano, Smith & Jefferys, 2003; Edwards, 2013*b*).

The occurrence of refuges of the central rock-rat is strongly associated with topographic position. These quartzite ridges and mountain peaks are fixed in the landscape and will not change over ecological timeframes. Central rock-rat refuges therefore fit the fixed refuge concept (Fig. 1, models 2A–D). The available information suggests that the species' use of refuges fits model 2A – fixed refuge with stability in refuges within and between busts. However, it is important to note that central rock-rat occupancy is currently very low (*c*. 10%) within the greater matrix of apparently suitable quartzite refuge habitat (McDonald *et al.*, 2015*b*). As yet there is no evidence of movement between refuges during a bust phase (P. J. McDonald, unpublished data).

(*d*) *Drivers of population and occupancy dynamics*

The only thoroughly documented, known-population irruption occurred in response to elevated primary productivity associated with high rainfall in 2000–2001

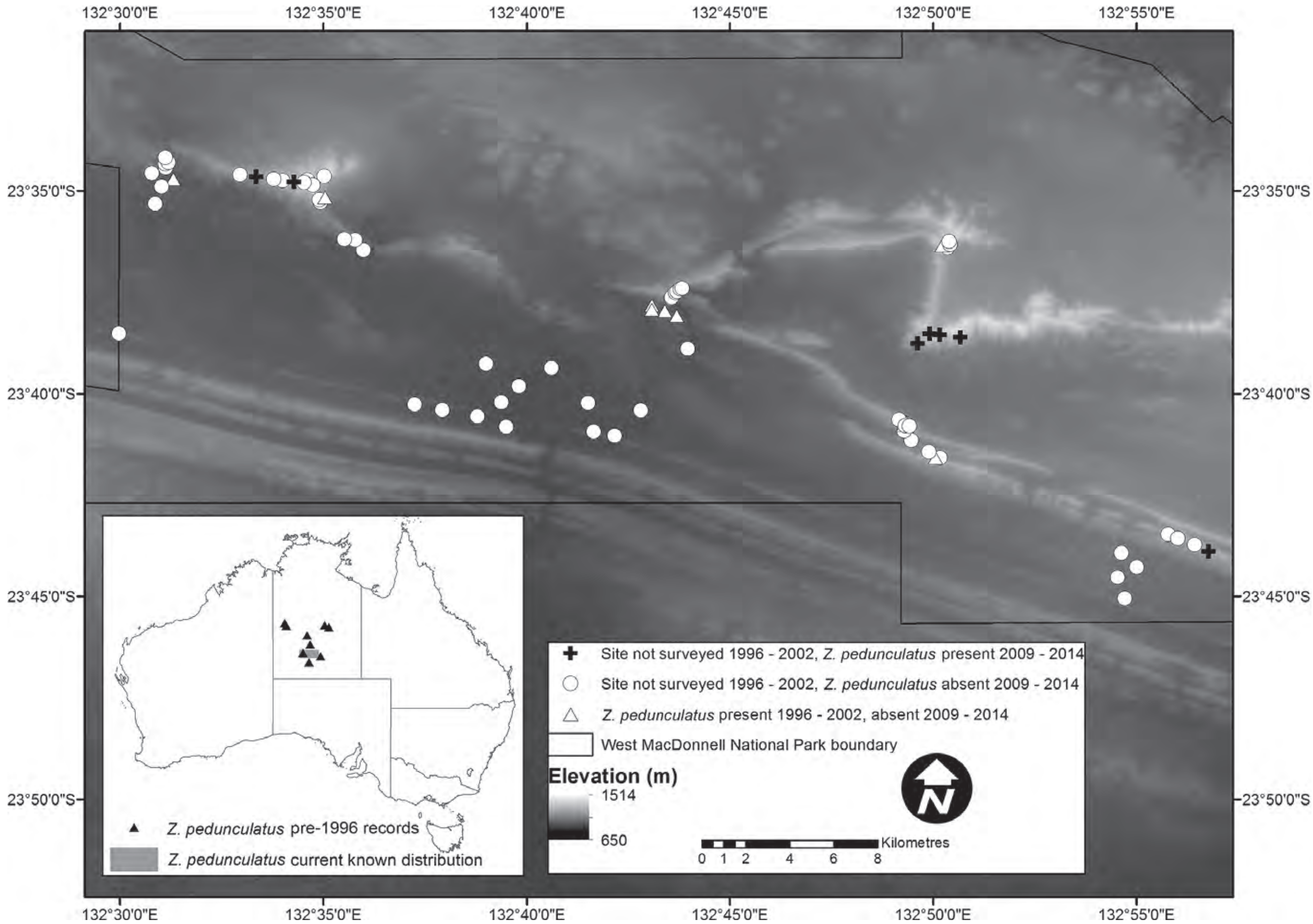

Fig. 2. Presence ($N = 7$) and absence ($N = 72$) records of the central rock-rat (*Zyzomys pedunculatus*) made in 1996–2002 and 2009–2014 in relation to elevation and the West MacDonnell National Park boundary, Northern Territory, Australia. An additional record was made approximately 70 km to the west, on Haast's Bluff Aboriginal Land Trust. Inset map denotes historical records (pre-1996) and the current known distribution (1996–2014) in Australia.

(Edwards, 2013*a,b*). At this time and over the preceding 4 years, central rock-rats occurred on a range of geology types in the Ormiston Gorge region of the West MacDonnell NP, including at sites as low as 750 m elevation. Precipitation of similar magnitude to that in 2000–2001 occurred in 2010–2011 and, although reproductive activity was observed within high-altitude refuge habitat, the species was not recorded outside of these refuges (McDonald *et al.*, 2013). Therefore, it is difficult to discuss with any certainty the factors driving population dynamics in the central rock-rat. It seems possible that the central rock-rat is suffering ongoing population declines, with its geographical range declining within successive bust phases.

(*e*) *Persistence in refuges*

Limited information is available on the persistence of this species in refuges during the low phase of the population cycle. The populations that irrupted during 2000–2001 and occupied habitat outside refuges went extinct during 2002 (Edwards, 2013*b*). A population of the central rock-rat disappeared in 2011 from a (likely refuge) site where it had been recorded breeding 12 months prior to and during a period when individuals were breeding at another location (McDonald *et al.*, 2013). This suggests that, in contrast to arid Australia's other irruptive rodents, large rainfall events alone are not a reliable predictor of population irruptions and that, within core refuge habitat, occupancy by the central rock-rat may shift over time. Alternatively, central rock-rats may be suffering an ongoing, predation-driven decline that is resulting in reduced occupancy in refuge habitat over time and therefore a reduced ability to respond numerically to resource pulses.

(3) Spinifex hopping-mouse, *Notomys alexis*

(*a*) *Species characteristics*

Distributed widely across dryland Australia, the spinifex hopping-mouse (*Notomys alexis*) is a small (body mass 27–45 g) endemic rodent (Muridae) that occurs primarily on sandy soils that can be excavated readily for burrows (Watts & Aslin, 1981). Although often present at very low density

(<0.1 animals per ha), this species can increase in numbers by more than two orders of magnitude within a year if conditions are favourable (Dickman *et al.*, 1999). As with the plains mouse and central rock-rat, females have four nipples and suckle three to four young at a time, produce multiple litters when conditions are favourable, and can extend breeding from the usual spring–summer period to autumn and winter if resources are available (Finlayson, 1940; Breed, 1979, 1992; Breed & Leigh, 2011). Population irruptions most likely arise from the extension of the usual vernal breeding period, increased survival of young, and immigration of some animals from drought-stricken areas into locales that have received recent rain (Masters, 1993; Dickman *et al.*, 1995; Breed & Leigh, 2011). The area of occupancy of the spinifex hopping-mouse expands during irruptions, with animals occupying more varied habitats at these times than during periods of rainfall deficit (Newsome & Corbett, 1975).

(*b*) *Habitat preferences*

Spinifex hopping-mice occur primarily in areas dominated by perennial hummock grasses (*Triodia* spp.), but also occur in other vegetation on alluvial flats and in shrubland dominated by chenopods, as well as in areas of low woodland and tussock grassland (Burbidge *et al.*, 1976; McKenzie, Hall & Muir, 2000; Moseby, Hill & Read, 2009). The distributional stronghold of the species is in the hummock grasslands that cover about 25% of the Australian land area (Dickman *et al.*, 2014). Unlike many other dryland-dwelling Australian rodents, there is no evidence that the geographical range of the spinifex hopping-mouse has declined; despite the dramatic fluctuations that characterise its population dynamics, it appears to be secure (Woinarski *et al.*, 2014).

(*c*) *Refuge use and type*

Despite its preference for spinifex grassland, the spinifex hopping-mouse may disappear for prolonged periods in this habitat and elude even the most determined efforts to locate it. For example, Masters (1993) captured on average ≤ 1 animal per plot on six 2.88-ha trapping plots in spinifex grassland over the course of a year, but within months of heavy rain the capture rate had risen to >60 animals per plot. Dickman *et al.* (1999) reported zero captures for 4 years on 12 intensively trapped 1-ha plots before animals began to reappear. Similar disappearances of this species have been recorded in most other longitudinal studies (Predavec, 1994; Southgate & Masters, 1996; Breed & Leigh, 2011). These nil-records at known sites appear to be real and do not reflect declines in detectability or trapability; Dickman *et al.* (2011) showed that independent measures of animal activity such as the presence of burrows and counts of footprints on transects correlated strongly with actual captures.

Despite the paucity of captures of spinifex hopping-mouse for prolonged periods when conditions are unfavourable, two pieces of evidence suggest that animals are still present within or close to spinifex grassland. First, remains of the species can be recovered from the scats/pellets of mammalian and avian predators (feral cat, red fox, dingo, owls) that hunt in spinifex grassland even at times when hopping-mouse densities on sampling plots are low or zero. Although the representation of spinifex hopping-mouse in the diets of these predators may be low at these times (<10% by frequency of occurrence; Pavey *et al.*, 2008*a*,*b*; Spencer, Crowther & Dickman, 2014*a*), the species clearly still persists. Second, within months of a widespread rainfall event, spinifex hopping-mice reappear in traps on distantly spaced sampling plots at about the same time and in similar numbers (Dickman *et al.*, 2011). This suggests that animals are present in the spinifex grassland system all the time and are not dispersing from refuge habitats that are located in discrete or geographically remote places. Indeed, intensive surveys in other vegetation communities associated with spinifex grasslands that are often believed to provide refuge to other mammals and birds, such as riparian channels, confirm that these elements do not constitute refuge habitats for the species (Free *et al.*, 2013).

Instead, available evidence suggests that the spinifex hopping-mouse uses an unusual form of refuge habitat: tall shrubs that occur as isolates or as small stands of <10 individual plants that are embedded but widely scattered within the spinifex grassland biome (Dickman *et al.*, 2011). Radio-tracked individuals spend periods of 4–5 days within a radius of <100 m of these shrubs before moving rapidly to different shrubs that may be 2–3 km distant, presumably after the resources that the species relies upon have been reduced to marginal levels at the initial shrub sites (Murray & Dickman, 1994; Dickman *et al.*, 2011). In the eastern Simpson Desert, where the most detailed studies have been carried out, the cover of shrubs that are used by this species is no more than 6% (Greenville *et al.*, 2009). The local activity of animals around particular shrubs and rapid movement to other shrubs every few days probably accounts for the very low trappability on small, fixed sampling plots during periods when conditions are unfavourable; Dickman *et al.* (2011) suggested that most captures at these times represented individuals that were intercepted while dispersing between shrubs. If these interpretations are correct, the spinifex hopping-mouse probably makes sequential use of multiple small and highly localised refuge habitats, shifting from one refuge to the next as resources become exhausted. Thus the spinifex hopping-mouse is the species on which the shifting refuge concept used herein has been developed (Fig. 1, model 1).

(*d*) *Drivers of population and occupancy dynamics*

As for the other two case-study species, the primary driver of population increase in the spinifex hopping-mouse is rainfall. The absolute amount that is needed to be physiologically effective and to drive pulses of primary productivity varies between times and places, and the rate of population increase also is dependent on the starting level of the population and the timing of rainfall (Southgate & Masters, 1996; Dickman *et al.*, 2014). In general, winter rainfall does not appear to stimulate reproduction, whereas summers with heavy rainfall (>200 mm) are likely to increase reproductive activity and improve the survival of young (Breed & Leigh, 2011). However, smaller amounts of summer rainfall also have stimulatory effects if winter rains have been heavy, and consecutive summers with above-average rainfall can lead to densities of >50 animals per ha (Dickman *et al.*, 2014). There is also some evidence that population increases may not occur even after very heavy summer rainfall events if an irruption has occurred within the previous 5 years or less. Ricci (2003) showed that the amount of spinifex seed produced following summer rain is a key determinant of the subsequent numbers of spinifex hopping-mice, and speculated that at least 5 years must elapse between spinifex seeding events to allow time for nutrients to recycle and become available to support further episodes of seeding.

Populations of the spinifex hopping-mouse show marked increases 3–6 months after heavy summer rains (Predavec, 1994; Dickman *et al.*, 1999), with adult animals becoming more sedentary and social as density rises (Dickman *et al.*, 2010). Sub-adults appear to be mobile during periods of population expansion, and are observed more frequently in habitats other than spinifex grassland such as claypans, shrubland and stony desert (Dickman *et al.*, 2014). In some populations social suppression of reproduction occurs when densities reach a certain threshold (>25 animals per ha; Breed, 1979, 1992), but in others the rate of population increase is slowed by declining resources and increased levels of predation from feral cats, red foxes and birds of prey (Letnic, Tamayo & Dickman, 2005; Pavey *et al.*, 2008*a*; Dickman *et al.*, 2010). Predation is also thought to suppress populations of spinifex hopping-mice and dampen the boom phase. Moseby *et al.* (2009) recorded 15 times more hopping-mice where predators were removed compared with sites where predators were present. High populations were sustained in the absence of predators even during dry conditions. In contrast to the plains mouse, there is no evidence of spinifex hopping-mouse declines owing to disease or increased parasite loads (Ricci, 2003).

Two further drivers are important for the spinifex hopping-mouse. In the first instance, grazing by introduced livestock can deplete food and shelter resources, reducing the average size of populations and muting their response to heavy rainfall events (Frank *et al.*, 2013). Second, fire removes vegetation cover, reduces food and shelter resources, and exposes small mammals to greater risks of predation from visually hunting predators (Letnic *et al.*, 2005; McGregor *et al.*, 2014). Small-scale fires (<10 ha) appear to have limited effects on activity or numbers, but populations decline markedly if broadscale wildfires occur (Pastro, Dickman & Letnic, 2011; Letnic, Tischler & Gordon, 2013). However, if moderate levels of vegetative cover (5–10%) are available, the spinifex hopping-mouse appears to use the sparse cover and its fast hopping speed (4.5 m/s; Stanley, 1971) to elude cursorial predators (Spencer, Crowther & Dickman, 2014*b*). During prolonged droughts and in the post-fire environment, tall shrubs such as mallee-form eucalypts that regenerate from below-ground storage organs appear to provide key refuge habitat for the spinifex hopping-mouse.

(*e*) *Persistence in refuges*

The pattern of persistence in refuges found in the spinifex hopping-mouse contrasts markedly with that of the plains mouse and central rock-rat. This difference results from the use of shifting refuges by this species. Because the ground cover provided by the shrubs and shrub-clusters used as refuges is limited (typically 10–500 m^2), hopping-mice spend less than a week at each refuge before moving to another (Dickman *et al.*, 2011). Deep leaf litter at the bases of shrubs provides both shelter and a local source of seeds and invertebrates, and it appears to be the depletion of these food resources to marginal levels that prompts animals to move on (Dickman *et al.*, 2010, 2011).

The strategy of making transient use of small and highly localised refuge habitats is likely to succeed most effectively in landscapes where the costs of moving between these patches are outweighed by the benefits of gaining access to them. Dispersal costs could be expected to be minimised if patches are in close proximity. In the eastern Simpson Desert, Tischler (2011) reported an average of 15.4 shrubs and trees (>3 m tall) per ha in spinifex grassland (range 0–20 per ha), although the proportion of these shrubs that may have been suitable for spinifex hopping-mice is not known. During the low phase of the population cycle radio-tracked hopping-mice have been recorded moving distances of 550–3340 m between patches of tall shrubs (Dickman *et al.*, 2010, 2011; C. R. Dickman, unpublished data); these distances clearly allow persistence of the species in spinifex grassland, but the effects of larger spacing between refuge habitats is not known.

(4) Other refuge-using species

The three case studies above cover rodents in the family Muridae all of which are endemic to the drylands of northern and central Australia where rainfall is highly unpredictable. We have used Australian murid rodents as a case study to provide focus; however, we predict that refuge use will be widespread among dryland small mammals and not only an Australian phenomenon. Rodents in the family Muridae are a diverse and widespread component of the fauna of the drylands of Asia and Africa including regions such as the Thar, Kalahari–Namib and Somali Deserts that experience highly unpredictable rainfall similar to our Australian dryland case study area (van Etten, 2009). We expect that this combination of life-history characteristics and climatic conditions will have produced conditions suitable for the evolution of refuge use in these drylands. In addition, we note that refuge use among small mammals is already known in dryland South America where several members of the family Cricetidae in the Norte Chico of north-central Chile use riverine shrublands and fog-forest patches as refuges during dry years within dominant thorn-scrub habitat (Milstead *et al.*, 2007). Small-mammal refuges also occur on the Eurasian steppe (Naumov, 1975; Bykov, Shabanova & Bukhareva, 2011).

The case studies above indicate the species-specific nature of refuges and provide a significant conceptual advance from the view of refuges as being concentrated in mesic areas such as riverine vegetation. This clarification suggests that refuges are unlikely to be shared by a large number of species. However, in some habitat types there is emerging evidence of the presence of multiple refuge-using species. As an example, the refuges of the plains mouse on cracking clay are also occupied by dasyurid marsupials including *Sminthopsis crassicaudata* and *S. macroura*. Each of these species is potentially also refuge-using. However, the current level of information is insufficient to draw conclusions on refuge-use patterns of ecologically and taxonomically similar species. The future research agenda (Section VII) provides an outline for how this knowledge can be gained rapidly.

Patterns of refuge use of most of the larger carnivorous dasyurid marsupials are currently also unclear. The brush-tailed mulgara (*Dasycercus blythi*) and crest-tailed mulgara (*D. cristicauda*) potentially use shifting refuges but available evidence is tenuous. The kowari (*Dasyuroides byrnei*) is a medium-sized (70–175 g) species that inhabits stony plains in Australia's Lake Eyre Basin where it preys on a range of invertebrates, mammals, reptiles and birds (Canty, 2012). Precipitation events and their associated plant and faunal production are the main drivers of kowari population dynamics (Lim, 1998). Available evidence suggests that it occupies fixed refuges. Sand mounds over 40 cm deep, which form in minor impermeable depressions across the landscape, are a key habitat component as they support kowari burrow systems. Sand mounds are restricted to patches in the landscape with minimal slope and small drainage depressions favourable for sand mound development. These therefore represent fixed refuges over the scale of decades.

V. METHODOLOGY FOR REFUGE LOCATION

We develop below a three-step approach to refuge identification relying on autecological research, modelling and field verification.

Initial research should include a review of available literature on the target species and consider previous records from fauna atlases or museum databases. This information may then be used to direct field research into the target species' basic biology and ecological requirements (e.g. shelter sites, diet, reproduction, life span and movements). Optimum detection methods for the species then need to be determined and detectability should be accounted for in study design and analysis, particularly if the target species is known or likely to be imperfectly detected (MacKenzie *et al.*, 2002). Sampling should use rigorous design (e.g. stratified random) as it is ideal to establish where the target species does and does not occur in the landscape. Specifically, known absence sites can increase the predictive power of presence–absence type habitat modelling, although other techniques are available (see below). Sampling should at least be conducted during the bust period. However, sampling in both the boom and bust periods would allow a comparison of habitat preference between these periods and could provide important insight into the ecological drivers of the refuges. Location information obtained from previous bust periods and/or field sampling can then be used broadly to identify potential refuge habitat of the species. Landscape-scale identification of potential refuge sites could be based on a number of physical or temporal habitat attributes including soil or rock type, elevation, patch size, fire age, rainfall and vegetation. Locating potential refuges therefore may be as simple as identifying a single landform type on a map or could use one of a range of species distribution modelling tools. For example, generalised linear models are frequently applied to presence–absence data to build habitat models and are readily incorporated into global imaging system (GIS) programs to produce probability of occurrence maps (Elith & Leathwick, 2009). More complex non-linear models (e.g. generalised additive models, multivariate adaptive regression splines) can also be used to predict distributions and may outperform the more established methods (Elith *et al.*, 2006). Powerful machine-learning programs are also available (e.g. Maxent) and can be used to model distributions with presence-only data (Phillips & Dudik, 2008).

Regardless of the modelling technique used to identify potential refuge sites at a landscape scale, field verification is required to confirm presence during a bust period and determine whether hypothesised refuge areas actually facilitate persistence of the target species during the bust. Ideally, a range of predicted absence sites should also be sampled at this time to ensure rigorous validation of the habitat models. The results can then be used to refine habitat models if required (Luck, 2002). This sampling is also important so that refuge characteristics operating at finer scales than the available map layers can be identified, and a range of outbreak and potential refuge sites should be monitored and compared during the bust phase. To verify correctly a species' refuge, the species' presence and persistence should ideally be recorded during two successive bust periods. While a larger number of sampling periods would be ideal, the rarity of boom periods means that verification during more than two bust periods could take decades. Two bust periods is a reasonable balance between minimising the possibility of presence due to migration or chance, and the ongoing scarcity of long-term monitoring programmes in dryland areas.

This stage should include field-based techniques designed to identify species presence at a site level as well as methods designed to test for evidence of within-bust persistence (reproduction, immigration or longevity). While difficult to anticipate, field surveys to record presence/absence in potential refuge sites should ideally occur towards the end of the bust cycle. Evidence of persistence may require capture–mark–recapture studies and recording of reproductive condition and age if the species' life span is shorter than the average bust period. It is important at this stage to identify fine-scale habitat attributes that characterise refuges so that field monitoring will be able to include measurements of specific habitat variables at both hypothesised refuge and outbreak sites. Once these steps have been completed, species distribution models can be updated and used to identify potential species-specific refuge sites at a landscape scale. If required, the presence of fine-scale site characteristics can then be used to verify or prioritise specific refuges during confirmatory ground-truthing exercises.

VI. POTENTIAL THREATS

In the drylands of Australia, factors considered to have contributed to declines of refuge-using small mammals include altered fire regimes (e.g. Cockburn, 1978), environmental degradation from grazing by livestock and feral herbivores (Smith & Quin, 1996; Lunney, 2001), predation from introduced carnivores (Dickman *et al.*, 1993; Johnson, 2006), and epidemic disease (Abbott, 2006; Green, 2014). The relative importance of these threats has been difficult to quantify, with a multitude of causal factors probably contributing. However, modelling (e.g. Smith & Quin, 1996; McKenzie *et al.*, 2007), dietary analysis (e.g. Corbett & Newsome, 1987; Kutt, 2012) and field-based experimental evidence (e.g. Kinnear, Onus & Bromilow, 1988; Predavec & Dickman, 1994; Moseby *et al.*, 2009) increasingly implicates predation as the highest order cause of present-day declines of small mammals. Aridity, low reproductive rates and small body size are, in turn, believed to increase vulnerability to predation (Smith & Quin, 1996; McKenzie *et al.*, 2007).

The presence and use of biophysical structures that shelter small mammals, such as optimal-aged spinifex patches or soil textures that allow for digging or the production of cracks, has minimised range reductions in a number of small mammal species (Smith & Quin, 1996; Burbidge & Manly, 2002). While there is sometimes little relationship between vegetation structure and small mammal populations (Letnic & Dickman, 2010), this may not be the case during periods of high predator activity (Letnic *et al.*, 2005) particularly at sites of high small mammal density such as refuges. For species such as the plains mouse, cracking clays provide both resources and shelter against predation by birds and mammals (Brandle *et al.*, 1999). Altered surface hydrology may cause flooding or the deposition of silt and sand from upslope areas, leading to a temporary or more permanent loss of shelter and food resources, and downgrading of these areas to secondary habitat (Brandle *et al.*, 1999).

Although poorly examined in the Australian drylands, changes in surface hydrology, soil microtopography and surface integrity can potentially change the availability of food in refuges. Most small mammals in the Australian drylands do not require free-standing water to survive (Watts & Aslin, 1981). Although these species can subsist during bust periods on invertebrates, dry seed, and whatever green material is available (Murray *et al.*, 1999), during boom periods primary productivity needs to be sufficient to produce the seeds that are an important part of the bust-period diets of small mammals (Watts & Aslin, 1981). Changes in surface hydrology can reduce soil moisture, and therefore primary productivity, with high levels of herbivory reducing seed production in the short term and primary productivity in the longer term (Whitford, 1995; Ludwig *et al.*, 2005). That said, the scant empirical data that are available suggest that fire and grazing may have little effect on some refuge-using species during boom periods (D'Souza *et al.*, 2013; Frank *et al.*, 2014), and the opportunistic and omnivorous diets of many dryland-dwelling rodents (Murray *et al.*, 1999) may potentially buffer the dietary restrictions associated with declining biomass.

Changing species interactions pose a threat to small mammal refuges when these involve an increase in absolute levels of predation or competition, or if the amplitude of population cycles alters such that relative levels of predation or competition increase during significant periods. Increased densities of mesopredators such as foxes or cats through, for example, an increase in artificial waterpoints (Brawata & Neeman, 2011) or a decline in dingo numbers (see Letnic, Ritchie & Dickman, 2012), are an obvious and direct threat to small mammal species reliant on refuges. This risk can be multiplied if refuge habitats are subjected to structural changes (Letnic & Dickman, 2010). Refuge-using species may be particularly vulnerable to predation by mesopredators during the shift between boom and bust periods. During this time, population densities of refuge species may become relatively more concentrated in refuge areas than in the surrounding landscape and, with densities of alternative prey sources beginning to decline, predators may target refuges (Newsome & Corbett, 1975; Smith & Quin, 1996; Letnic & Dickman, 2010; Pavey *et al.*, 2014*a*). Although a few dispersed individuals could be the founders of new colonies after predator starvation, this mechanism may explain why plains mouse refuges can disappear despite the availability of abundant food (Watts & Aslin, 1981). Species using shifting refuges may therefore be less vulnerable to localised change than those that are spatially fixed, as widespread and frequent movement allows for minimisation of predation risk at any one refuge (Newsome & Corbett, 1975).

Climate change may affect refuges and refuge-using species *via* direct physiological or habitat impacts, or by altering the amplitude of population cycles. Temperatures are generally expected to increase in dryland Australia but there is significant uncertainty associated with expected changes in precipitation (Healy, 2015). Given that precipitation is the primary determinant of the dynamics of small mammals with life histories that allow opportunistic breeding, this uncertainty is unfortunate. That said, modelling of the regional climate of the Simpson Desert does suggest an accelerating trend for larger and more frequent rainfall events that punctuate periods of extreme drought (Greenville, Wardle & Dickman, 2012) and recent research suggests a doubling of extreme La Niña events globally (Cai *et al.*, 2015). Changes in these stochastic events are expected to exaggerate the amplitude of population cycles and increase the risks associated with extreme population fluctuations.

The ability of refuges to buffer temperature changes in future will be a product of a variety of factors including soil type and burrow or crack depth, as is the case currently (Geiser & Pavey, 2007; Körtner, Pavey & Geiser, 2008). While fire and predation are current postulated threats to the central rock-rat (McDonald *et al.*, 2013), climate-change modelling suggests there will be no suitable habitat available for this species by 2085 (A. Reside, unpublished data, see Reside *et al.*, 2013). The Barkly Tableland and Lake Eyre Basin may contain the majority of refuges for the long-haired rat (Plomley, 1972; Carstairs, 1974; Newsome & Corbett, 1975) but again modelling suggests there will be no suitable habitat in this region for the species by 2085 (A. Reside, unpublished data, see Reside *et al.*, 2013).

Current ecological knowledge suggests that the changing amplitude of population cycles, either through ongoing ecological perturbations in post-colonial landscapes like Australia or through climate change, may pose a more subtle threat to refuges than implied by suitable climate-change envelopes. Most research to date shows refuge species to be in good body condition and reproductive status during bust periods (Brandle *et al.*, 1999; Pavey *et al.*, 2014*a*), and that this may be due to low levels of resources that become periodically available during localised, bust-period precipitation events (Newsome & Corbett, 1975; Nano & Pavey, 2013; Pavey & Nano, 2013). Dickman *et al.* (1999) rejected the hypothesis that too-frequent heavy rain could potentially have a negative effect on food stores on the basis that Australian dryland rodents do not cache food. However, changes in the temporal and spatial variability or intensity of precipitation events may change food resources, fecundity, and population viability in other ways during bust periods. The dampening of booms may affect outbreeding and increase predation risk; the probability of a population irruption of the long-haired rat increases rapidly after annual rainfall of 600 mm, with an 80% probability of an irruption occurring after annual rainfall of 750 mm (Greenville *et al.*, 2013), but changes in the period between such events may affect population viability.

The changing amplitude of boom–bust cycles may also affect predator–prey relationships by affecting the length or severity of Smith & Quin's (1996) 'predator pit'. Currently, the high mortality rate of mesopredators during the bust phase (Newsome & Corbett, 1975) allows refuge species to reproduce when localised resources become available and predation risk is low. It is likely that predators suppress small mammals only when boom periods are close enough for them to survive, despite a major bust-period reduction in their food supply (Newsome & Corbett, 1975). Predator die-off may not occur if climatic patterns shorten periods between booms. Boom–bust amplitudes and frequency thus affected may provide alternative food sources to mesopredators (which are generalist feeders, e.g. Kutt, 2012; Mifsud & Woolley, 2012), dampening their high mortality rate. Refuge-using prey species may not be similarly advantaged (see Dickman *et al.*, 1999) but their exposure to these mesopredators will be extended and potentially ongoing, increasing their risk of extinction within their refuges. The small size and limited connectivity of refuges are endogenous features that may increase the vulnerability of their inhabitants. Brandle *et al.* (1999) found genetic subpopulations, but little evidence of inbreeding, in wild populations of plains mice. Lacy & Horner (1997) noted that boom–bust cycles may provide optimal conditions for the purging of deleterious alleles expressed through inbreeding in the long-haired rat. Nevertheless, irruptions interspersed with contractions to refuges could theoretically still lead to inbreeding during bust periods (Lacy & Horner, 1997). Recent developments in landscape genetics could be used to quantify such possibilities (Galpern *et al.*, 2014).

VII. FUTURE RESEARCH AGENDA

An ongoing research agenda should focus on four key questions. First, what constitutes a refuge, particularly one that is of high quality? Second, what are the spatial and temporal population interactions within and among refuges, and how might these interactions relate to long-term species survivorship? Third, what is the nature of threats to refuge quality and connectivity? Finally, how widely applicable is the refuge concept, both geographically and taxonomically, beyond irruptive mammals?

The refuge typology proposed herein highlights the diversity of potential refuge forms, but it is the case studies that suggest that what constitutes a refuge, and high refuge quality, is likely to be species-specific. This specificity involves interactions between species behavioural traits, dietary and microclimate requirements, and reproductive characteristics. It is thus likely that there is no easy answer to the question of what constitutes a refuge. Similarly, it is likely that there will be no one location where managers can target effort in an attempt to improve refuge quality for a large number of species. However, it remains possible that multiple species may occupy similar refuge habitat, as is suggested above (Section IV.4) for the plains mouse and several species of small dasyurid marsupials. This possibility requires further investigation as it will enable more efficient management to be undertaken.

Understanding population interactions within and among refuges, and how these might relate to long-term species survivorship, is an important part of clarifying the temporal and spatial boundaries of refuges better, and understanding patterns of gene flow and population viability. A fundamental aspect of this work will be to understand the fate of individuals in expanded populations (i.e. those that move outside refuges during booms) during contraction phases when busts begin. The key question is whether populations outside refuges make any contribution to the long-term evolution of the species (Stewart *et al.*, 2010). This understanding is important for the design of management strategies. For example, currently it is unclear whether management should be focussed at the very small scale of a refuge (sometimes only a few hectares), or whether broader connectivity issues at the landscape scale make the management of inter-refuge corridors equally important. Clarifying the scale of connectivity through time and space will be an important step.

Some of the hypothesised threats highlighted above, including high levels of predation at key times in the population cycle and potential shifts in population amplitudes with climate change, are threats likely to be applicable to all refuge-using mammals. Our knowledge on the extent and severity of these threats will need to be refined with an increase in more temporally nuanced understanding of climatic drivers and species responses. Longitudinal assessments of species interactions and landscape ecology that are embedded within their climatic context will be a key requirement.

Finally, this review has necessarily focused on the small mammal refuges in dryland Australia as this is the dryland system where this concept and its field assessment have been pioneered and developed. The applicability of the refuge typology outlined herein to those outside Australia, and the suitability of the suggested methods for identifying refuges and potential threats are as yet unclear. It is similarly unclear as to whether the overall patterns and processes of refuges can be applied outside of the small mammal context. Could the boom period colonisation and bust period retreat of some dryland plants be functionally analogous to the use of a refuge, for example? We therefore encourage the refinement of the refuge concept in light of global research across a range of taxa.

VIII. CONCLUSIONS

(1) Refuges of dryland fauna are little known and available information is disparate. In this review we have synthesised available information and provided conceptual advances in recognition and delineation of refuge types; application of refuge ideas to boom–bust environments and the recognition that not all refuges are fixed within the landscape; the variable nature of refuges and the resulting biological consequences; and the approaches needed to locate and manage refuges.

(2) A wide range of dryland-dwelling fauna with irruptive population dynamics contract to refuges during the bust phase of their population cycles. For dryland small mammals, these refuges differ from the refugia occupied by fauna and flora in response to changing climate in being occupied for shorter timescales (months to years as opposed to millennia) and being smaller in size.

(3) Irruptive small mammals may occupy refuges that are relatively fixed in location or (more rarely) refuges as small as groups of trees or shrubs that shift in suitability regularly at short timescales of days or weeks. Available evidence suggests that refuge type and usage patterns are species-specific. It is possible that multiple species may share the same refuge habitat if the ecology and environmental requirements of the species overlap, but available evidence suggests that this is rare. Three case studies of dryland rodent species show variation across species in refuge location, occupancy patterns and stability.

(4) Refuges are vital locations for the conservation management of irruptive dryland mammals. It appears likely that local populations of such irruptive species located outside of refuges go extinct as the landscape dries following each boom period. Therefore, refuges are the only locations occupied by irruptive species for the duration of the long bust periods. The small size of refuges makes them highly vulnerable to threatening processes. Known and potential threats to refuges include predation by introduced carnivores, structural changes to the environment leading to a reduction in availability of shelter and food, climate change and stochastic factors resulting from the small size and limited connectivity of the refuges.

(5) The small size and associated high vulnerability of refuges, their species-specific nature, and their use by globally threatened fauna such as the plains mouse and central rock-rat make the identification of locations and management of refuges of dryland fauna a high priority. However, the information we summarise here indicates that refuges comprise a small portion of the landscapes they occupy and will not be detected during standardised faunal surveys or, most likely, by remote-sensing methods. Therefore, refuges need to be searched for using specific approaches. Our three-step approach will maximise the success of such targeted searches.

IX. ACKNOWLEDGEMENTS

We thank the Biodiversity Portfolio of CSIRO (especially Andy Sheppard), Territory NRM and ACRIS for financial support. C.R.D. thanks the Australian Research Council and the Long Term Ecological Research Network for funding, and Glenda Wardle and members of the Desert Ecology Research Group for discussions. We are grateful to April Reside for providing us with access to her unpublished species distribution modelling. We thank two anonymous reviewers for thoughtful and helpful critiques of this manuscript.

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(*Received 4 May 2015; revised 11 November 2015; accepted 12 November 2015; published online 21 December 2015*)

ATTACHMENT K:

LETTER DATED 24 SEPTEMBER 2021 FROM DR BEN SCAMBARY, CEO OF AAPA, TO EVA LAWLER, MINISTER FOR WATER SECURITY

Aboriginal Areas Protection Authority
protecting sacred sites across the territory

File: 2021/282
Ref: CAB202100473

The Hon. Eva Lawler
Minister for Water Security
Parliament House,
Darwin NT 0801

Cc: The Hon. Chanston Paech
Minister for Arts, Culture and Heritage;

Cc: Ms Joanne Townsend
Northern Territory Controller of Water Resources

Dear Minister Lawler

RE: FORTUNE AGRIBUSINESS WATER EXTRACTION LICENCE SINGLETON STATION

I am writing to express concerns about the protection of sacred sites in the context of the Western Davenport Water Allocation Plan 2018-2021, and as a consequence of the water extraction licence (**WEL**) granted to Fortune Agribusiness (**Fortune**) on 8 April 2021.

These concerns arise from recent representations from the Central Land Council (**CLC**) to the Authority concerning the protection of specific sacred sites, and media related to its assessment of the protection of sacred sites at, and within the vicinity of, Fortune's Singleton Horticulture Project.

Background

As you will be aware, in May 2019, Fortune applied to the Authority for an Authority Certificate for the Singleton Horticulture Project.

On 2 October 2019, the Authority issued Authority Certificate C2019/083 (**Attachment A**) in relation to:

> *'All works associated with agricultural land use including: … water extraction, use and access including dams/watercourse upgrades, bores,* [and] *drainage.'*

The Certificate also contains protective measures for a number of sacred sites within the subject land that stipulate that no work and no damage shall occur to the identified sacred sites.

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Provided Fortune complies with the terms of C2019/083 when carrying out this work, it will, for all intents and purposes, be indemnified against prosecution under the *Northern Territory Aboriginal Sacred Sites Act 1989* (NT) (***Sacred Sites Act***).

While the Authority is of the view that C2019/083 operates to prohibit any groundwater drawdown that might damage sacred sites, this is not beyond doubt. Particularly, as the application for C2019/083 was not supported by information or data about the quantity of water to be extracted for the project, or the possibility or level of groundwater drawdown. Therefore, it is arguable the Certificate was issued in relation to an unspecified amount of water.

Unfortunately, these matters were only recently revealed to the Authority following the media attention associated with the WEL that was issued to Fortune in respect of the Singleton Horticulture Project.

Current Situation

Having assessed the materials provided in support of Fortune's WEL application, the Authority is now aware that:

1. the proposed agricultural blocks are close to two potentially groundwater dependant sacred sites (soaks and bean trees) protected by C2019/083, namely sacred sites 5756-54 and 5756-55; and
2. groundwater drawdown will be up to 50 metres in some areas, and between 15 to 30 metres in the vicinity of these two sites.

These sites have not been mapped by the applicant as groundwater dependant ecosystems (**GDE**). If they are GDEs, the estimated level of drawdown is likely to be problematic for the integrity and protection of sacred sites 5756-54 and 5756-55. This level of drawdown also appears to be prohibited by the Western Davenport Water Allocation Plan on the basis that the area of the two above mentioned sacred sites falls within a GDE protection area that limits groundwater drawdown to no more than 15 metres.

A further concern of the Authority is that the subsurface extent of potential drawdown permitted by Fortune's WEL exceeds substantially the subject land of C2019/083. The Authority holds records of approximately 93 sacred sites within this broader drawdown area. The Authority is concerned that there has been no assessment of the protection of sacred sites within this broader area and that the Authority and custodians have not been given the opportunity to consider the potential impacts on these sacred sites from the proposed activities of Fortune or their WEL.

In light of this additional information, the Authority is concerned that:

1. Fortune's WEL potentially permits impacts to sacred sites that are prohibited by C2019/083; and
2. as a result, its decision to issue C2019/083 was *ultra vires,* or is otherwise susceptible to judicial review by other interested parties.

The Authority is currently seeking legal advice on these matters.

Clearly further information is required about the impacts of drawdown on sacred sites 5756-54 and 5756-55, and the approximately 93 sacred sites located within the broader drawdown area. The Authority requests that further assessment of these issues should be undertaken by the Water Controller or the applicant in the context of any variation to the WEL arising from the current review of the decision to grant the WEL.

Based on the outcome of this assessment it is open to you Minister, to mandate the applicant to seek a variation to Authority Certificate C2019/083 to ensure adequate protection of sacred sites in the context of the Singleton Horticulture Project and the associated WEL held by Fortune.

Thank you for considering these concerns. I would be happy to provide further briefing on these matters.

Yours sincerely

Dr Ben Scambary
Chief Executive Officer
24 September 2021

ATTACHMENT L:

SINGLETON WATER LICENCE ABORIGINAL CULTURAL VALUES ASSESSMENT – PUBLIC REPORT

Prepared by Susan Dale Donaldson, Anthropologist
1 September 2021

Singleton Water Licence
Aboriginal Cultural Values Assessment

PUBLIC REPORT TO THE CENTRAL LAND COUNCIL

Singleton Pastoral Lease, Neutral Junction Pastoral Lease, Warrabri Aboriginal Land Trust and Iliyarne Aboriginal Land Trust, Northern Territory, Australia.

SUSAN DALE DONALDSON (ANTHROPOLOGIST)

Environmental & Cultural Services

1 September 2021

WARNING: THIS REPORT CONTAINS REFERENCE TO ABORIGINAL PEOPLE WHO HAVE DIED

Front cover: First Trip to Grandfather's Country with Rangers © Lindy Brodie 2021

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ACRONYMS

AAPA	Aboriginal Areas Protection Authority
AC	Authority Certificate
AIATSIS	Australian Institute of Aboriginal and Torres Strait Islander Studies
ALT	Aboriginal Land Trust
CLC	Central Land Council
DA	Drawdown Area
FPIC	Free, Prior and Informed Consent
GDE	Groundwater dependent ecosystem
GL	Gigalitre
ha	Hectare
ICN	Indigenous Corporation Number
ICOMOS	International Council on Monuments and Sites
km	kilometre
km^2	square kilometres
ML	Megalitre
NOI	Notice of intention
NTG	Northern Territory Government
PL	Pastoral Lease
PPL	Perpetual Pastoral Lease
RNTBC	Registered Native Title Body Corporate
RWA	Restricted Work Area
SWL	Singleton Water Licence
UNESCO	United Nations Educational, Scientific and Cultural Organization
WDWAP	Western Davenport Water Allocation Plan

Executive summary

In September 2020, Fortune Agribusiness Funds Management Pty Ltd (Fortune Agribusiness) applied for a water licence over Singleton Pastoral Lease (PL) located within the Central Plains management zone of the Western Davenport Water Allocation Plan (WDWAP), near Wycliffe Well in the Northern Territory. Whilst the proposed water extraction zone (development wells / bores) is located on Singleton PL, the groundwater drawdown area is estimated by Fortune Agribusiness as extending beyond the water extraction zone to other parts of Singleton PL, and across Neutral Junction PL, Warrabri Aboriginal Land Trust (ALT) and Iliyarne ALT.

In May 2021, the Central Land Council (CLC) was instructed by Aboriginal owners to identify the cultural values associated with the Singleton Water Licence (SWL) area and to consider how these values might be impacted by the granting of the water licence. Anthropological consultant Susan Dale Donaldson was engaged by the CLC to undertake the cultural values assessment.

The cultural values assessment involved a literature review and consultations with 80 Aboriginal owners in June 2021 which identified a complex Aboriginal cultural landscape across the SWL groundwater drawdown area including important cultural values directly associated with groundwater dependent ecosystems (GDEs). The assessment found the SWL area to be situated on the traditional lands for four *Kaytetye* speaking groups (*Anerre, Waake-Akwerlpe, Iliyarne* and *Arlpwe)*. An additional 23 Aboriginal groups were also identified across the broader Western Davenport District as holding kinship and ritual ties to these Kaytetye groups and to the drawdown area.

Traditional Owners' belief in the *Altyerre* (Dreaming) Law and the need to follow the Law is the cornerstone cultural value arising from this assessment and the foundation of all other identified cultural values. Taking care of country into the future according to ancient laws and customs appeases the creator spirits residing at important places. If traditional roles and responsibilities are not carried out by Traditional Owners, and if country is damaged as a result of the actions of Traditional Owners or others, punishment is imposed on senior Traditional Owners by *Altyerre* forces resulting in sickness, injury and even death. Spiritual punishment can lead to psychological stress and guilt linked to people's sense of internal moral failure associated with being responsible for damaging the country belonging to their spiritual ancestors, their actual ancestors, the current generation of kin and their descendants. Social sanctions may also result; Traditional Owners can be forced into temporary or permanent isolation from their traditional group. This was a major theme expressed during this assessment, as described below:

‘Aboriginal law is strong. If I do the wrong thing and my trees dies, I’ll be gone. If Dreaming trees get lost, we be gone too. We got to tell them this. Someone will be in trouble, the bloke not listening to us, he will get sick. That’s our law. Our law is in the ground and will not change. When I’m gone my family got him (The Law). Our main word to them is “please take it easy on the water all around the world”.’ *Frankie Holmes Akemarre*

This assessment also revealed the strong spiritual connection between Traditional Owners and sacred sites, the places embodying the *Altyerre* (Dreaming). Background research combined with consultations with Traditional Owners identified 40 sacred sites associated with 20 *Altyerre* mythologies within the drawdown area. Considering not all of the identified sites were visited during the assessment combined with the cultural complexities of the region, it is possible that one or two of the sites identified are actually the same place known by different names. It is also possible that other sites exist within the drawdown area that were not identified during this assessment.

Many of the *Altyerre* tracks traversing the drawdown area interlink with places across the broader cultural landscape. Whilst all of the mythologies across the drawdown area relate to the *Altyerre* creation of the land and water, a number of mythologies specifically relate to water such as ancestors carrying and digging for water, ancestors teaching others how to sing for rain, and groups attending large rain ceremonies. These mythological episodes continue to be re-enacted by Traditional Owners today in ritual, through song, dance, paint, story-telling and by visiting the spiritual ancestors residing at sacred places. Damage to sacred sites can impact Traditional Owners’ spiritual connection to country.

‘If we Iliyarne people let our land go dry, other people will growl at us. We need to keep the water until we die so that it can jump over to our children and their children all the way like that. The spirit people will get upset if we let that country go dry. They will make us sick, especially Rodger Tommy the main *kirda* (owner through father), and his sons and daughters. We are his *kwertengerl* (owner through mother) and we watch over that country for him.’ *Heather Anderson Narrurlu*

Each of the 40 sacred sites identified within the drawdown area were beyond the extraction zone and all have features associated with GDE: soakages, bean trees, orange trees, coolibah trees, creeks, swamps, supplejack trees, ghost gum trees, and bloodwood trees. It is understood that sandhills and mulga patches associated with sacred soakages are not GDE features.

The Aboriginal Areas Protection Authority issued the company with a sacred sites Authority Certificate (AC) for the proposed work; the subject land covers an area larger than the extraction zone but less than the estimated groundwater drawdown area (C2019/083). The current assessment identified 5 sacred sites within the AC subject land, not included in the AC. Moreover, a further 32 sacred sites were identified outside the AC subject land within the drawdown zone.

The assessment found that the spiritual connection Traditional Owners have with their country is strengthened by ritual activity which is also linked to the powerful forces of the *Altyerre*. There are a number of ceremonial grounds close to the drawdown area, used in the past, as well as today. Whilst there is a strong belief held by Traditional Owners in the power of ritual, for instance for rainmakers to make rain to increase water supply regardless of secular activities and impacts, many Kaytetye rituals require specific flora and fauna species obtained across the drawdown area. The current proposal to reduce groundwater has the potential to adversely impact GDE species which Traditional Owners customarily require for ritual activity. These potential changes concern the current generation of Traditional Owners, they fear the consequences of not following their ancient Law.

The extraction and drawdown areas have been identified as prime hunting ground by Traditional Owners. A vast array of flora and fauna species utilised by Traditional Owners were documented during this assessment, many of which depend on groundwater. The Wakurlpu and Alekarenge communities in particular utilise their 'back yard', within the drawdown area, to collect natural resources. Continuing to 'go hunting' is vital to the maintenance of good mental, physical and spiritual health for Aboriginal people and an important way to transmit cultural knowledge and practices to younger generations.

The importance of soakage water to Aboriginal people in the region was first documented by Stuart in 1862 when in the vicinity of the Crawford Range and Taylor Creek he recorded 'soakages dug in the Creek by the natives. There is no surface water, but apparently plenty by digging in the bed of the creek'.[1] Aboriginal people's reliance upon and valuing of water and other natural resources in this dry region continued throughout the 1900s (see Bell 1983; Koch & Koch 1993; Olney 1999; Turpin 2000; CLC 2008). The establishment of Warrabri settlement in 1956, now known as Alekarenge (Ali Curung), enabled Kaytetye families and their neighbours to remain on or close to their traditional lands. Others worked and lived on nearby Singleton and Neutral Junction Stations. Historical accounts in the 1960s reveal how the Aboriginal people who call this region 'home' in a traditional sense, were 'apparently prepared to stay at Singleton no matter how bad the conditions'.[2] Oral histories reveal

[1] Stuart 1865:79.
[2] Singleton Station CENSUS F133/22 (65/32); 1967.

that Traditional Owners and their ancestors have never ceased hunting and gathering on their traditional lands which includes collecting water from soaks, springs, swamps and creeks.

There is concern that this culturally important activity will be impacted by a reduction in groundwater and there will be a subsequent loss of associated cultural knowledge. Traditional Owners fear that the bigger animals will go to other areas to find water, and the smaller species will die out. People will feel a sense of shame and loss if they allow species to die out or find a 'new home'.

Traditional Owners have roles and responsibilities to maintain and protect their country including the plants and animals; in Aboriginal thinking, everything is connected and especially to water. Looking after country in a broad sense relates to sustaining the biodiversity through regular burns, cleaning out/covering up soakages and other activities. These cultural activities relate to preserving all aspects of the cultural landscape, including water sources, for future generations so that culturally valued natural resources can be sustained. The potential for Traditional Owners to get sick or die as a result of the believed consequences of non-compliance with the Law, by not looking after the water upon which the plants and animals living on their country rely, was a key theme expressed during this assessment.

As evidenced by existing literature and consultations with Traditional Owners, it is apparent there was much historical seasonal movement between soaks and living areas and ceremonial grounds across the drawdown area and beyond. Seasonal movement was previously a matter of ongoing residence, subsistence and ritual obligation, whereas nowadays seasonal movement to water sources is on a visiting/camping/hunting/ritual basis. Whilst country continues to be accessed for cultural purposes, movement between water sources has reduced. The continued cultural pattern being expressed links people to their past and provides promise for the future of their important cultural practices.

Today there are hundreds of Aboriginal people living close to the drawdown area and or regularly accessing the land for cultural purposes. There is a fear amongst Traditional Owners that their families will not attempt to travel lengthy distances for fear of getting thirsty and dying. Similarly, they fear that people will 'stay in town' if there is no available water on country. Concerns have also been raised by Traditional Owners that if people breakdown in their motor vehicles when out hunting in remote areas, they might not be able to rely on their traditional ecological knowledge to survive because the landscape and its resources may be altered.

> 'Don't they see that there are people living on this land? Living off this land? It's like when the British tested rockets at Maralinga they were blind and didn't see that people were living there. Then they made

the people sick and blind. The birds fell out of the sky. Their country was ruined. Yami Lester was blinded and he had no idea what was happening. Today we know what's about to happen, there is about to be a water crisis. We have to stop it before it happens.' *Maureen O'Keefe Nampijinpa*

Based on in-depth discussions with Traditional Owners when undertaking this assessment, it is clear that Traditional Owners would prefer to sustain the current health of their country and maintain their custodial responsibilities to it by opposing the Singleton Water Licence, rather than the alternative scenario of seeing their country get sick, having their traditional rights and interests eroded, and holding the psychological stress and guilt associated with knowing their descendants may lose important cultural values which have been sustained by Kaytetye people for thousands of years.

Traditional Owners desire to continue their active role in managing their traditional lands and waters for the future benefit of their society and culture. They want to guard the foundation of their ancient religion by defending their cultural values. To enable this to occur, it is recommended that the broad range of cultural values identified be sustained and safeguarded in accordance with national and international cultural heritage management practice (UNESCO 2003; ICOMOS 2017).

Good practice in the field of cultural heritage management includes working in cooperation with Traditional Owners to develop and apply an approach to cultural heritage management inclusive of a broad range of tangible and intangible cultural values. Traditional Owners' cultural values should not only be documented, Traditional Owners themselves should be empowered as active stakeholders and decision makers in matters that affect their land and waters.

1.0 INTRODUCTION

1.1 Background

On 2 September 2020, the Central Land Council (CLC) received a notice of intention (NOI) to make a groundwater extraction licence (water licence) decision. Fortune Agribusiness Funds Management Pty Ltd (Fortune Agribusiness) applied for the water licence over Singleton Station (see Figure 1). The application volume is 39,800 ML (megalitres)/year for agricultural purposes and 200 ML/year for public water supply purposes, a total volume of 40,000 ML/year.

Figure 1 Singleton Water Licence drawdown area and surrounding Aboriginal communities

Source: CLC 2021 [based on Fortune Agribusiness data][3]

[3] Georeferenced from Singleton Horticulture Project Summary Report (August 24:2020) and Groundwater Dependent Ecosystem Mapping and Borefield Design prepared by GHD (Sheet 8 of 12 from Figure 4-9: July 2020).

Singleton Station is situated within the Central Plains management zone of the Western Davenport Water Allocation Plan (WDWAP) (Northern Territory Government (NTG) 2018) and is located in the Central Australia region of the Northern Territory, 100 kilometres (km) south of Tennant Creek and 300 km north of Alice Springs.

According to the WDWAP, the NTG has committed to the long-term sustainable management of the Territory's water resources.[4] The WDWAP applies to the Western Davenport Water Control District (the District), which covers an area of almost 24,500 square kilometres located approximately 150 km south of Tennant Creek. The purpose of the plan is to ensure that water resources are managed in a way that protects and maintains environmental and cultural values while allowing water to be sustainably used for productive consumptive beneficial uses.[5] The objectives of the WDWAP are to:

1. Meet the environmental water requirements of water dependent ecosystems.
2. Protect Aboriginal cultural values associated with water and provide access to water resources to support local Aboriginal economic development.
3. Allocate water for future public water supply and rural stock and domestic purposes.
4. Provide equitable access to water to support ecologically sustainable regional economic development.

Three management zones have been recognised within the WDWAP district based on hydro-geologically distinct environments: the Davenport Ranges, the Southern Ranges and the Central Plains (Figure 2). The major groundwater resource occurs within the Central Plains Management Zone which is the subject of the Fortune Agribusiness water licence over Singleton Station. The WDWAP also acknowledges that a range of important tangible and intangible Aboriginal cultural values exist across the district:

> 'Aboriginal people within the District have a strong connection to country. The cultural landscape of this area includes physical (e.g., sacred sites, ancestor trees and other features such as stone arrangements) and non-physical (e.g. knowledge, practices, songs, ceremony) cultural values. All water sources such as soaks, rock holes, springs and rivers play a major role in the social, spiritual and customary values of the Traditional Owners of the District…the use of a water resource is not only physical and extends to other cultural values through activities such as visiting and maintaining sites, sharing and teaching cultural knowledge, conducting ceremony, or participating in management decisions. The significance of water for Traditional Owners is not limited to surface water and GDEs as it is found throughout the country and in all living things. Water availability also affects many activities, like hunting and harvesting for bush tucker, bush medicine, tool and craft making.' (WDWAP) (NTG 2018:28)

[4] NTG 2018:6.
[5] NTG 2018:6.

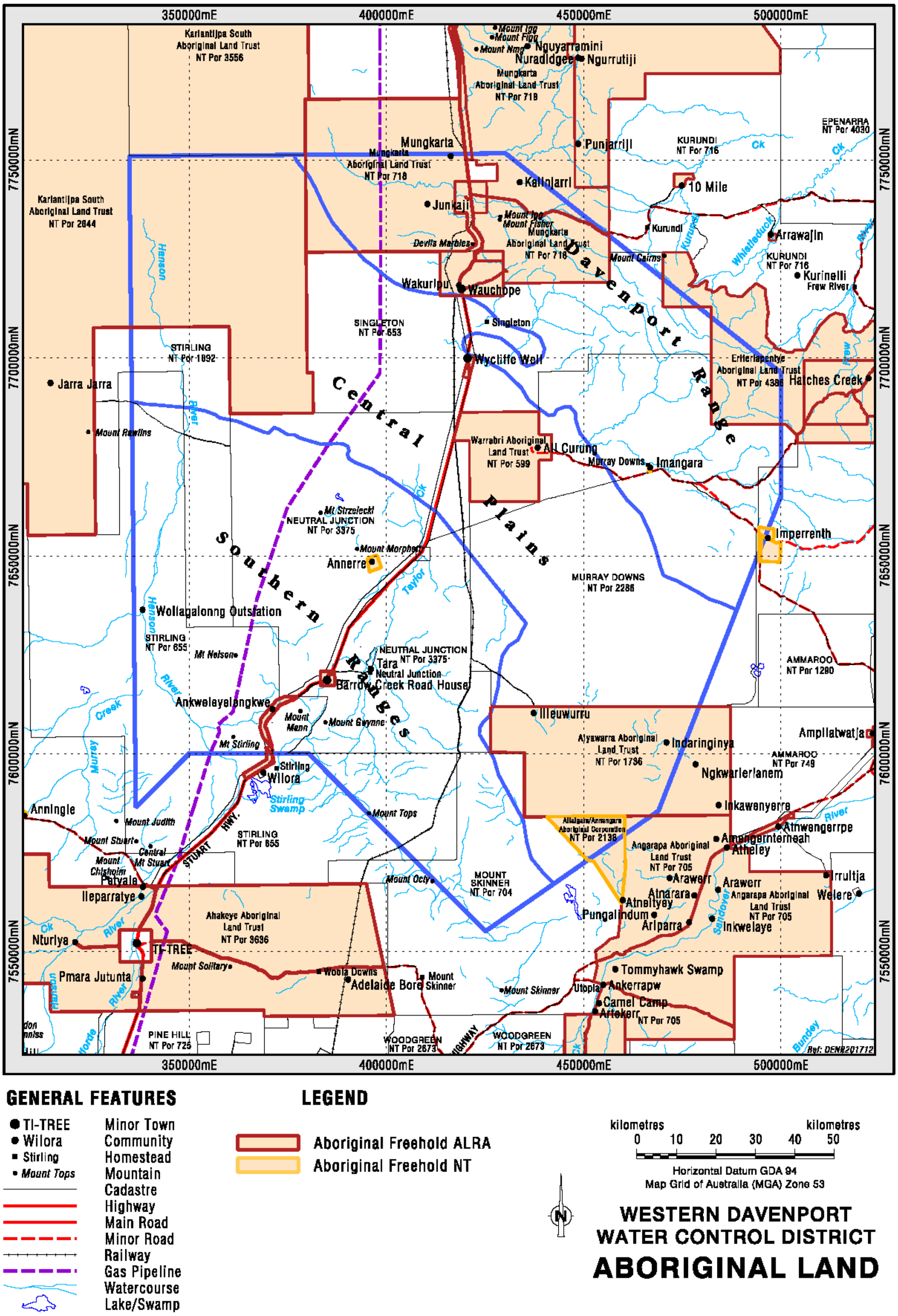

Figure 2 Western Davenport Water Control District

Source: NTG 2018.

Whilst the proposed water extraction zone (the proposed development wells / bores) is located on Singleton PL (see Figure 3), the projected groundwater drawdown area, as estimated by Fortune Agribusiness, extends beyond the water extraction zone to other parts of Singleton PL, and across Neutral Junction PL, Warrabri Aboriginal Land Trust (ALT) and Iliyarne ALT.

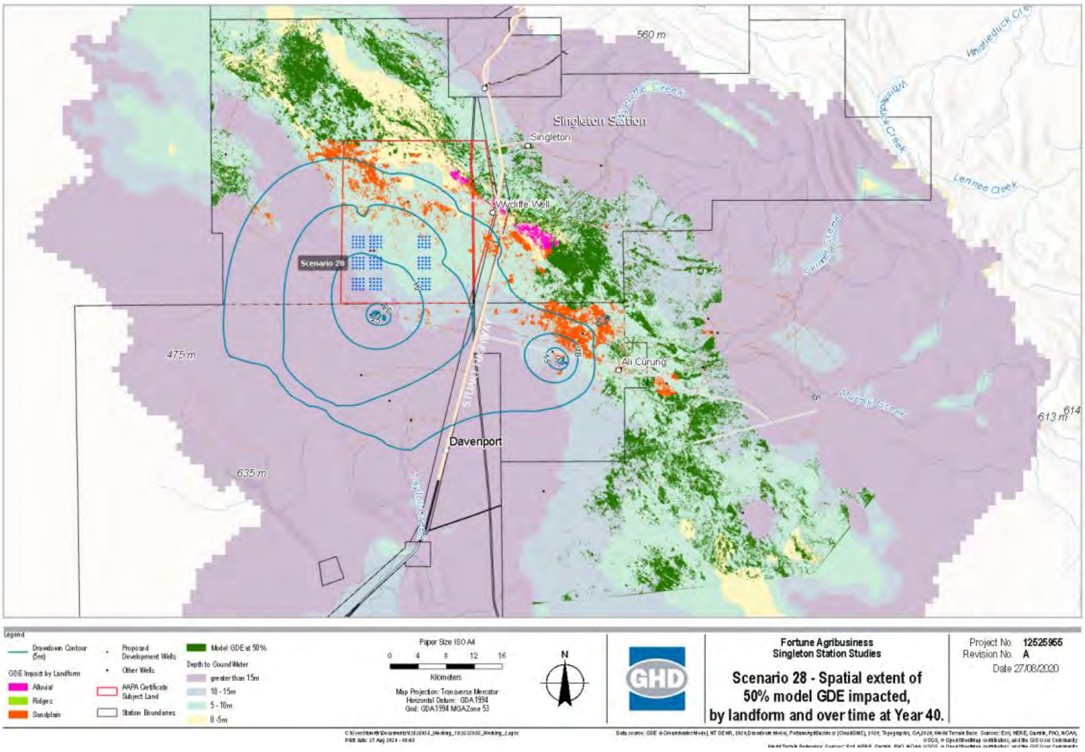

Figure 3 Spatial extent of Development Wells, Drawdown Contours, GDE impact by Landform and AAPA Certificate Subject Land

Source: Fortune Agribusiness 2020:28.

The definition of the drawdown area used in this report is the area identified by Fortune Agribusiness where impacts to GDEs will occur which include the area covered by the drawdown contours and GDE impacts by landforms (see Figure 3). This area was digitised by CLC geospatial staff (see Figure 4) using georeferenced map images submitted by Fortune Agribusiness in its application for the water licence.[6] The "Outer extent of drawdown area" (in Figure 4) is inclusive of GDE impact to alluvial and sandplain landforms described in the project documentation.[7]

[6] Singleton Horticulture Project Summary Report (August 24:2020) and Groundwater Dependent Ecosystem Mapping and Borefield Design prepared by GHD (Sheet 8 of 12 from Figure 4-9: July 2020).
[7] GHD (Sheet 8 of 12 from Figure 4-11: July 2020).

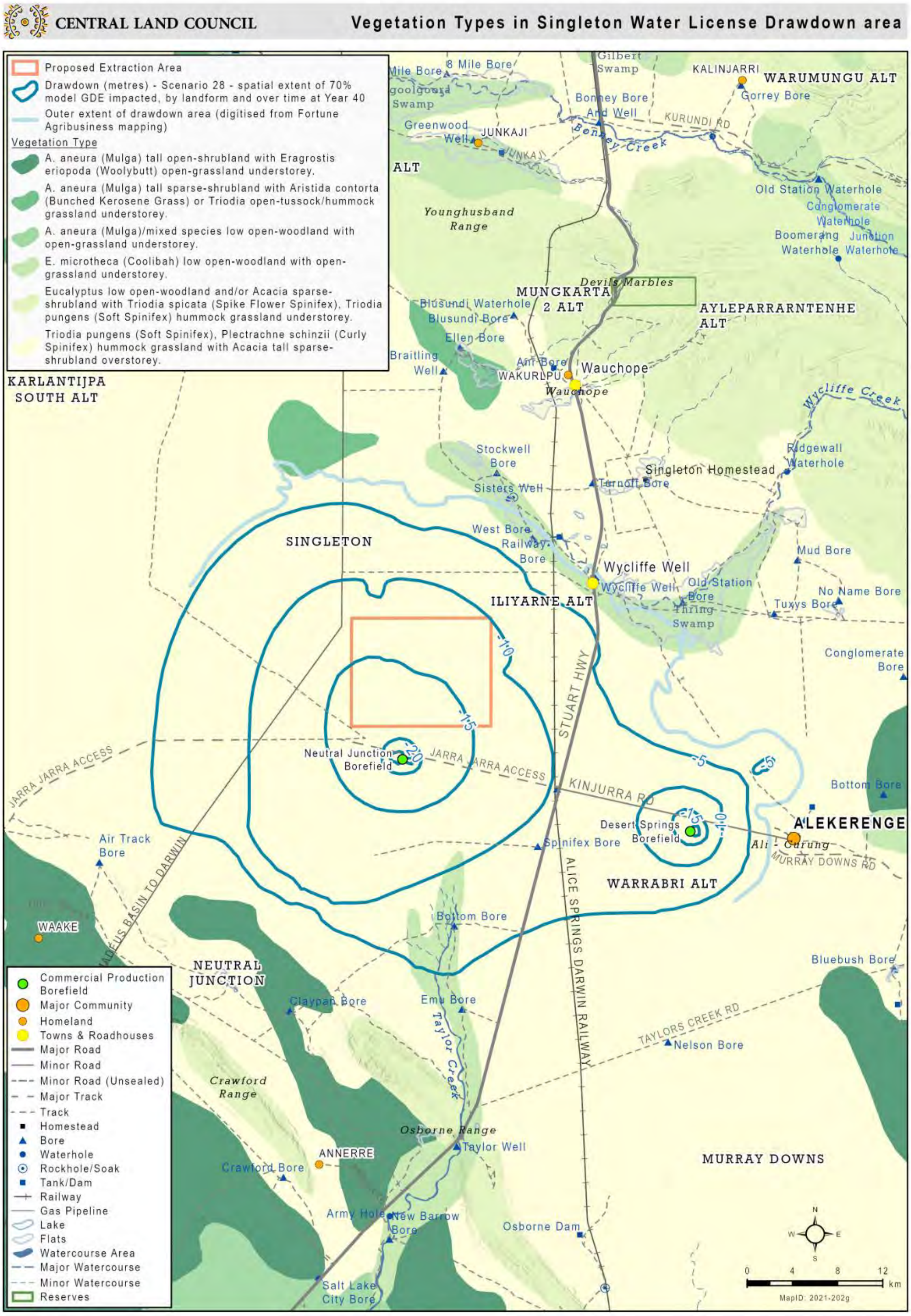

Figure 4 SWL drawdown area and vegetation map

The focus of this assessment, 'the study area', is the drawdown area (see Figure 4) which is predominantly sandplains containing termite mounds, sparse shrubs and low trees including *Acacia anuera* (Mulga), *Triodia basedowii* (Spinifex), *Triodia pungens* (Spinifex*), Triodia bitextura* (Spinifex) and *Eragrostis eriopoda* (Woollybutt).[8] A landform known as 'ghost gum rise' is located in the west of the study area in sandplain country. Alluvial plains are also found in the south of the study area where Taylor Creek forms a floodout, and in the north east of the study area which includes part of Thring Swamp and Wycliffe Creek and associated floodout. This vegetation type has a mixture of a small amounts of *Eragrostis eriopoda* (Woollybutt grass), *Aristida browniana* (Kerosene grass) and *Eucalyptus victrix* (Coolibah) over short grasses and forbs.[9] Both the alluvial plains and sandplains contain soakage water.

This assessment considers the study area in the context of the surrounding cultural landscape affected by the SWL including Wycliffe Sandhill immediately northeast of the drawdown area, the Crawford Ranges to the south, the Hanson River to the west and to the east the Davenport Range. This broader area encompasses Murray Downs PPL to the southeast, the Davenport Range National Park to the east, Kurundi PPL to the northeast, Mungkarta ALT and Devils Marbles (KARLU KARLU) Conservation Reserve to the north, and Karlantijpa South ALT to the west.

Singleton PL and Neutral Junction PL are subject to native title determinations; Mpwerempwer Aboriginal Corporation is the Registered Native Title Body Corporate (RNTBC) managing native title for Singleton PL and the Kaytetye Tywerate Arenge Aboriginal Corporation RNTBC and the Eynewantheyne Aboriginal Corporation RNTBC manage native title across Neutral Junction PL. The Traditional Owners across these determination areas have legal rights to access and travel over any part of the land and waters; live on the land; hunt, gather, take and use the natural resources of the land and waters; access, maintain and protect places and areas of importance on or in the land and waters; engage in cultural activities; conduct ceremonies; hold meetings; teach the physical and spiritual attributes of places and areas of importance; participate in cultural practices relating to birth and death including burial rites; regulate the presence of others at any of these activities on the land and waters; make decisions about the use and enjoyment of the land and waters by Aboriginal people; share and exchange natural resources obtained on or from the land and waters, including traditional items made from the natural resources.[10] The cultural values identified in this assessment are generally reflected in these legal rights.

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[8] Pers. comm. Jessica Burdon 27.07.2021.
[9] Pers. comm. Jessica Burdon 27.07.2021.
[10] In Rex on behalf of the Akwerlpe-Waake, Iliyarne, Lyentyawel Ileparranem and Arrawatyen People v Northern Territory of Australia (2010) FCA 911 (Singleton PL).

Fortune Agribusiness obtained a sacred sites Authority Certificate (AC) from the Aboriginal Areas Protection Authority (AAPA) for the proposed works. The AC subject land includes and extends beyond the water extraction zone but does not cover the entire estimated drawdown area (see Figure 3 and section 3.2).

On 8 April 2021, the Controller made its decision on Fortune Agribusiness's water licence application and decided on a staged approach; each stage is two years from the completion of the preceding stage; the final stage will continue until the end of the licence (i.e., from years 7–30 if Fortune Agribusiness proceed through the stages at full pace).

On 7 May 2021, CLC put in a submission seeking a ministerial review of the Water Controller's decision to grant the Singleton Water Licence (SWL). Of note is CLC's position that the Water Controller fails to take into account the impact that the SWL will have on Aboriginal cultural values in the Western Davenport District. Concurrently, the CLC was instructed by Aboriginal owners to further identify the cultural values associated with the SWL area and to consider how these values might be impacted by the granting of the water licence.

Anthropological consultant Susan Dale Donaldson was then engaged by the CLC to undertake the cultural values assessment. Donaldson was requested to prepare a report regarding the cultural landscape of the area affected by the SWL and the extent of the native title holders and traditional owners' rights and interests and their cultural beliefs and practices. The report is to be culturally non-restricted and requires free, prior and informed consent (FPIC) by informants for use in the public domain.

1.2 Methodology

The methodology for this assessment involved reviewing literature; engaging with Aboriginal owners who hold knowledge of the area; analysing all the available evidence and considering how the identified values may be impacted by the proposed work. The approach was based on the Australian Burra Charter Practice Note on Intangible Cultural Heritage and Place (ICOMOS 2017).

LITERATURE REVIEW

The literature review covered a broad range of published and unpublished sources relating to Aboriginal traditional and contemporary life, as well as key project documents, land claim materials, archaeological and historical materials and ecological papers relating to groundwater dependent ecosystems.

Specific project reports reviewed include the WDWAP (NTG 2018); the AAPA Certificate C2019/083 (NTG 2019); the Singleton Horticulture Project summary report (Fortune Agribusiness 2020); and the recent NTG report on the ecological characteristics of potential groundwater dependent vegetation in the Western Davenport Water Control District (Nano et al. 2021).

Historical materials reviewed include Stuart 1865 (1975); Spencer & Gillen (1904); Davidson (1905); Aboriginal Land Commissioner (1982); Flood (1983); Petrick (1983); Bell (1983); Nash (1984); Smith (1987); Aboriginal Land Commissioner (1988); Koch & Koch (1993); Horton (1994); Courto (1996); Mulvaney & Kamminga (1999); records from the National Archives of Australia (NAA); Federal Court of Australia (*FCA 472* 2004); and personal communication with past and present Aboriginal owners.

Anthropological and ecological materials reviewed include The Rainbow-serpent in South-east Australia by Radcliffe-Brown, A. R. (1930); 'Aboriginal Territorial Organization: Estate, Range, Domain and Regime' Stanner, W. E. H. (1965); The Australian Aborigines: A portrait of their Society by Maddock, K. (1972); Tribes and Boundaries in Australia by Peterson N. (ed.) (1976); *The Nutrition of Aborigines in Relation to the Ecosystem of Central Australia* Hetzel, B. & H. Frith 1978 (eds.); The World of the First Australians by Berndt, R. M. & Berndt, C. H. (1988); Bushfires & Bush tucker: Aboriginal Plant Use in Central Australia by Latz, P. (1995); *Nourishing Terrains: Australian Aboriginal Views of Landscape and Wilderness* by Rose, D. (1996); 'Freshwater' in ATSIC Background Briefing Papers- Water Rights Project by Langton, M. (2002); Ngapa Kunangkul: Living Water. Report on the Aboriginal Cultural Values of Groundwater in the La Grange Sub-basin by Yu, S. (2002); United Nations Educational, Scientific and Cultural Organization (UNESCO) *Convention for the Safeguarding of the Intangible Cultural Heritage* (2003); The National Water Initiative and Acknowledging Indigenous Interests in Planning by McFarlane, B. (2004); 'Fresh Water Rights and Biophillia: Indigenous Australian Perspectives' by Rose, D. (2004); Study of Groundwater-Related Aboriginal Cultural Values on the Gnangara Mound, Western Australia by McDonald, E., B. Coldrick & L. Villiers (2005); 'Water Ways in Aboriginal Australia: An Interconnected Analysis' by Touissant, S., Sullivan, P. and Yu, S. (2005); 'Compartmentalising Culture: The Articulation and Consideration of Indigenous Values in Water Resource Management' by Jackson, S. (2006); Cultural Values Associated with Alice Springs Water by Kimber, R. G. (2011); *The Kalpurtu Water Cycle: Bringing Life to the Desert of the South West Kimberley in Country, Native Title and Ecology* by Sullivan, P., H. Boxer (Pampila), W. Bujiman (Pajiman) & D. Moor

(Kordidi) (2012); Burra Charter Practice Note on Intangible Cultural Heritage and Place (ICOMOS 2017); and Framing the Loss of Solace: Issues and Challenges in Researching Indigenous Compensation claims by Pannell, S. (2018).

ENGAGING WITH TRADITIONAL OWNERS

Engagement with Traditional Owners was undertaken according to current Australian best practice in cultural heritage management. This includes consideration of the following documents: Working with Indigenous communities leading practice Sustainable Development Program for the Mining Industry (Australia Government 2016); Guide to Free, Prior and Informed Consent (Oxfam Australia 2010); Ask First: A Guide to Respecting Indigenous Heritage Places and Values (Australian Heritage Commission 2002); and Guidelines for Ethical Research in Australian Indigenous Studies (Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS) 2012).

Qualitative ethnographic research methods were undertaken including participant observation, physical inspection of sites with the Traditional Owners, community meetings, mapping workshops, in-depth one on one interviews and small semi-structured, focus group sessions. The consultant was assisted by CLC staff members to consult 80 Aboriginal people including:

- Kaytetye Traditional Owners from the Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe groups associated with the drawdown area across Singleton PL, Neutral Junction PL, Warrabri ALT and Iliyarne ALT
- members of neighbouring groups Anterrengeny (Alyawarr), Jarra Jarra and Warlapanpa (Kaytetye), Kelantjerrang, Karlu Karlu, Jalyjirra, Miyikampi and Kanturrpa (Warumungu/Warlpiri)
- members of other groups across the region Warupunju and Kunapa (Warumungu); Thankgenerang and Etwerrpe (Kaytetye) and Ngappa (Jingilli/Mudburra), and
- residents of affected communities including Alekarenge, Wauchope, Barrow Creek, Tara, Wilora, Anerre, Waake, Mungkarta, Kalinjarri and Imangara.

Consultations took place within and beyond the drawdown area over the period 8–27 June 2021. Twenty-two sacred sites were visited with Traditional Owners across Warrabri ALT, Singleton PL and Neutral Junction PL; of these 11 were within the drawdown area and 11 beyond it. Many more sites within and beyond the drawdown area were identified through desktop research and / or discussed with Traditional Owners during the consultation period, but not visited. All of the sites visited have features dependent on groundwater.

Background research combined with consultations with Traditional Owners identified 40 sacred sites associated with 20 *Altyerre* [Dreaming] mythologies within the drawdown area. Considering not all of the identified sites were visited during the assessment combined with the cultural complexities of the region, it is possible that one or two of the sites identified are actually the same place known by different names. It is also possible that other sites exist within the drawdown area that were not identified during this assessment. More time on the ground with Traditional Owners would provide further clarity on the cultural landscape in terms of the presence and significance of sacred sites.

Following the identification of current cultural values and how native title rights and interests are exercised today, potential material and non-material loss was investigated. This enabled an understanding of potential impact to native title rights and other cultural values.

ANALYSING AVAILABLE EVIDENCE

Following community engagement, the documented evidence was analysed to determine the cultural values and the relationship between the elements across the cultural landscape. A landscape or a feature may be associated with a number of different heritage themes and cultural activities and the feature's physical form may have been altered over time.

In determining the significance of intangible values across a cultural landscape, its features, and the relationships between them, consideration was also given to how well the themes and historic periods are represented and how the important characteristics of the cultural landscape compare with those of other places. The scale of the significance needs to be determined, i.e., whether the place is of local, regional, state, national or international significance.

IDENTIFYING IMPACTS

The Burra Charter Practice Note on Intangible Cultural Heritage and Place (ICOMOS 2017) does not directly define how intangible values can be harmed or damaged nor does it provide a framework for assessing impacts to intangible values. It does however outline how change to a place may impact on a cultural practice and equally changes to a cultural practice may impact on the cultural significance of a place. Possible changes that might impact on cultural practices include:

- changes to use or access
- changes to the form, fabric or layout of the place
- restrictions on the spaces available for cultural practices.

Generally, impacts can be both positive and negative and may result in the need for management, whether broad landscape processes or small-scale actions. If the existing condition of certain individual features are in poor condition, it may be the case that the proposed works will improve the situation. Processes likely to degrade the values and condition of the landscape and its features also need to be identified. Threats include an increase in usage or the potential to pollute waterways, for instance. Different components of the cultural values across the landscape will almost certainly require different treatments or impact mitigation measures in order to safeguard the identified values. Whilst impact mitigation is not addressed in this assessment, it is worthwhile outlining current best practice framework around ways to sustain and safeguard intangible cultural values nationally and internationally.

The Australian ICOMOS Burra Charter Practice Note on intangible values outlines ways to 'sustain cultural practices' involving collaboration between the associated communities and the place manager/land owner. Suggested management policies and actions may be needed to help sustain the cultural practices including:

- protection of any fabric or parts of the place which are integral to the cultural practices
- introducing cultural protocols such as restrictions on access or activities undertaken in parts of the place
- checking that the circumstances at the place support continuation of the cultural practices.

Similarly, the United Nations Educational, Scientific and Cultural Organization (UNESCO) Convention for the Safeguarding of the Intangible Cultural Heritage (2003) focuses on 'safeguarding' the processes from which the intangible values arise. This approach aims to ensure intangible cultural heritage is continuously recreated and transmitted. For UNESCO safeguarding intangible cultural heritage is about the processes involved in transferring of knowledge, skills and meaning from generation to generation, rather than on the production of its concrete manifestations, such as dance performances, songs, music instruments or crafts. As with the ICOMOS approach above, safeguarding measures must be developed and applied, with the consent and involvement of the community itself. Moreover, safeguarding measures must always respect the customary practices governing the access to heritage, which might, for instance be the case when dealing with sacred or secret intangible cultural heritage manifestations (UNESCO 2003).

2.0 IDENTIFIED ABORIGINAL CULTURAL VALUES

The cultural values assessment identified a complex Aboriginal cultural landscape across the SWL groundwater drawdown area including important cultural values directly associated with groundwater dependent ecosystems (GDEs).[11] The assessment found the SWL area to be situated on the traditional lands for four *Kaytetye* speaking groups (*Anerre, Waake-Akwerlpe, Iliyarne* and *Arlpwe)*. An additional 23 Aboriginal groups, from *Kaytetye, Alyawarr, Warumungu* and *Warlpiri* language regions were also identified across the broader Western Davenport District as being culturally associated with the SWL drawdown area.

2.1 Following the *Altyerre* Law & cultural obligations

Kaytetye people believe that the traditional laws and customs by which they are connected to the land and waters were created in a mythological era known in Kaytetye as *Altyerre* and in English as 'The Dreaming'.[12] The term *Altyerre* covers a range of interconnected concepts including ancestry, mythological beings and their creative journeys when the landscape was given form, religious laws and ritual objects, sacred designs and songs, important places, and codes of social order. Natural features across the landscape are believed to be an embodiment of *Altyerre* power and are thus revered, and cared for so they can be handed onto succeeding generations intact. Whilst the *Altyerre* is the basis of the Kaytetye religious system and directs Kaytetye ritual life, the concept extends across the continent.[13]

> 'When the wild spirit men flew over Iliyarne country they saw no water. Then when the country men, the Iliyarne men flew over they saw the water shining in the sun light. The country showed them the water. The spirit people who live there are tricky ones.' *Heather Anders*on

Traditional Owners' belief in the *Altyerre* is the cornerstone cultural value arising from this assessment and the foundation of all other identified cultural values. 'Sacred sites' (*Ihangkele*) are places where mythological *Altyerre* ancestors reside and, in this region, primarily relates to reliable sources of water (*arntwe*) including *artnwep* (swamps), *ngentye* (soakages) and *elpaye* (creeks), and *ilinjera* (floodouts).

Undertaking cultural obligations such as visiting sacred sites, speaking to the spiritual ancestors and re-enacting mythological stories in song and dance, according to *Altyerre* laws and customs, appeases the creator spirits residing in country (*apmere*).

[11] GDE as defined in Cook and Eamus 2018:1; also pers. comm Ryan Vogwill and Jessica Burton 10.08.2021.
[12] Spencer & Gillen 1904:13–14; Kaytetye orthography in this assessment was developed by Turpin 2000.
[13] See Maddock 1972; Berndt & Berndt 1988; Rose 1996.

The beliefs of present-day Traditional Owners reflect observations made by Spencer and Gillen in 1904. They found that:[14]

> From time immemorial, that is, as far back as ever native traditions go, the boundaries of the tribes have been where they are now fixed. Within them their ancestors roamed about, hunting performing their ceremonies just as their living descendants do at the present day. Very probably this is associated with the fundamental belief that his alcheringa (=*Altyerre*) ancestors occupied precisely the same country which he does now. The spirit parts of these ancestors are still there…The spirit individuals would not permanently leave their old home, and where they are there must he stay.

This observation is significant in the present context as it emphasises how Kaytetye people's traditional connection to the drawdown area is based on religious associations to particular ancestral lands in accordance with an acknowledged system of traditional land ownership. Moreover, permanent waterholes are usually associated with highly restricted *Altyerre* activities and rituals. Whilst no permanent springs were identified within the drawdown area there are many nearby that are associated with highly significant water dreaming mythologies and rituals as Mr Jones explained:

> 'The springs are important places and each have a story. In Warumungu we say *Junjunpartin* for water bubbling up, springing up. We don't really have a word for underground water. Under is *kantangara* and water is *Ngappa*. There is a spring between Karlinjarri and Kurundi. There is a spring at Old Elkedra station where the underground snake scared the station manager away, they were forced to relocate. Another story, Ngappa came underground from the west all the way to KELLY WELL, near the tower, then travelled to a spring where the lightning struck. It then travelled to the east.' *Michael Jones*

Turpin recorded the story about the establishment and subsequent failure of Old Elkedra Station, mentioned by Michael Jones. According to Tommy Thompson (dec.) the station managers built their cattle yards and house near the water edge at NKWARRENY:

> …where the snake lives in the water…the rainbow snake was left alone because he was underwater in a cave, like a well. A big rain came and fell on them; it was huge…It was still the rainy season; the snake rose up from there, from that waterhole, it rose up really high and soon there was a big wind and they

[14] Spencer & Gillen 1904:13–14.

saw lightning and rain. The old men were looking at it while it was standing. First, they woke up the bosses, Bill Riley and Kennedy, then the others…The whitefellas saw the snake, grabbed their rifles and shot at the eye of the huge snake coming out of the waterhole. The snake went down then, during the night time. It was the power of the snake that made the rain flatten the trees and the creek flood. It was the snake that let that water out. The old people who knew about the rainbow snake said 'that's the rainbow snake all right…'…the old people knew the song to sing the snake down. After the snake went down, a rainbow shone there. A rainbow was in the sky…the people left because of the snake…they were heading to ARRTYELER.[15]

An example of the intersection between groundwater dependent ecosystems and the Traditional Owners' obligations under traditional laws and customs relates to a highly significant, ancient coolibah tree at MPWEREMPWER-ANGE swamp close to Wycliffe Creek (see Figures 5 and 6). The Coolibah tree is the home, the main place of residence for the *Altyerre* beings that created MPWEREMPWER-ANGE. The coolibah tree is the subject of Iliyarne family stories, ritual songs and paintings. Iliyarne people also visit the tree and at such times, speak to their spiritual ancestors residing in and around the tree. These ritual acts appease the spiritual ancestors who in turn provide ample lilies for Iliyarne people to collect and consume. An increase in lilies indicates to Traditional Owners that the ancestors are pleased that the Law is being followed and traditional culture is being maintained. These ritual acts also maintain the health of the tree into the future, in accordance with customary law. This in turn leads to a sense of wellness amongst the Iliyarne Traditional Owners.

Figure 5 Mature Coolibah tree in MPWEREMPWER-ANGE swamp, Iliyarne ALT

Source: Photograph by Susan Dale Donaldson.

[15] Turpin 2003:38–52; see also Elkin 1930.

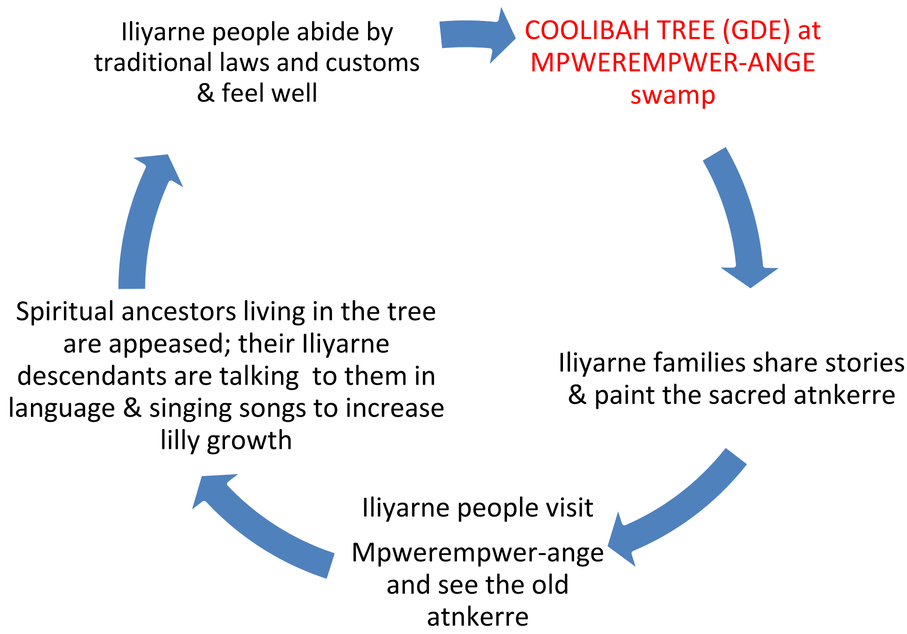

Figure 6 The intersection between the importance of following the Law and groundwater dependent ecosystems

If the *Altyerre* Law is not followed as a result of the actions of Traditional Owners or others, senior Traditional Owners and non-Indigenous people may be punished by *Altyerre* forces resulting in sickness, injury and even death (see Section 3.1).

> 'We know the *Nguramulla* (Spirit people) live in the land and if we don't look after our land, they will feel sad and get sick and so will Traditional Owners. That's why we always look after our country.' *Michael Jones*

> '*Kwertengerl* need to start talking to protect that big coolibah tree at MPWEREMPWER-ANGE. That Dreaming Tree is the Kwerrimpe [ceremonial women] digging lilies. If that tree is touched or injured sickness will come and blindness for Aboriginal people and white people too. That lily wasn't a traveller, it just belongs to this one place. People need to say no to this water or go blind.' *Ned Kelly*

Overall, it is believed that the powerful forces of the *Altyerre* will remain in the land and waters for eternity, but the current generation of Traditional Owners responsible for looking after the land and water will be punished if cultural obligations are not undertaken in their lifetime. All Kaytetye families hold stories about individuals who broke the Law and were punished because they didn't exercise their custodial responsibilities and look after their country.

2.2 Maintaining spiritual connections and protecting sacred sites

Traditional Owners maintain that they have descended from *Altyerre* (Dreaming) ancestors and that their *etnwenge* (a person's spirit) is deeply connected to one's country (*apmere*) and especially to water (*arntwe*).[16] In the *Altyerre* the landscape was given form by the activities of mythical beings, the spiritual ancestors of Kaytetye people today. Across the SWL area, these spiritual ancestral beings were in the form of animals such as possums, kangaroos, dingos, frogs and birds; plants such as the lily, bush plum and orange tree; and natural phenomena such as the wind and rain. The routes taken by ancestral beings and the places where they camped, danced and hunted were transformed into natural features such as rivers and valleys, waterholes and trees. Traditional Owners consider these places associated with ancestral creation, sacred sites.

This assessment revealed a strong spiritual connection between Traditional Owners and 40 sacred sites identified within the drawdown area.[17] Each of the 40 sacred sites were beyond the immediate extraction zone and all have features associated with GDE as outlined below. These sites all have unique Kaytetye names and are associated with at least 20 *Altyerre* mythological episodes as depicted in the dynamic cultural landscape diagram (see Figure 7). Due to sensitivities surrounding cultural knowledge and information the specific name of each *Altyerre* Dreaming track and each sacred site is not described in the diagram (Figure 7); the coloured lines relate to the many *Altyerre* tracks and the 40 dots each represent a sacred site within the drawdown area. It is clear from this image that the SWL drawdown area contains specific cultural values and is concurrently integrated into a broader cultural landscape from which it draws significance.

Most of the identified *Altyerre* tracks traverse the drawdown area and interlink with places across the broader cultural landscape. Some *Altyerre* creation stories cover vast distances whilst others are more localised, marking discrete territories. Across the drawdown area for instance, the *Ankerratye* (Coolibah grub) waited at a soakage on Taylor Creek, and was integral in making rain there. Similarly, the *Aterre* (Cicada) story wasn't a traveller, it always resides at a particular soakage in the Taylor Creek floodout and the *Mpwerempwer* (Lily) resides within a sacred coolibah tree at Thring Swamp [also known as 'Lily Swamp']. These places are within the drawdown area.

Travelling mythologies can relate to vast areas and multiple sacred sites. The *Atherre Aleke* (=Two Dingos) Dreaming for instance is associated with a stretch of country between Western Australia and Alekarenge, traversing close to the drawdown area. The *Ahakeye* (Bush Plum) Dreaming is another extensive traveller and is associated with two important soakages within the drawdown area, close to the extraction zone.

[16] Spencer and Gillen noted 'alcheringa' (1904:11–14,161). In this region, the Dreaming is also known as *Altyerr* (Alyawarr), *Wirnkarra* (Warumungu), and *Jukurrpa* (Warlpiri). See also Sullivan et al. (2012).
[17] 29 sacred sites were identified within the drawdown contour zone and a further 11 sacred sites within the GDE impact by landform zone [total 40 sacred sites across drawdown zone].

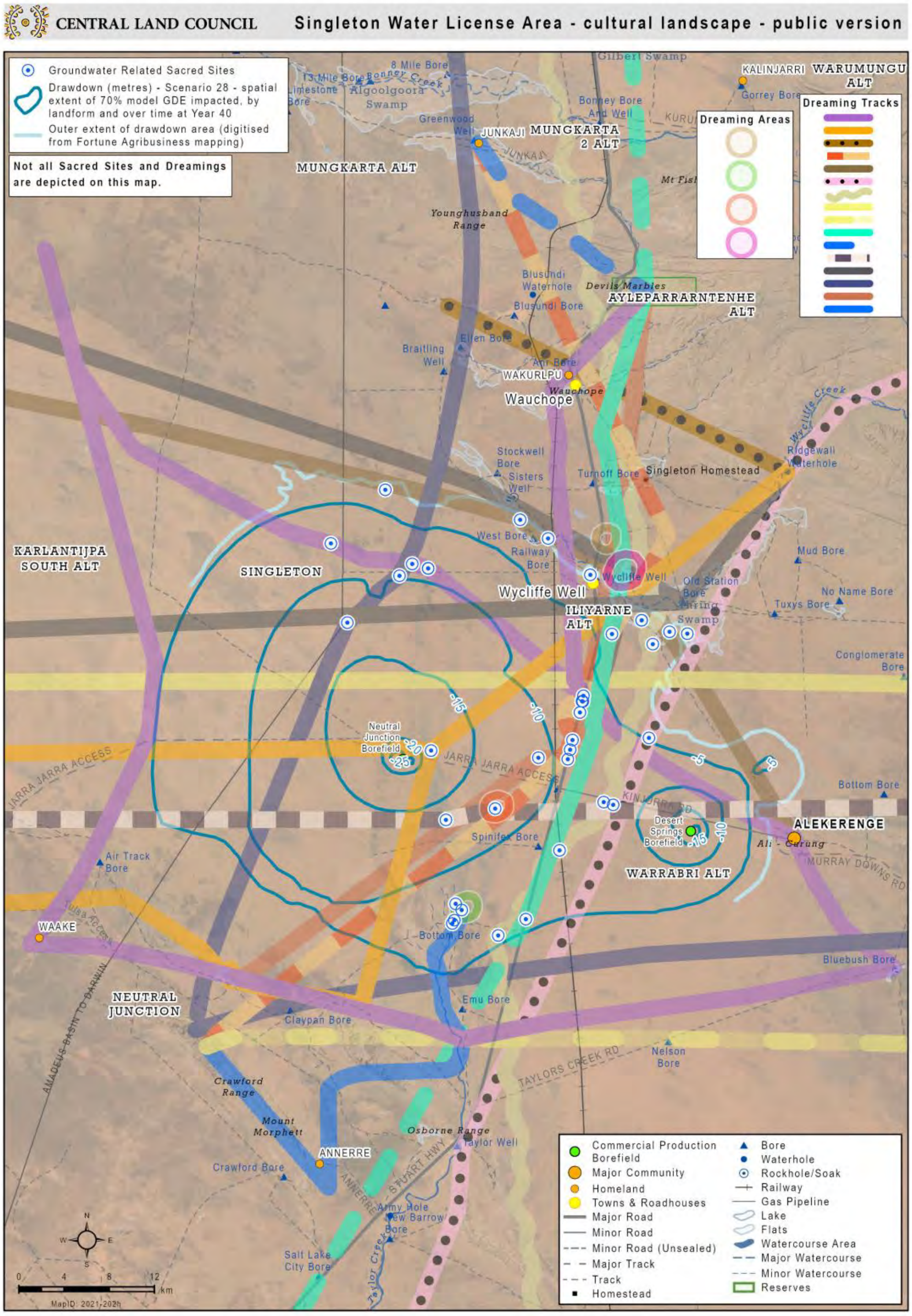

Figure 7 Cultural landscape diagram: Altyerre (Dreaming) activity across the SWL area

Source: CLC 2021 (based on data collected by Donaldson).

Other extensive travellers associated with sacred soakages within the drawdown area include the *Awentyerrenge* (Whirliwind) Dreaming; *Therre Antywempe* (Two Taipans); *Therre Atyewtere* (Two bandicoots); *Anatye* (Yam Dreaming); and the *Atnhelengkwe* (Emu). Whilst the *Ilperalke* (Sugar Bag) Dreaming travelled across the extraction zone and drawdown area, no sacred sites associated with this tradition were identified within the extraction zone or drawdown area. The *Ilperalke* (Sugar Bag) travelled underground close to the drawdown area and rituals associated with this tradition are believed to increase sugar bag (= honey from native bees) supplies across the drawdown area to *Anerre, Waake-Akwerlpe, Iliyarne* and *Arlpwe people* as well as to the people with whom they share their country.

Whilst all of the mythologies across the drawdown area relate to the *Altyerre* creation of the land and water generally, a number of mythologies specifically relate to water. For instance, *Arnkerrthe* (Thorny Devil Lizard) ancestor carried water on his back in preparation for a rain ceremony as he travelled making soakages across the drawdown area*; Kwerrimpe* (Ceremonial Women) dug for water as they travelled and in doing so made a stand of Coolibah trees within the drawdown area; *Therre Arinenge* (Two euro rainmakers) travelled far and wide, including to two soakages within the drawdown area, teaching their neighbours how to make rain and lightning and collecting people for a regional rain ceremony; and the *Akwelye* (Rain) Dreaming specifically travelled around Anerre country, defining the boundaries of that country and creating three important *Akwelye* (Rain) soakages along Taylors Creek within the drawdown area.

Other dreamings have been identified immediately beyond the drawdown area including the travelling *Arinenge* (Euro) Dreaming and the localised *Anemarranenke* (Sand Frog). These two traditions are associated with GDE and form important connections across the cultural landscape, but they were not found to be associated with sacred sites within the drawdown area. Another important Dreaming found within the cultural landscape but beyond the drawdown area, is associated with culturally restricted information and is not outlined in this assessment.

One particular sacred site, a soakage close to the extraction zone and within the drawdown area, is an important yam dreaming site owned by the Anerre group (Figure 14). Anerre people visit the place to clean the soak, to talk to their spiritual ancestors and to teach younger Anerre people about the sacred site. The soakage has been protected by Traditional Owners over the years through these customary actions and by participating in sacred site clearances associated with roadworks. The water collected from the soak embodies *Altyerre* power and is highly valued and therefore protected by Traditional Owners in accordance with their traditional laws and customs.

As noted above, participants also hold linguistic connections to sacred sites and their ongoing use of unique Kaytetye terms and place names to describe the importance of groundwater across the drawdown area was apparent. In 1901 when Spencer and Gillen camped at Wycliffe Well, Gillen recorded the Aboriginal name for Wycliffe Well as 'Nan-pu-lunga' (=INYANPULUNGKU) and noted the presence of one Kaytetye man, his three wives and a child.[18] INYANPULUNGKU is sacred soakage within the drawdown area. Given the cultural sensitivities an exhaustive list of sacred site names is not outlined here. A collation of site types within the drawdown area, described in Kaytetye, has however been produced as a way for the reader to better understand the cultural landscape in relation to GDE and sacred sites (see Table 1). Over half of the sacred sites identified are soakages which continue to be valued by Traditional Owners today as an important source of water as well as spiritual sustenance.

Table 1 Kaytetye GDE terms by known sacred sites within drawdown area

Dominant feature	Number of sites within DA	Other associated sacred features
ngentye (soakage)	28	*Atwerety* (bean tree), *artetye* (mulga tree), *akerleye* (bush orange).
elpaye (creek)	3	Ghost gums and *aylpele* (river red gum).
ilinjera (floodout)	2	-
artnwep (swamp)	1	*Mpwerempwer* (lily)
arrkarakw (bloodwood)	3	-
atnkerre (coolibah tree)	1	*artnwep* (swamp)
Supplejack tree	1	-
Ghost gum tree	1	*elpaye* (creek)
TOTAL	40	-

[18] Gillen 1968:171–172. Gillen named the Aboriginal man 'Spencer'.

In 2003, linguist Myfany Turpin recorded a story told by senior Kaytetye man Tommy Kngwarraye Thompson (now dec.), relating to a spring and the origins of the Kaytetye language.[19] Thompson tells of how the source of the Kaytetye language is associated with a spring called ELKEREMPELKERE, at Barrow Creek:[20]

> …they (the *Kwerrimpe* women) spoke their language; it was Kaytetye…they told each other Dreamtime stories, special stories that had the power to create. From these stories the Kaytetye language and people were born. The *Kwerrimpe* women were talking Kaytetye, laughing, having fun and eating bush onions…From just one bush onion shoot the Kaytetye language and people spread out…The Dreaming at ELKEREMPELKERE is the origin of the Kaytetye language and people.

Today, Kaytetye people expressed a desire to ensure their Kaytetye place names are maintained into the future, and in particular the Kaytetye names of the water sources including the drawdown area. Intergenerational visits to country are one way that Kaytetye people pass on cultural and linguistic knowledge sustaining this important value, which also relates to spiritual connections to country given the places names were allocated in the *Altyerre* past.

Whilst the facts about the extent of groundwater deduction and the groundwater dependence of vegetation are not known at present, it is assumed that at some point of groundwater reduction there will be effects on GDEs and cultural values related to shallow groundwater.[21]

Of the identified 40 sacred sites within the drawdown area, 11 were visited during this assessment between 22 and 24 June 2021. These site features were all groundwater dependent including such as soakages, bean trees, orange trees, coolibah trees, creeks, swamps, ghost gum trees and bloodwood trees.

Figure 8 Kaytetye men at a sacred soakage, Warrabri ALT

Source: Photograph by Susan Dale Donaldson.

[19] Turpin 2003.
[20] Turpin 2003:2–5.
[21] See Nano (Appendix 4: 2021) for a listing of species which are "closely associated with sandplain and alluvial potential GDV". These species are more likely to be affected by groundwater drawdown.

Each of these sites are sacred to Kaytetye people, and in particular to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people. Each of these sites are interlinked with the broader cultural landscape. A few examples are shown in Figures 8–10.

Figure 9 Kaytetye women at a sacred soak and red river gum on Taylor Creek, Neutral Junction PL

Source: Photograph by Susan Dale Donaldson.

Figure 10 A sacred soakage and bean tree, Singleton PL

Source: Photograph by Susan Dale Donaldson.

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A further 11 important sacred sites were visited across the broader cultural landscape beyond the drawdown area between 22 and 24 June 2021.

Most of the sites were within 5–10 km from the drawdown area and three significant sites 15–20 km away from the drawdown area were also visited for cultural context.

The site features visited beyond the drawdown area were all groundwater dependent and include soakages, springs, bean trees, fig trees, red river gum trees, coolibah trees, creeks, swamps, and ghost gum trees (see Figures 11–13).

Figure 11 A sacred bloodwood, Warrabri ALT

Source: Photograph by Susan Dale Donaldson.

Figure 12 Kaytetye men at a sacred creek, Iliyarne ALT

Source: Photograph by Susan Dale Donaldson.

As with the sites visited within the drawdown area noted above, each of the sites visited beyond the drawdown area are sacred to Kaytetye people, and in particular to the Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe groups and interlink with the broader cultural landscape including places within the drawdown area.

Figure 13 Kaytetye group at sacred swamp, Iliyarne ALT

Source: Photograph by Susan Dale Donaldson.

The spiritual connection Kaytetye people have to sacred sites, that is the intangible link between a person and a sacred place, is directly associated with the condition of sacred sites (Figure 14).[22] If the state of a sacred site is diminished, the spiritual connection people have to that place is also diminished. Maintaining spiritual connections to country also occurs when mythological episodes are re-enacted by Traditional Owners in ritual, through song, dance, paint, story-telling and by visiting the spiritual ancestors residing at sacred places.

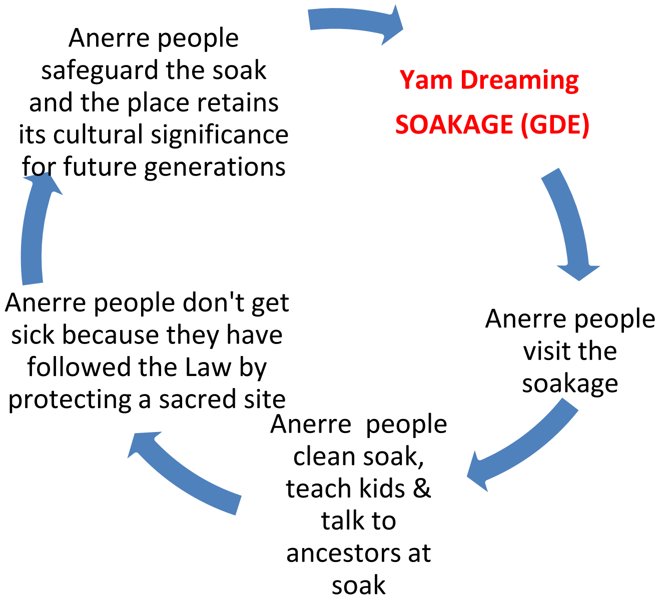

Figure 14 The intersection between the importance of protecting sacred sites and groundwater dependent ecosystems

[22] See also McDonald et al. 2005:2.

2.3 Undertaking rituals associated with groundwater and GDE

The assessment also found that the spiritual connection Traditional Owners have with their *apmere* (country) is strengthened by ritual activity which is also linked to the powerful forces of the *Altyerre*. Kaytetye ceremonies undertaken by men are called *etnherrantye* and women's ceremonies are called *erntweyane.* There are a number of ceremonial grounds close to the drawdown area, used by Traditional Owners or their ancestors in the past. These ritual grounds retain ritual significance and cultural associations and are hoped to be used by Traditional Owners again in the future. The rainmakers undertake rituals to make rain and other ritual leaders undertake rituals to increase species across the drawdown area such as lilies, frogs and bees.

> 'The songs and the ceremonies will be alive forever; nothing can touch them. The rainmakers have powers. In the early days they (stations) not use too much water now they want more, too much. Each one (Aboriginal group) has *Ngappa* (water) dreaming, they follow their line and hand it over.' *Donald Thompson Akemarre*

> 'My grandmother Molly O'Keefe used to dance and sing on Singleton Station at Stockwell Bore. They used to walk from there to the sandhill to get water on the north side.' *Evangeline Presley*

> 'We do ceremony to liven up the bees' wings to make them strong, so they make more honey. We know the different types of honey, from the different flowers. The white gum flowers make sweeter honey than bloodwood flowers. We take the honey and leave the bee house because that's where he lives. That's his place. We call water *Arntwe* in Kaytetye and *Kwaty* in Alyawarr and *Ngappa* in Warumungu and Warlpiri. That's the water that falls from the sky and the water that's in the ground. It's all water. It's all from the Dreaming. It's all precious.' *Frankie Holm*es *Akemarre*

> 'My *tyatye* (mother's fathers) country is Warlapunpa. They have rain makers too. When people dance and paint, they think about their *apmere* (country) and sometimes they cry for that country. When I visit soakages around Warlapunpa I put leaves over the soaks to keep them wet. We danced all night at a bush camp, this side of the railway. The painted designs belonged to Anerre, Kaytetye country.' *Selma Thompson*

> 'When we do the *Kwaty Awely* (water ceremony for women) the rain comes. My mother taught Selma how to collect white clay for the dancers. The rain is made when the *kwertengerl* chuck the white clay onto the ground. The rain will come quick all over Kaytetye country.' *Hilda Pwerle*

> 'I am teaching Selma the *Kwaty Awely* (water ceremony for women) from Warlapunpa country, that's Kaytetye too. Water Dreaming. They knocked down that *Kwaty* tree on the highway (=KWATY TREES) and that made us sad. It brings us worry because that tree has a spirit and a name. It is Pwerle like me. That story holds the country alive. Pwerle sings for the *Kwaty Awely* and is the main teacher. *Ngampeyarte* are the *kwertengerl*, they are the dancers.' *Lena Pwerle*

The results of Kaytetye ritual activity were acknowledged by the early pastoralists in the region as described by a senior Kaytetye man:

> 'If station managers needed rain in the early days, they would ask the rainmakers to make rain and would pay them in food. Birchmore at Kurundi Station, Harris at Murray Downs, Hayes at Neutral Junction, they all did this. They knew Aboriginal law was strong. If the land dried up the rainmakers would sing and the rain would come. After that there would be more water in the soakages and more food around the place. The station managers used to pay the rainmakers to sing for rain. True.' *Ned Kelly*

While in the region in 1901 Spencer and Gillen witnessed the performance of 88 'sacred totemic ceremonies' some of which related to sacred sites within the drawdown area. They were impressed by how elaborate and enduring were ceremonies concerning initiation, marriage, the increase of species, the maintenance of the 'alcheringa' (=*Altyerre*), tree burial and mourning practices. In relation to what is now the broader Western Davenport Water Control District, Spencer and Gillen recorded 'Aneara which is the great rain making site in the Kaitish tribe' and 'the great centre of the rain people'.[23] Details about the Kaytetye *kwerrenarr* (rainbow serpent) are highly restricted and not discussed in this report.

[23] Gillen 1968:147; Spencer & Gillen 1968(1904):158; see also Stanner 1934.

In her 1970s ethnographic study at Alekarenge on women's ritual, Bell discusses a number of characteristics applicable to Kaytetye land and society, including ritual obligation to kin and country, roles and responsibilities in relation to land and the maintenance of the landscape through ceremonial activity.[24] Bell recorded many traditional mythologies including that associated with the *Ahakeye* (=Wild Plum) Dreaming belonging to the Akwerlpe-Waake group.[25] See Figure 15.

Figure 15 Bush plum *Ahakeye* (*Canthium attenuatum*), Warrabri ALT

Source: Photograph by Jessica Burdon (CLC).

Many of these ritual activities require specific flora and fauna species obtained across the drawdown area as observed by Gillen in 1901 who recorded his Aboriginal guides capturing galahs and a duck, and keeping the feathers 'for future ceremonies'.[26] See Figure 16.

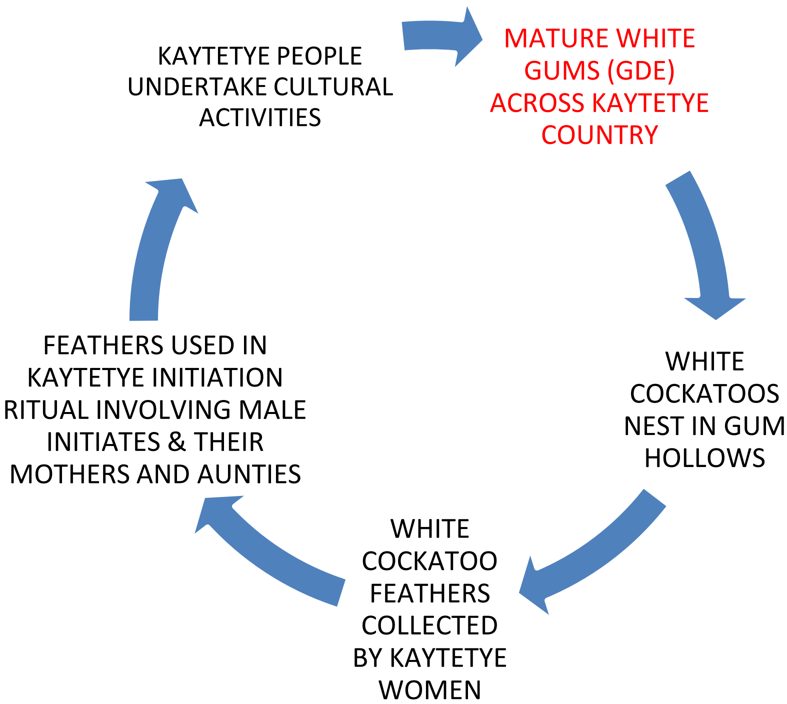

Figure 16 The cyclical interdependence of groundwater dependent ecosystems and ritual activities

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[24] Bell 1983 (1993). The research for this work was carried out between 1975 and 1978.
[25] Bell 1983 (1993):131–132.
[26] Gillen 1968:242–247.

Records reveal that many Kaytetye people were born on Neutral Junction and Singleton Stations including Zigfreid Nelson Kemarre, Billy Dobbs Kngwarraye (dec.), Lena Thangale, Joe Murphy Kngwarraye (dec.), Carol Thompson and Cyril Jabangardi. In accordance with Kaytetye customs Lena Thangale's bush name is *Mpwerempwer-ange* (=Lily) after the site on Singleton Station near where she was born in 1930.[27]

> 'My sister Carol was born at a soakage on Taylor Creek called ARWENGANENYE near Emu bore. My mother and father were living in the bush, moving from soak to soak.' *Selma Thompson*

A number of Kaytetye people are known to have died and were buried in the drawdown area. Ritual activities associated with dying on country strengthens spiritual connections to important places and is reinforced by the Kaytetye land tenure model which ensures country is inherited in a systematic way, enabling intergenerational occupation of the same terrain and religious teachings about places and within it.

> 'Bill Crook put down that well at Stockwell (Stockwell Bore Singleton Station). People lived there for a long time, all the Aboriginal families, Kaytetye, Alyawarr…Warumungu. People are buried there. My father worked at Old Singleton. Bill Crook was a good manager. Barry Donahue was cheeky. He took too many Aboriginal wives. The Aboriginal men were stockmen and the women looked after the nanny goats. They all lived across the creek. There are people buried all around Old Singleton. Polly Napaljarri, my aunty, and one Nakamarra, Louise Fitz grandmother…and others, but we don't know who.' *Ned Kelly*

Of great cultural importance to the participants is the belief that the spirits of their deceased [actual] ancestors, their parents, grandparents, great grandparents and so on, have returned to the land and reside in their country in perpetuity. As such, when Traditional Owners visit their country, they feel the spiritual presence of their forebears and through that intangible connection attain a sense of inner comfort. An intangible cultural connection is formed between Traditional Owners and places associated with the spirits of their deceased kin; visiting these places and treating them with respect is another way Traditional Owners maintain kinship connections to past ancestors. An integral aspect of the Kaytetye religion is how the actions of Traditional Owners cause happiness amongst the spirits and strengthen Traditional Owners' connection to country; this is a life-sustaining spiritual force for Traditional Owners.

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[27] Pers. comm. 24.3.2006 Mary Kemarre; pers. comm. 01.09.2005 Johnny Nelson Pwerle and Zigfried Nelson Kemarre; CENSUS F133/22 (65/32). Letter dated 04.04.1996 Lovegrove to Welfare in Tennant Creek.

‘We remember the old people when we visit places. Somehow, they are still there. If the country dries up, they all finish up, we all finish up’. *Sonny Curtis*

‘My mother’s spirit came back to this land. She’d be happy that we are here, that we came to look around. The country welcomes we home. This is home. If we lose our home, we would be too sad. If it changes, we feel sick and the old people will feel bad. The spirits in the land feel the same.’ *Karen Morrison*

Another Kaytetye ritual is for family members to be given Aboriginal names or ‘bush names’ (based on the names of sacred sites / natural phenomena) providing another link between people and country. These names were often also the names given to their grandfathers and have been used for countless generations. When sacred sites associated with people’s bush names are damaged the intangible link between the person and the place is also impacted; people feel a sense of loss that they will not be allocating these names to future group members if the site is gone. Generations and generation of their ancestors have allocated these names to past kin; Traditional Owners understand the future allocation of this name may be redundant forever.

‘*Mpwerempwer-ange* [lily] is Lindy’s mother’s bush name. We paint that one to tell the story, to teach the kids. I tell the kids stories about coming here with my mother and about their grandfather. We tell them the stories then show them the places so that the story gets fixed in their minds.’ *Karen Morrison*

An important value associated with Kaytetye ritual and spirituality is simply being on country and enjoying it with family forging strong bonds between generations of kin. The availability of water and shade trees are linked to this value:

‘We love to swim in the creek and hunt for bush turkey and collect ducks. We sit in the shade next to the creek and cook the turkey and duck, have a swim, have a feed.’ *Lindy Brodie*

‘My father brought me here to THANKWE and we will bring our kids here too. I can’t believe this tree is still standing. It is so old. This is the main tree connecting me to my grandpa and to my grandkids. I will feel no good if it dies.’ *Brian Jakarra*

The cultural values outlined in section 2.3 are entwined; having fun on country isn't just about fun, it's also about reinforcing and experiencing spiritual connection, transferring knowledge, caring for country and fulfilling ritual obligation. Traditional Owners don't separate these concepts.

2.4 Upholding ecological knowledge associated with collecting natural resources

Another important element in Kaytetye society is the cultural knowledge and practices associated with collecting natural resources; hunting, gathering, sharing, consuming and trading. Upholding cultural knowledge and practices associated with ecological processes is very important to Traditional Owners. Whilst this research did not identify any sacred sites within the immediate extraction area, the extraction area has been identified by Traditional Owners as prime hunting grounds regularly used by Traditional Owners and members of nearby communities.

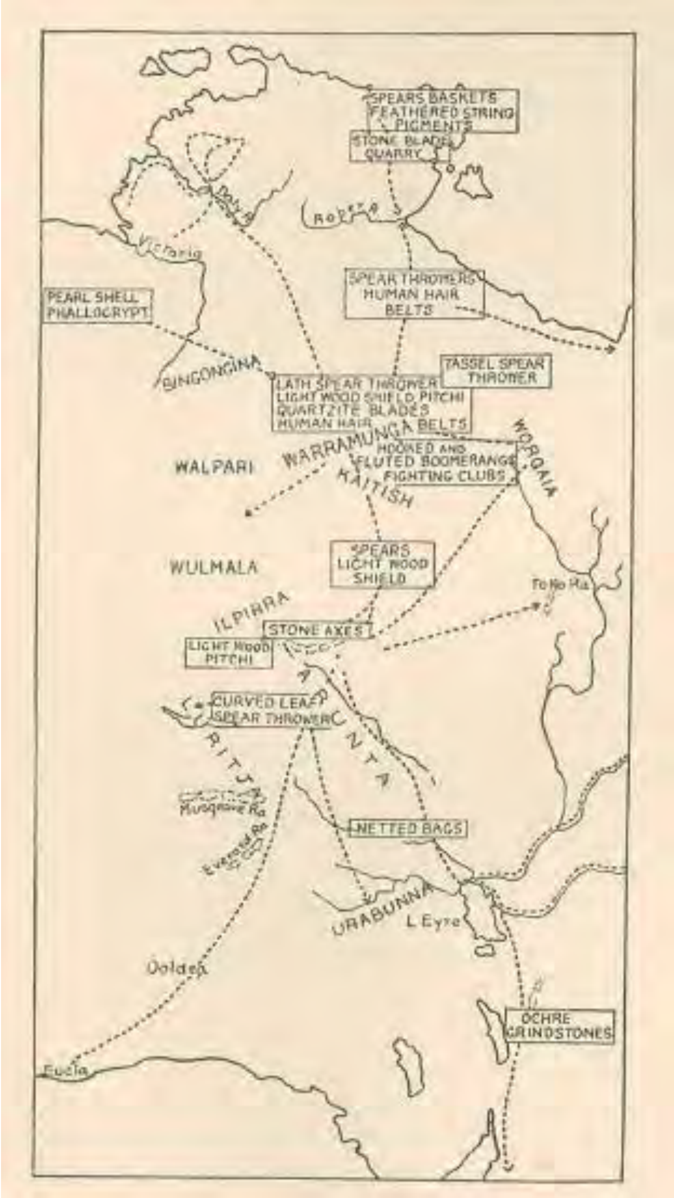
Additionally, the broader drawdown area and the surrounding cultural landscape including Taylor Creek and the sand dune/floodout systems associated with Wycliffe Creek are regionally significant resource rich areas utilised across a range of seasons. A vast array of flora and fauna species utilised by Traditional Owners across the extraction zone and drawdown area were documented during this assessment, many of which are dependent on groundwater. A similar study by McDonald found that water is central to Aboriginal culture and way of life and that groundwater dependent environmental features and ecological processes are themselves Aboriginal cultural values (2005:16).

The importance of soakage water to Aboriginal people in the region was first documented by Stuart in 1862 when in the vicinity of the Crawford Range and Taylor Creek he recorded 'soakages dug in the Creek by the natives. There is no surface water, but apparently plenty by digging in the bed of the creek'.[28] Half a century later Gillen observed a 'very fine and nutritious yam weighing 1–3 lbs of which the blacks are especially fond' growing between Kelly Well and Wycliffe Well.[29]

Aboriginal people's reliance upon and valuing of water and other natural resources in this dry region continued throughout the 1900s (see Bell 1983; Koch & Koch 1993; Olney 1999; Turpin 2000; CLC 2008). The establishment of Warrabri settlement in 1956, now known as Alekarenge (Ali Curung), enabled Kaytetye families and their neighbours to remain on or close to their traditional lands.

[28] Stuart 1865:79.
[29] Gillen 1968:171.

For Aboriginal people living at Wakurlpu and Alekarenge communities in particular the drawdown area is their 'back yard' where they regularly collect natural resources. Continuing to 'go hunting' is vital to the maintenance of good mental, physical and spiritual health for Aboriginal people and an important way to transmit cultural knowledge and practices to younger generations. Being based at Alekarenge in the 1970s, Bell observed Aboriginal people finding frogs in 'cool damp sand' and water sources in 'wide, dry creek beds'.[30] She also found that 'land was a living resource from which people drew sustenance – both physically and spiritually'.[31]



In his investigation into Aboriginal trade relations Frederick McCarthy found that the 'Warramunga–Kaitish tribes' were an important 'distributing group across north Australia'.[32] Hooked boomerangs were traded along what McCarthy termed the 'Central Route' (see Figure 17), which traversed vast distances, including through Kaytetye country. Spencer and Gillen had also noted how boomerangs were 'constantly being traded from one part of the country to another and from one tribe to the other' in the region between Alice Springs and north of Tennant Creek.[33]

Participants in this assessment continue to collect natural resources across the region to make boomerangs and other items to sell and exchange. Many of these items are derived from GDEs present across the extraction and drawdown area including bloodwood trees.

Figure 17 Central Trunk Trading Route

Source: McCarthy 1939:429.

[30] Bell 1983 (1993):22.
[31] Bell 1983 (1993):48.
[32] McCarthy 1939 (Part 1): 405–438; (Part 2):81–104.
[33] Spencer & Gillen 1904:12.

The following quotes were gathered during recent fieldwork for this assessment. They are representative of a wider body of evidence of continuing and contemporary Aboriginal use of country and ecological interconnections (see Figure 19).

‘The land of honey that Singleton, and frogs. The land of plenty, our own big garden, that’s how I look at it. It is everyone’s hunting ground, especially from Alekarenge.’ *Maureen O’Keefe Nampijinpa*

‘We know what we are looking for because we have been taught. We love sugarbag and if my kids can’t taste it, that will make me sad.’ *Renele Aplin*

‘There are a lot of bush potatoes and bananas in the [site name redacted] area, near Neutral Junction bore fields. We go hunting in that area often.’ *Selma Thompson*

Figure 18 Bush potato *Anatye* (*Ipomoea costata*), Neutral Junction Station

Source: Photograph by Jessica Burdon (CLC).

‘

‘There is good hunting ground west of Wauchope. We collect beans from the bean tree to make jewellery. The bloodwood has everything, it is like a supermarket, it even collects water.’ *Maureen O’Keefe*

‘We share our country with the Alekarenge mob. They come here to collect sugarbag and water lilies and frogs.’ *Karen Morrison*

'The Taylor Creek floodout comes out to the ALYERERNYE area. There are plenty of potatoes here after the rain. It is good open country. People come hunting here all the time from Alekarenge.' *John Duggie*

'We used to camp at the swamp when we were kids and collect ducks and yams. We'd also collect frogs from the Wycliffe sandhill. We would dig down up to 2 metres. I remember jumping into the hole. It was moist at the bottom of the hole where the frogs were.' *David Curtis*

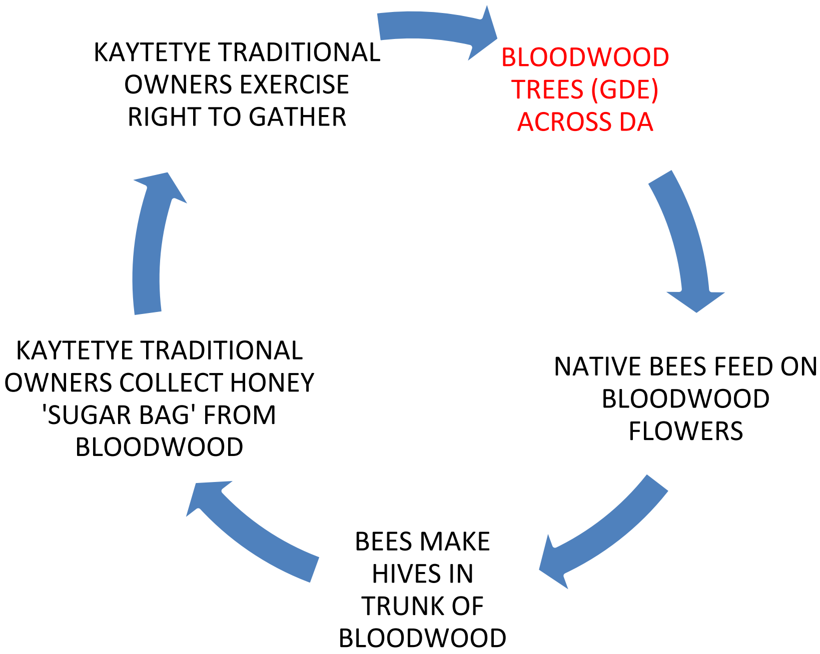


Figure 19 The intersection between the right to use natural resources and groundwater dependent ecosystems

A list of culturally important plant and fungus species observed or discussed within the drawdown area and their indigenous names was collated by Jessica Burdon (CLC) (see Attachment 1). The information is based on field observations, discussions with Traditional Owners and Latz (1995 & 2018). The listed plants are also referenced in Nano et al. (2021) as closely associated with sandplain and alluvial potential Ground Dependent Vegetation (GDV) in the Western Davenport study area.[34]

[34] Pers. comm. Jessica Burdon 27.07.2021.

Food resources obtained from the drawdown area, recorded during this assessment, include roots from the *Mpwerempwer* (Lily), fruit from the *ahakeye* (Bush Plum or Currant/*Canthium latifolium*), fruit from the *nkwerleye* (Bush Plum/*Santalum lanceolatum*), fruit from the *akerleye* (Bush Orange/*Capparis umbonata*), seeds from the *artetye/ntang* (Mulga/*Acacia aneura*) which are ground for making bread, *kayte* (Grub), and *kwardenge* (wild duck eggs),

Figure 20 Bush tomato *anemangkerr* (*Solanum chipendalei*), Warrabri ALT

Source: Photograph by Susan Dale Donaldson.

Figure 21 Cole's Wattle/Soap wattle *Alarrey* (*Acacia colei*), Neutral Junction Station

Source: Photograph by Susan Dale Donaldson.

Tungkarne (Bush Beans), *anatye* (Bush Potato/Ipomea costata), *arlatyeye/arpetye* (Pencil Yam/*Vigna lanceolata*), *ikwarreye* (Wild Banana/*Leichardtia australis*), honey from the *ilperalke* (Sugar Bag), *kartepa* (Bush Coconut from the bloodwood tree), *tharrkarre* (honey from the Grevillea Holly), desert raisin (*Solanum centrale*), *arlkerre* (Bush Tomato/*Solanum chipendalei*), *mpwelengk* (Desert Spadefoot Toad/Notaden nichollsi), *atnhelengkwe* (emu), *atweynterl* (Sand Frog), *kalyeyampe* (another type of frog), *arelwatyerre* (sand goanna), *aherre* (kangaroo), *arwengerrpe* (Bush turkey), *atnhelengkwe* (emu), *enewaylenge* (echidna), *arwengerrpe* (bush turkey), a*rnewetye* (Conkerberries/*Carissa lanceolata*), *kungkarte* (Sweet Bush tea leaf), *alarrey* (Cole's Wattle/*Acacia colei*), *atywenpe* (Perentie lizard) and *tyanywenge* (Bush Tobacco) were also found across the drawdown area. See also species list in Attachment 1.

There are also many Kaytetye terms associated with ecological knowledge and use of groundwater across the drawdown area including *aherbe* (ground), *ahepetewe* (hot weather), *arrertame* (permanent), *kwene* (under), *etwerrpe (*Sandhill/sand), *elye (shade), ahepetewe* (summer), *aherrke* (sun)*, arntweng-areye* (rainy season), *aynterrke* (dry), *arntwe* (fresh water and rain), *angenke* (dig), *kartawerre* (root), *arne* (water vessel), *kwathenke* (drink), *anerre* (rockhole), *artnwep* (swamps), *ngentye* (soakages)*, elpaye* (creeks), *and ilinjera* (floodouts), and *irrigkudu* (green, grassy flatlands). Maintaining the Kaytetye language is linked to Kaytetye people sustaining traditional ecological knowledge into the future.

> 'We say *Kantangara* for under and *Ngappa* for water…so for the underground water in Warumungu we say *ngappa kantangara kuna*.' *Heather Anderson*

Interconnections between water, traditional ecological knowledge, spirituality, survival and GDE was expressed by Traditional Owners throughout the assessment:

> 'The bean trees at the soaks are part of the story and can't be cut. They are Dreaming trees and can't be cut. They were planted in the *Altyerre*; they show us where the soakages are when we are travelling. The trees need the soakages and we need the trees to find the soakages to get water.' *Ned Kelly*

'At ALKETALKERREY we would dig a long way down to get a drink. After we finished there, we would walk to ATYEWANTEYE and stay there for a while. The bean trees at ALKETALKERREY and the orange tree at ATYEWANTEYE can't be touched. We can use the ones away from the soakages, the ones that aren't sacred.' *Donald Thompson*

'We see the large trees and know there is underground water. The old men used to dig for water near the old trees. We don't know what is going to happen if they take that water and what are they using it for? We have to think about it more'. *Brian Tennison*

Figure 22 Northern wild orange *akarley* (*Capparis umbonate*)

Source: Photograph by Jessica Burdon (CLC).

Figure 23 Woolybutt grass *antyer* (*Eragrotis eriopoda*)

Source: Photograph by Susan Dale Donaldson

'The *Kwerrimpe* were bush onion ladies, they were Kaytetye and travelled around Kaytetye country. They left onions for us and we still find them along Taylor Creek even when there is no rain. We also get bush plums, bush potatoes, tomatoes, banana, honey ants, sugar bag, coconuts, goanna, turkeys, kangaroos, echidnas, grass seeds, and beans. We use the root of the acacia to make boomerangs and the best sugar bag is in winter from the bloodwood, it is stored in the trunk of the tree like a fridge.' *Selma Thompson*

'Not all soaks hold water all year around. They can be good after rain but then dry up. There are springs that always have water. I've never thought about where the water comes from, it is just always there. I don't know how the springs will be affected. If the water is taken it's gone forever and we can't get it back. Once it's gone, it's gone.' *Michael Jones*

'I dug for sand frogs in the sand hills at Wycliffe with my grandmother Molly O'Keefe. We used a stick and a crowbar. I was carrying my son in a coolimon at the time. He is now 32! We dug about one metre down, not far and the sand was dry around the frog, but the frog carried water in him.' *Evangeline Presley*

'Our old people originally found water; we can find water too in the same places. Water is precious. We can't give away our water, we have to think of our family and future. We will hold the money in our pocket only a little while.' *Michael Wilson*

'The insects live in the trees and they eat the leaves and flowers from the trees. The flying ants make ant beds and we collect the spinifex wax. The bees make sugar bag. So, the insects need the big trees to survive and we need the insects to make us wax and honey. It is all connected.' *Michael Jones*

‘We used the wood from the bloodwood to make boomerangs. The bees also like the bloodwood trees to make sugarbag and we also get bush coconuts from bloodwoods. We can’t lose the bloodwoods, they are important for lots of things, even the ones that aren’t sacred.’ *Michael Jones*

Figure 25 Spinifex wax Atnkere, Warrabri ALT

Source: Photograph by Susan Dale Donaldson.

‘Bloodwood sap is used to make a medicine drink. We also get sugar bag from bloodwoods and coconuts.’ *Selma Thompson*

Figure 26 Collecting sap Arrkiper from bloodwood tree (*Corymbia opaca*) on Warrabri ALT

Source: Photograph by Susan Dale Donaldson.

Historically Kaytetye people shared important ecological knowledge with early European explorers in good faith.

‘The old people at Singleton knew where the water was and showed it to the white explorers. They had a map in their memory from a long time ago.’ *Derick Walker*

Figure 24 Bush coconuts (kathip) from bloodwood (*Corymbia opaca*), Singleton Station

Source: Photograph by Jessica Burdon (CLC).

2.5 Continuing customary roles and responsibilities

In 1901 Spencer and Gillen identified 'Kaitish' (=Kaytetye) territory as extending from Barrow Creek in the south to the Davenport Range/Bonney Creek area in the north, and extending either side of the Overland Telegraph Line (see Figure 27).[35]

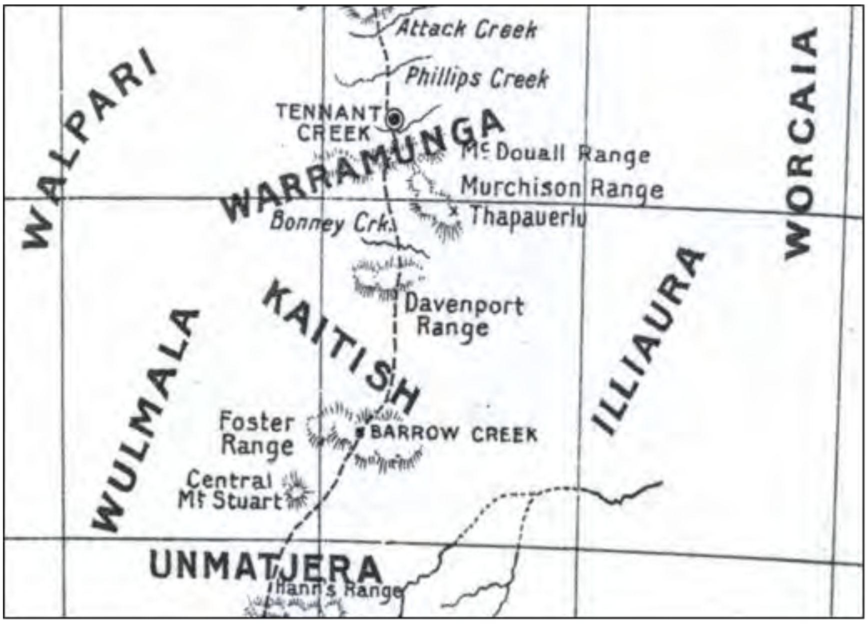


Figure 27 Spencer and Gillen tribal map

Source: Spencer and Gillen 1904.

In the Kaytetye belief system Traditional Owners see themselves as custodians of their land and waters and they have customary roles and responsibilities to maintain and protect their country and the things that live there; in Aboriginal thinking, everything is connected and especially to water. Looking after country in a broad sense relates to sustaining the biodiversity through regular burns, cleaning out/covering up soakages and other activities. These cultural activities relate to preserving all aspects of the cultural landscape, including water sources, for future generations so that culturally valued natural resources can be sustained and sacred sites protected.[36]

[35] Spencer & Gillen 1904: endpaper.
[36] Stanner 1935.

For Traditional Owners, managing country 'proper way' requires being part of making decisions about how country is used and accessed according to ancient laws and customs based on specific land tenure systems. Within each landholding group, people inherit certain roles in relation to land depending on their genealogical link to it. Those people affiliated with land through their father's father (FF) are called *apmerek-artwey (mangaya* in Warumungu and *kirda* in Warlpiri*)* and those affiliated with land through their mother's father (MF) are called *kwertengerl* (*kurdungurlu* in Warumungu and Warlpiri)*.* Those affiliated with the estate through their father's mother (FM) and mother's mother (MM) also hold important connections to country.[37]

Apmerek-artwey are required to pass on the ritual and corporate property of their country to their patrilineal descendants, perform as actors in ceremony and together with their *kwertengerl* make decisions about access to their country's economic and spiritual resources. The role of *kwertengerl* usually involves painting their *apmerek-artwey* for dances and ensuring performances unfold in accordance with Law. *Kwertengerl* are required to ensure sites are protected. Today these complementary roles are also transferred into contemporary non-ritual decision-making processes involving Traditional Owners and their land.

In the 1970s Bell observed rituals associated with the *Ngapa* (=rain) mythology which involved rainbows, rain, lightning and waterholes around the Devils Marbles area.[38] She found that the patrilineal descent-based roles and responsibilities pertaining to country, as outlined above, were defined in the Dreaming and aim to ensure 'the proper management of country – that is, to see the nexus between the use of the land and the maintenance of the land is not threatened'.[39] The link between maintaining areas of importance and GDE was often expressed by Traditional Owners during this assessment (Figure 28).

[37] Bell 1993; Sutton 1993.
[38] Bell 1983 (1993):167.
[39] Bell 1983 (1993):139.

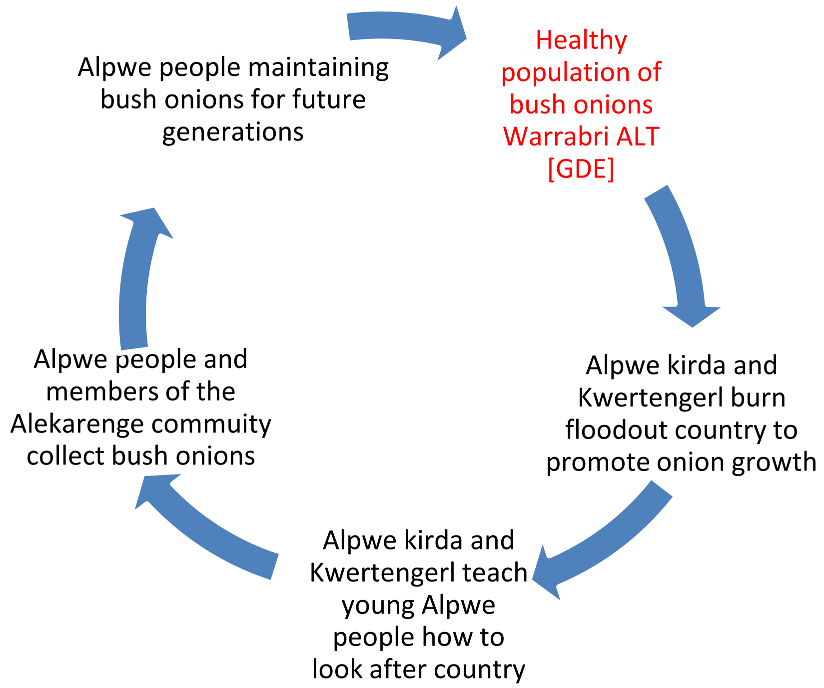


Figure 28 The cyclical interdependence of maintaining areas of importance and groundwater dependent ecosystems

Looking after precious water sources and the range of interconnected species is an important part of Kaytetye people's customary roles and responsibilities, and in particular for *kwertengerl.*

> 'We cover up soakages after they have been dug to protect them from getting damaged by Kangaroo poo, camels, bullocks. We cover them with leaves and branches and logs after the hole has been levelled. We don't want animals falling in the holes and getting trapped either. Anyone passing by can use the soak and cover it up before they leave, ready for the next family. We share our water in the desert with all the families, not just for one person. We keep that water cool for the next family passing by. Some soakages we dig after rain; others are good all year around like ATYEWANTEYE. People lived there because there was water in cold weather and hot weather. We dig that one in from the side, we sit on the side and as we dig, we keep moving in, deeper and deeper. There is a bush orange tree there too.' *Selma Thompson*

> 'There are plenty of bilbies on the Hanson River. They eat witchetty grubs. When the grubs are eaten out, they move on, the whole family moves on. Witchetty grubs grow up in the yellow wattle trees, the turpentine and acacias. Jarra Jarra side they make more witchetty grubs; they sing them up.' *Donald Thompson*

For a Kaytetye person to not be part of decision making in matters that affect their country, then affects their relationship with their country and kin. Today, as in the past, traditional decision-making takes time because it considers complex religious elements, an array of social networks and detailed traditional ecological knowledge systems.

2.6 Being able to live and travel on country

As evidenced by existing literature and consultations with Traditional Owners, it is apparent there was much historical seasonal movement between soaks and living areas and ceremonial grounds across the drawdown area and beyond (see Figure 29). Seasonal movement was previously a matter of ongoing residence, subsistence and ritual obligation, whereas nowadays seasonal movement to water sources is on a visiting/camping/hunting/ritual basis. Whilst country continues to be accessed for cultural purposes, movement between water sources has reduced. The continued cultural pattern being expressed links people to their past and provides promise for the future of their important cultural practices.

As noted earlier in this assessment, the drawdown area traditionally belongs to Kaytetye people associated with four Aboriginal land-owning groups: *Akwerlpe-Waake, Iliyarne, Anerre and Arlpwe*. These four country groups have determined native title rights and interests to the drawdown area in accordance with traditional laws and customs and are deeply intertwined with their neighbouring groups through ritual, mythology, kinship, trade, economic activity, language and shared historical experience.

The broader cultural landscape including the Western Davenport District includes an additional 23 Aboriginal land-owning groups who have kinship and ritual ties to the four immediate groups: Miyikampi, Kanturrpa, Kelantyerrang, Lyentyawel Ileparranem, Arrawajin, Errene, Wurulju, Kwerrkepentye, Pwerrk, Antarrengeny, Rtwerrpe, Arlekwarr, Akalperre, Amakweng, Ahalper, Tyarre Tyarre, Alhalker, Anangker, Atnerlelengk, Akweranty/Anwerret, Akaneng, Ngkwarlerlanem, Arnkawenyerr, Mitartu and Arnapwenty/Imangker.[40]

[40] CLC 2016:4; Kaytej, Warlpiri and Warlmanpa Land Claim 1981. Transcript of Proceedings. Aboriginal Land Commissioner; McLaren Creek Land Claim 1988. Transcript of Proceedings. Aboriginal Land Commissioner; Alyawarr, Kaytetye, Warumungu and Wakay Native Title Claim 2000. Transcript of Proceedings. Transcript Australia; pers. comm. Andrew Fahey 09.08.2021.

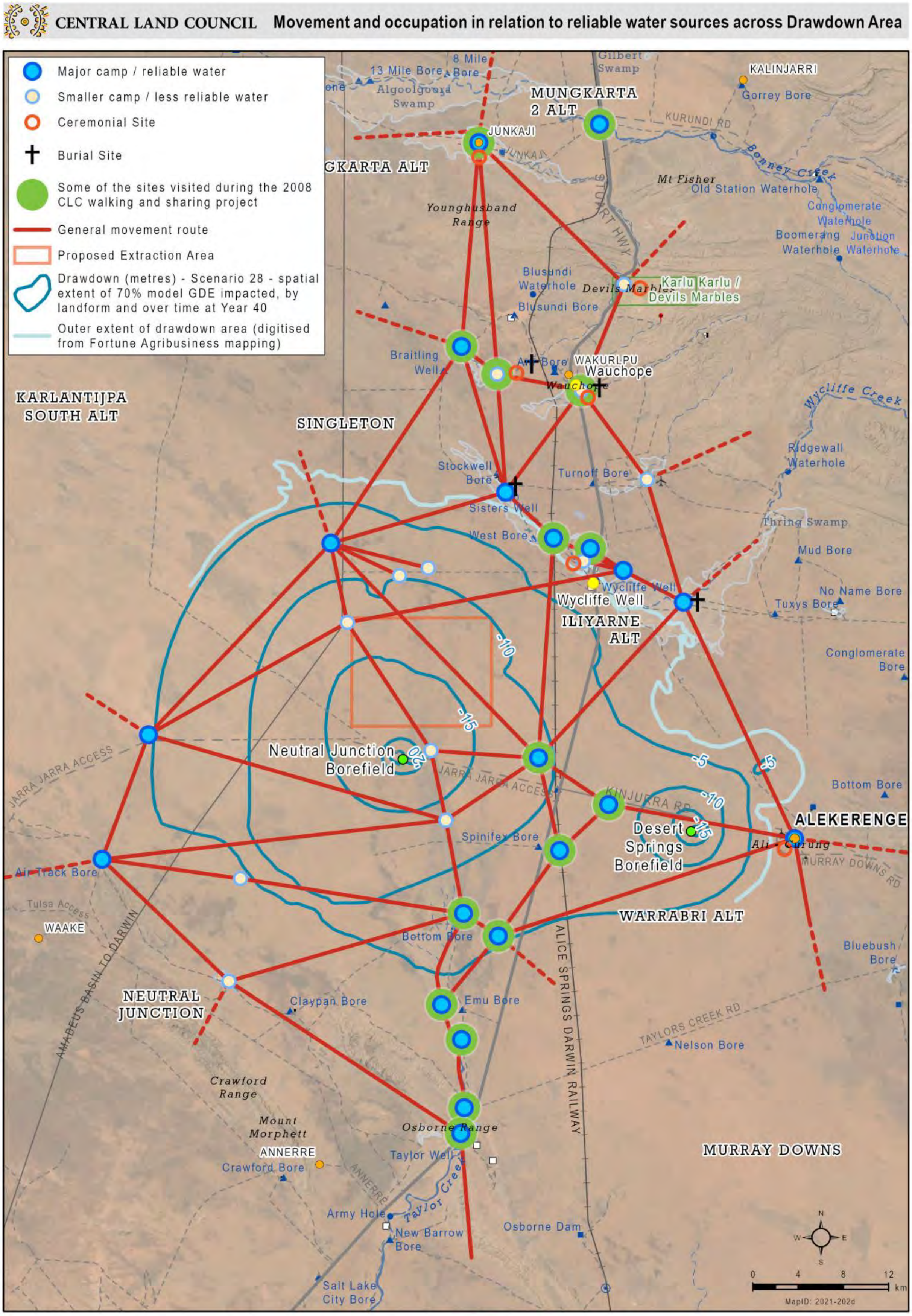


Figure 29 Movement and occupation diagram in relation to reliable water sources across the study area

Source: CLC 2021 (based on data collected by Donaldson).

Human colonisation in Australia's arid zone took place 20,000–30,000 years ago with varying levels of migration and depopulation taking place during the last glacial era followed by a reclamation of rangeland areas.[41] Archaeological excavations at Ingaladdi rock shelter, near Katherine, 800 km north of the study area, indicates human occupation of the area more than 7,000 years ago.[42] Archaeological investigations in the Davenport Ranges National Park immediately to the east of the study area, dated rock engravings as being at least several thousand years old – providing clear evidence of pre-historic Aboriginal use of the region.[43]

Observations of Aboriginal people living within the drawdown area extend back to John McDouall Stuart's 1862 expedition when he documented people hunting and gathering of food and was presented with opossums and birds.[44] Stuart and his party came across 'a beautiful pond of water, and about a mile along the pond the ground was sufficiently firm to allow of the horses going to drink; this is a beautiful sheet of water, 50 yards wide, and seems to be permanent; some of the horses had a swim in it. This I have named Thring's Pond.'[45] Thring Swamp is an important site belonging to the Iliyarne group located on the southern side of Wycliffe Creek on Singleton Station.[46]

While in the vicinity of the Crawford Range and Taylor Creek, Stuart saw 'several natives' and recorded 'soakages dug in the Creek by the natives. There is no surface water, but apparently plenty by digging in the bed of the creek, judging by the number of native wells that he saw with water in them'.[47]

Aboriginal people were observed at Taylor Creek by Renner and his party in 1872, where 'blacks annoyed him very much after he left the Taylor, by constantly setting fire to the grass along the road.' [48] In 1874, during a time of severe drought across the region there was an increase in pressure on water resources. These difficult conditions together with an incident involving ration distribution at Barrow Creek led Kaytetye men to attack and kill two European men who were stationed there. Settlers responded by mounting a reprisal expedition which resulted in a number of Kaytetye people being killed in the region, including at Taylor Creek.[49]

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[41] Mulvaney & Kamminga 1999:190–191; Smith 1987:710–711.
[42] Flood 1983:126. See also Horton 1994:493.
[43] Federal Court of Australia (2004) *The Alyawarr, Kaytetye, Warumungu, Wakay Native Title Claim Group v Northern Territory of Australia (2004) FCA 472*:33.
[44] Stuart 1865 (1975):198–215.
[45] Stuart 1863:13.
[46] Stuart 1865:79.
[47] Stuart 1865:79.
[48] Petrick 1983:20.
[49] Aboriginal Land Commissioner 1982:4; Koch & Koch 1993:xiv; Bell 1983 62–65.

In 1896 Eylmann was travelling through Kaytetye territory 19 miles west of Taylor Creek and observed the remains of a living area and ‘cave paintings’.[50] After passing through Wycliffe Well where he noted an abundance of food and water Eylmann visited Kelly Well where he found ‘an Aboriginal camping place’ comprising ‘rough huts built from gum tree twigs, and wind breaks’ as well as:

> …yam sticks, feathers from emus and galahs, remains of the native pear, broken weapons, ochre and chalk used for painting, small bones, trough-shaped pieces of bark…a hand-sized flat stone…covered on one side with a reddish, easily crushed resin, and a piece of bark that contained this resin in a liquid form…a long heavy club, painted red, decorated with carnelian rings and short diagonal incisions.[51]

In 1899 Spencer and Gillen passed through the region and documented Kaytetye society. They found Palaeolithic and Neolithic objects including spears with stone-flaked heads attached by resin and string; flint/flakes were used like a chisel for decorating coolamons and adze with flints. Knives, specially designed by Kaytetye women, were also documented.[52] Tree burials were also recorded across Kaytetye country.

The initial exploration of Kaytetye territory by Stuart and others was promptly followed by the development of the overland telegraph line and the pastoral and mining industries. Kelly and Wycliffe Wells were constructed in 1875 and the first pastoral lease in the region was at Barrow Creek, granted in 1877.[53] In the 1880s Murray Downs, Elkedra and Frew River stations were established, only to be abandoned a short time later, due to violent clashes between the newcomers and local Aboriginal people. In 1888, George Hayes leased Neutral Junction and Frank Scott, Stirling Station. In 1930, Greenwood Station was established at Bonney Creek (now Mungkarta ALT) and around the same time a grazing licence existed over what is now Singleton Station.[54]

The correlation between permanent (*arrertame)* water (a*rntwe)*, sacred sites and social organisation has been widely documented across Australia.[55] Treating important water sources with reverence and respect, an aspect of Kaytetye laws and customs, ensures future generations of Kaytetye people can survive as a society on the land as well as enjoy spiritual satisfaction. The Kaytetye ideal is to ensure springs, soaks and swamps remain in the original condition provided to them in the past *Altyerre* era, when they were created, so that future generations can enjoy the same qualities. When country changes or is damaged, Traditional Owners feel this is a direct reflection that they haven’t followed the Law.

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[50] Courto 1996:77.
[51] Courto 1996:78.
[52] Spencer & Gillen 1904:635–641.
[53] Aboriginal Land Commissioner 1982:5–6.
[54] Koch & Koch 1993:xv–xix
[55] Bell 1983 (1993); Rose (2004).

Latz discusses the importance of water in an arid environment. He found that:

> ...the locality of water is the most important factor governing the movement of people in the central deserts. Not only must every adult member of a community know exactly where every water source is located, but they must also have a good idea of how much water will be available to them when they arrive. The knowledge is obtained by careful observation of previous rains coupled with many years of experience on the hydrology of the area, evaporation rates and so on. Lack of water is, however, rarely a serious problem in the central desert, at least in normal years. Although large pools of permanent water are scarce the many and varied sources of underground water are relatively plentiful, much more than is generally realised... (Latz 1995:18).

Latz highlights that during droughts a lack of food around permanent water causes people to relocate rather than the depletion of water (1995:18). He identifies a number of plants obtaining water (*Brachychiton*) as well as plants that indicate the presence of underground water (sedge *Cyperus gymnocaulos*) (Latz 1995:65) and plants that are usually found near permanent water sources (wild orange) (1995:140). The later was identified in the current assessment close to a sacred soak as were bean trees.

'There was a big camp at ALKETALKERREY for Kaytetye, Warlpiri and Alyawarr and Warumungu. The soakage was made by the whirly wind from ATWERPE. Anerre come here too. This place is the bush name for Bundy Thompson. People walked here from ATARA in the olden days. If they take the water away or come too close, the bean tree will die and the soak will dry up.' *Ned Kelly*

Figure 30 Bats-wing coral bean tree *atywerety* (*Erythrina vespertilio*)

Source: Photograph by Jessica Burdon (CLC).

Kimber (2011) highlights how 'precious permanent' water sources in the arid region were relied on during times of droughts until 'good rains fell elsewhere in their country' (2011:13). He notes that 'as a consequence of these fluctuations in availability of water to Arrernte people (and indeed all desert peoples), they had learnt to pulse with the seasonal and also drought availability of water' (Kimber 2011:13). He also highlights how 'the key' to each Aboriginal country area 'was a reliable as possible water supply, normally requiring a spring, or very good long-lasting soakages and rock-holes, but could involve a known temporary water.' (Kimber 2011:28).

> ‘Iliyarne people used to live at MPWEREMPWER-ANGE and near ANEMARRANENKE it is good open country with plenty of food and good water. They would go between here and ALYERERNYE.’
> *Donald Thompson*

Drought conditions across the region in the 1920s and the growing practice of European men taking Aboriginal women as wives led to the 1928 violence at Coniston Station on the Lander River. Frederick Brooks was killed by Aboriginal people and this led to the killing of many innocent Aboriginal people.[56] Perry analysed the relationship between groundwater, land use and landforms and found that the dependence of both European and Aborigines on the same small portion of the land in central Australia is one reason for the strength of the land use conflict in the region (Perry 1978:74). Koch and Koch documented how families fleeing the Coniston conflict in 1928 camped at Stockwell Bore JAMPALJARN on Singleton Station on their way to Greenwood where mourners painted themselves white as part of Kaytetye mortuary ritual.[57] Speaking of the reprisals that followed, or a related incident, Johnny Nelson (now deceased) recalled:[58]

> …poor old my old fella, they bin make big business…they didn’t know the trouble there. They ran in, they grab them there, make it prisoner they bin have big business, you know…they ran into Murray then. Grab ’em them. Two of them bin shot in the Hanson Creek…(after) showing them all (rock holes and water).

Strong connections were formed to a number of places used to evade conflict at Coniston and Barrow Creek as noted by Bell who found that people’s memories were strongly tied to a history of fleeing conflict and seeking refuge at Barrow Creek, Singleton Bore, Wauchope, and Greenwood where rations were distributed in the early 1900s. Traditional Owners today recall the soakages visited by their ancestors fleeing the conflict. One soakage in the drawdown area used for this purpose was ALYERERNYE where people stopped on route to Greenwood [now on McLaren ALT].

Koch and Koch recorded oral histories about Kaytetye people working at the Wauchope wolfram mine, camping and collecting bush tucker at JAMPALJARN (Stockwell Bore) on Singleton Station, and buying melons at the Wycliffe Well farm.[59]

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[56] Koch & Koch 1993:xvii.
[57] Koch & Koch 1993:67–70.
[58] Aboriginal Land Commissioner 1982:6 (Exhibit 2).
[59] Koch & Koch 1993:113–114.

'We use to camp here at ALYERERNYE. Husband and wives would dig together, until they found water. First, they'd clear the grass, maybe burn it. The wife would be digging down in the hole, in the soak, and would pass water up to her husband sitting on top. We use a bucket now but they used coolamons they made from the bean tree. Not the sacred ones though. That is an old law and it's still there today. Maureen's mother and aunty were here and Ned Kelly. There is good tucker around here and in the sandhills to the west are plenty potatoes. West of here is Waake and to the east Wakurlpu.' *Donald Thompson*

'Sonny Jakarra can tell you about the old people living along Taylor Creek. My father and grandfather lived there too. People walked all around that area hunting. They would move around the area on foot in those days.' *Selma Thompson*

'People used to travel between ALKETALKERREY and ARLEPWARTE and ATYEWANTEYE. People were living at these places and would dig for water with their coolamons. There was plenty of tucker around, potatoes, conkerberries. People would stay at each place for a month so until the food ran out then move to the next soak. So, if there was plenty of food around people would stay longer before moving on. People couldn't live without food or water.' *Ned Kelly*

Participants in this assessment, and or their ancestors, have direct historical experience with a shortage of water. In 1945 a shortage of water led to the closure of Tennant Creek's 'Six Mile' Aboriginal Reserve resulting in Aboriginal families being relocated to Phillip Creek Native Settlement to the north of Tennant Creek.[60] However, the Phillip Creek site also lacked permanent water and Aboriginal people were moved to 'Warrabri' (now called Alekarenge) in 1956; according to Cliff Williams '…all the bosses decided to move us from Phillip Creek because the water made lots of people get sick'. [61]

Many Kaytetye families also lived and worked on the stations in the vicinity of Alekarenge, including on Singleton and Neutral Junction.[62] In 1961 Pitman wrote that 'Singleton appears to be coming a colony of aged wards…they are unwilling to live at Warrabri…several of the wards have been transported on a number of occasions back to Warrabri, only to return.'[63] The May 1966 census recorded 10 Aboriginal people residing on Singleton Station in 'humpies a quarter of a mile from the Homestead' with people regularly visiting Warrabri and other centres

[60] Aboriginal Land Commissioner 1988:48.
[61] NAA 1959/1897. Warrabri Corroboree Ed. 9/1959. See also Meggitt 1962:28 'The Story of my life', Cliff Williams: See also Aboriginal Land Commissioner 1988:49. NAA 1954/953.
[62] NAA 1957/122. CENSUS 1964.
[63] NAAE 155/20 (1960/86) inspection report, 1961.

around the station.[64] In June 1967 Pederson reported 19 people 'all living as Aboriginal' on Singleton Station. The Aboriginal residents lived in 'whirlies' and all the cooking was done individually over open fires around the whirlies. The Aboriginals 'presented as a reticent, shy group who are apparently prepared to stay at Singleton no matter how bad the conditions'.[65] Station life allowed for the continuation of a traditional lifestyle during that time of the year when people were not undertaking station work.[66]

When Traditional Owners visit a soak today, memories of how the place was visited in the past is recollected and new memories are made. Historical stories about places and the people who lived at particular soakages is an important way for their descendants to connect to their ancestor's country. Family connections were historically formed as men and women worked on Singleton and Neutral Junction Stations.

> 'My father brought me here and we will bring our kids here too. I can't believe this tree is still standing. It is so old. This is the main tree connecting me to my grandpa and to my grandkids. I will feel no good if it dies.' *Brian Jakarra*

> 'I came to THANKWE as a child with my mother and other families from Alekarenge. We camped at THANKWE and collected lots of yams, bush tobacco and ashes from the snappy gums.' *Maureen O'Keefe*

According to the WDWAP, approximately 1,000 people currently live in the District, including around 500 people in the major community of Alekarenge. The District also includes three smaller communities (Imangara, Mungkarta and Tara) and nine outstations (Ankweleyelengkwe, Annerre, Greenwood, Illeuwurru, Imperrenth, Indaringinya, Kalinjarri, Tjuperle and Wakurlpu).[67] The Aboriginal people residing in the district are either Traditional Owners or Aboriginal people with whom Traditional Owners share their land, water and resources including across the drawdown area.

> 'I enjoy being here at Wakurlpu. I can relax here and be with family. It is good for my health and I feel a lot happier being on country.' *Glenis Curtis*

> 'Home is home for Aboriginal people. Wakurlpu is our home, our country. When the country is green, we are happy. Water is like gold to our people.' *Jeffery Curtis*

[64] CENSUS F133/22 (65/32). Inspection report dated 01.09.1966 Cooke. Census 1966.
[65] CENSUS F133/22 (65/32). Census 1967 and 1968.
[66] E155/20, 57/25. Hamilton 1958 and 1960.
[67] NTG 2018:11.

> 'We have a farm here too at Alekarenge. We need water to keep local jobs. Wages for the locals. What about our children? If we lose water at Alekarenge what will happen to the people in the community? We can't move people away. This is their country. This is my home, my land. The families hunt around the community and across Singleton Station and Neutral. If the country is damaged, we will keep the law, our law. The law came from the past, we have it now, and it will keep going into the future. We will stay here and the story will stay here too and the names (of places). It will be sad if the animals go and the birds fly to another country. Maybe the rainmakers will make the country green again and the animals will come back. They can make a smoky fire to make clouds to bring on the rain.' *Michael Williams*

In 2008 the CLC undertook a mammoth cultural teaching project 'Walking and Sharing Stories from Bonney Creek to Barrow Creek' which involved 65 Kaytetye, Warumungu, Warlpiri and Alyawarr people walking 140 km over 15 days (see Figure 29). The participants visited 30 soakages along the way and shared cultural and historical stories and undertook cultural practices such as digging soaks to collect water.[68]

After participating in the walk, Ellen Haywood said she enjoyed visiting the soakages because 'we think back for the old people'. She also found that it was:

> important to learn about their history and to know the knowledge of everywhere where the waterholes are so that they can know whenever their car run out of fuel, they know where to get water and bush tucker as well. How to find food, how to find water and to know which direction we travelling which land, whose land. Sometimes some lands have boundaries that certain people have to carry on and if you're travelling from another place then they're the person-owner that has to take the lead.[69]

Ellen also felt:

> …excited and good to see the land that we travelling through and enjoying every walk and every place, every soakage…The best thing is the knowledge to be carried on by young people, handed down from old people to us young people and the stories need to be told about this walk and our history.[70]

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[68] CLC September 2008. Walking and Sharing Stories from Bonney Creek to Barrow Creek. *Land Rights News*, p.7.
[69] 20.06.2008 ABC Stateline transcript.
[70] 20.06.2008 ABC Stateline transcript.

Another participant Maureen O'Keefe recalled how her aunty used to:

> travel from each soak until the next one until they reach Barrow Creek. She spent most of her childhood wandering around these hills and these soaks with the Kaytetye people. She brought us back, she revisited them old soaks that she used to go to as a child with these Kaytetye people. She used to tell us stories about it before. Then she thought about it maybe one day we could do a walk and visit those soaks again. It was lovely you know walking all these soaks, visiting. Made me realise then how hard it was then for those people to travel. They had no cars back then and they travelled this dry Australian desert. I thought it was just a desert, I didn't know there were soaks there you know. I didn't know about it until she told me story about it. I was wondering, how did they get water? How did they travel this long distance from Wauchope to Barrow Creek and I was wondering, where did they get water when they were travelling through this land? But I didn't know there were soaks along the way until she told me a story…and I seen it all now, them soaks. I visit a few when I was a little girl, maybe three but now we visit a lot, some in creeks, some in plain country and water floodouts you know.[71]

Sheila Braeden felt that the walk was a good way to teach the next generation about the soakages and other resources. She said:

> …we decided to have this project going for our children so we can teach them and pass the knowledge down to them. So, this project is all about teaching their children so in the future that our great, great grandchildren will teach their children and tell them stories about what we did for them. It's just passing the knowledge on see if we passed away well there is something for them to see…they can learn the knowledge from them as well in different languages and in them days they used to share the land and the resources that were there that used from other different languages, teach the other languages. Different languages have done all same thing, like the same soakages, bush tucker that they had and they're passing it on to their children from different languages. So that's why we got together as Warlpiri, Alyawarr, Warumungu and Kaytetye.[72]

In the words of Tommy Thompson (dec.), who was an integral member of the walk, as a teacher:

> …we got our culture live in our mind, and a map in our mind, and a ceremony on our mind. Everything got all in the mind, no map, that's why you have to remember this country. What people took around when we were kids, mum and dad used to move around looking for food, find food, meat, water, to live, to give

[71] 20.06.2008 ABC Stateline transcript.
[72] 20.06.2008 ABC Stateline transcript.

us life. Wherever you live in town you have to come back and visit this grandpa's country. You got it free. Everyone can come. You have to find this, it's a different history.[73]

According to Brian Jakarra who also participated in the walk:

I've learnt a lot about these soakages, what he taught me and told me all the way by listening to him and him telling me all the stories, the stories about the land and the people, how our people, Kaytetye people used to live off the land and how he, as a kid, used to walk around with his mother and father and even mum, Mona, it was their idea to get all the families together, sons and daughters and grandchildren and take them on this walk. Show these soakages and how they used to live. It changed a bit. The soakage never changed the landscape has, mostly by erosions. The soakages some of them I recognise yep since I was a kid…these old people. They really want to pass on their knowledge and the stories, pass it on to the younger kids, the younger generation like to us, to me and so I can pass it on to these other little ones then, when these old people gone, so we can carry 'em on, see? We still got our old people alive. Some of these soakages, I haven't seen them in my life. Only a few that I know of we came past. These other ones just seem to spring up. It's really good so everyone can see it. Around Australia hopefully so people can get to know that we're the smallest tribe in the northern territory, the Kaytetye tribe and setting an example how these other larger language groups can do it. They might do one of these projects one day.

Some of the participants in the current study were involved in the 2008 walk and remember the time fondly. A number of water sites visited in 2008 were visited again in 2021 for the current research, further embedding cultural knowledge and practice associated with important water sources.

'We walked to Barrow Creek from Bonney Well stopping at soakages on the way. It was good to listen to the old people's stories and to find the old soaks. I have rain dreaming for the Helen Springs area. Other people have rain dreaming for this area. We all need water. We needed water on the walk.' *Louise Fitz*

[73] 20.06.2008 ABC Stateline transcript.

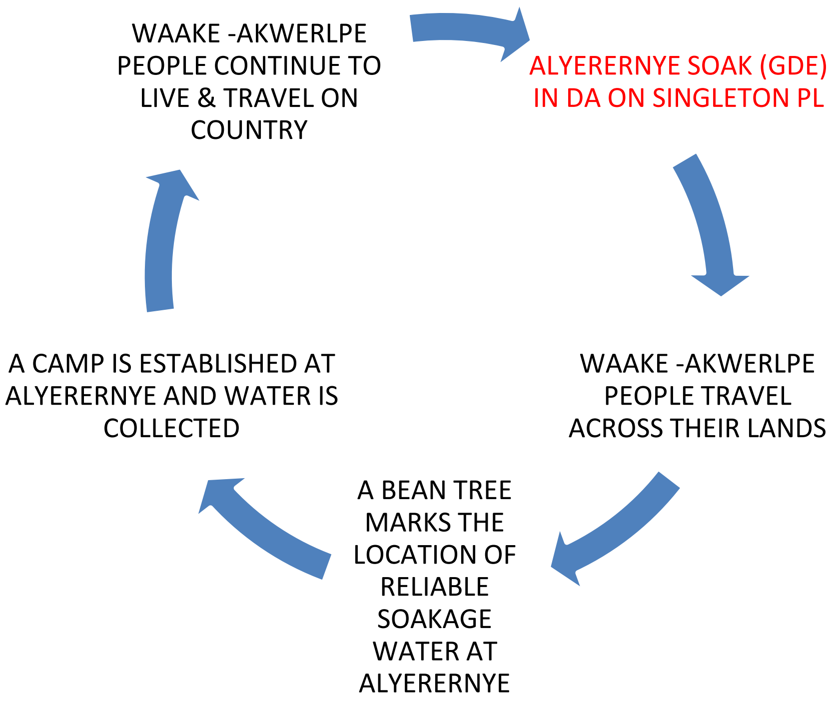

Figure 31 The intersection between the living & travelling and groundwater dependent ecosystems

In a similar study Sullivan found that:

> …fresh water sources are still important for their food resources and recreation. They may be vital from time to time, since an individual's survival can still depend on finding water when vehicles break down, bog in sand, or when people scout around on foot from the base of a bush camp. Just as the importance of water in this arid area has not diminished, the belief system and practices that surround it remain strong also… (Sullivan et al. 2012:47).

3.0 POTENTIAL IMPACTS TO ABORIGINAL CULTURAL VALUES

The following section outlines the impact that the SWL may have on cultural values in relation to the drawdown area, particularly those values affected by groundwater depth. The basis of opinion is the scientific premise that a reduction in groundwater can have 'severe negative impacts on GDEs' as outlined in the technical report specifically relating to the current study area (Nano et al. 2021:1):

> Globally, groundwater dependent ecosystems (GDEs) are recognised for their value as ecological refuges, specialised habitat and areas of high indigenous cultural importance. Particularly in the world's drylands, GDEs are often threatened as human water use increasingly exceeds aquifer recharge rates…Globally, overexploitation of groundwater represents a major threat to GDEs...Drawdown impacts are most pronounced in arid regions, especially following prolonged and severe drought, and in the context of climate change…Lowering water tables have been shown to have severe negative impacts on GDEs…

What Kaytetye cultural values are reliant upon GDEs and how will they be negatively impacted by a reduction in groundwater? The data reviewed has shown that there is a direct and obvious link between Kaytetye cultural values, groundwater and GDEs; they are cyclically interdependent and as such vulnerable to impacts caused by a reduction in groundwater. Moreover, there is a direct link between Traditional Owners exercising many of their determined native title rights, how they use their freehold land, the presence of groundwater and healthy ground dependent ecological systems.

3.1 Emotional and physical responses

This assessment has found a direct cyclical interrelationship between groundwater dependent ecosystems and Traditional Owners' ability to fulfill their cultural obligations in accordance with traditional laws and customs. Because the current proposal may have the effect of dramatically reducing groundwater which will subsequently damage GDEs, the proposal has the potential to undermine and adversely impact Traditional Owners' ability to fulfill customary responsibilities relating to appeasing ancestral spirit beings living in the landscape and at particular sacred sites. Traditional Owners will feel responsible for any damage caused to sacred sites associated with GDE as a result of reduced groundwater, causing cultural and spiritual pain and anxiety.[74] As a result, Traditional Owners believe they may get sick or die as a result of offending ancestral spirit beings and allowing sacred sites to be damaged whilst in their custodial care.

[74] See Mansfield in Pannell 2018: 257.

Traditional Owners' spiritual ancestors living in the land and waters can express their anger when the traditional system is not operating as it should – for example, when rituals are not undertaken according to the rules set down long ago. People can get sick and die if the law is not abided by. Moreover, there is a real fear held by Traditional Owners that the *Altyerre* powers residing in the land and water, across the region, will adversely react to the widespread demise of the biodiversity relying on their groundwater.

The cultural consequences for failing to fulfill the customary responsibilities (often described by Traditional Owners as 'breaking the law') are targeted at individuals whose traditional role it is to appease ancestral spirits; *apmerek–artwey* (*kirda*) and *kwertengerl (kurdungurlu*). All Kaytetye families hold stories about individuals who broke the law and were punished resulting in sickness, injury and even death. These ill-fated outcomes are more powerful, in the eyes of Traditional Owners, than the hard work of the ritual rainmakers, who will continue to make rain. The question is being asked by Traditional Owners, can they make enough rain to fill up the underground water supply? What if the rain makers die as punishment because the land dries out?

Whilst there is a strong belief held by Traditional Owners in the power of ritual, for instance for rainmakers (*angkethemwey*) to make rain *(arntwe)* to increase water supply, and a firm belief in the ongoing force of the *Altyerre* regardless of external activities, it is also apparent that the current generation of Traditional Owners fear the consequences of upsetting the creator spirits by not following the *Altyerre* Law. With a reduction in groundwater, Traditional Owners predict they will see sacred trees 'falling over', soakages drying up, animals finding a new home, bees making less honey, and in turn they may be directly blamed if their country (*apmere*) dries up *(errpatye)*. Emotional responses to breaching cultural rules has been documented and discussed elsewhere (see Pannell 2018). This was a major theme expressed during this assessment, as described below.

Participants in this assessment expressed a range of likely emotional responses if their important cultural values are negatively impacted by a decline in groundwater levels as a result of the SWL. These predictions are based on their previous experience relating to sacred site damage. Traditional Owners believe that their spiritual ancestors residing in the land also have emotions and will be emotionally impacted if country gets sick.[75] There are many Kaytetye terms to describe emotional responses to life events including *arlatnarrerane* (cry), *ampwarrenke* (die), *althere* (homesick), *amperrnge* (sad/unhappy), *nyerre* (shame), *arntetye* (sick), *athamarrerange* (worried), and *atere* (scared).

[75] See Pannell's (2018:263) discussion on the different ways Aboriginal people talk about their emotions and how the mythological beings in the landscape are also believed to have emotions.

Social sanctions may also result; Traditional Owners can be forced into temporary or permanent isolation from their traditional group which can lead to psychological stress and guilt associated with being responsible for damaging the country belonging to their spiritual ancestors, their actual ancestors, their current generation of kin and their descendants.

'I came to this place as a child with my father. This is a water dreaming place. The *Aylpele* (River Red Gum) and soak is the main place in the creek. The Murphy family are related in here too. If this tree dies the owners will go with it but another tree might grow. The story stays the same.' *Brian Jakarra*

Figure 32 Sacred River Red Gum and soakage in Taylor Creek, Neutral Junction PL

Source: Photograph by Susan Dale Donaldson.

With regard to the cyclical concepts described in Figure 6, if the sacred coolibah tree is damaged as a result of a reduction in groundwater on which it depends, Iliyarne Traditional Owners will be unable to fulfill their customary role in accordance with their traditional laws, and as a direct consequence, they believe senior Iliyarne *kirda* will be punished by *Altyerre* forces; they are likely to get sick, suffer ongoing 'bad luck' and potentially die. These forms of punishment are an important aspect of Kaytetye religion and cultural phenomenon. The cultural values associated with sacred trees in particular is of utmost importance to Kaytetye people and are usually diminished as a result of cultural obligations not being undertaken, as described by assessment participants:

‘We got to look out for the owners, they will get sick if they don’t do their job and look after their country.’ *Donald Thompson Akemarre*

‘Aboriginal law is strong. If I do the wrong thing and my trees dies, I’ll be gone. If Dreaming trees get lost, we be gone too. We got to tell them this. Someone will be in trouble, the bloke not listening to us, he will get sick. That’s our law. Our law is in the ground and will not change. When I’m gone my family got him. Our main word to them is “please take it easy on the water all around the world”.’ *Frankie Holmes Akemarre*

‘Country is happy when we talk to it and look after it. I did a painting about how lovely Wycliffe Creek is, with the ducks and the shade trees. Our old people might get sick and *kirda* might die if the shade trees fall. We would be sad as *kwertengerl* for Iliyarne if we lost our shade and our water and if the ducks flew away to find water. We would be sad and feel shame because Iliyarne wouldn’t be their home anymore, they can’t live without water. If the trees die the witchetty grubs die too, they can’t fly away like a duck can…We would feel sad for them too.’ *Lindy Brodie Nungarrayi*

Figure 33 ILIYARNE ILPAIYE, Wycliffe Creek

Source: Photograph by Susan Dale Donaldson.

3.2 Damage to sacred sites

The current research identified 40 sacred sites within the drawdown area, all beyond the extraction zone, associated with over 20 *Altyerre* (Dreaming) mythologies (see Figure 7). The proposal to reduce groundwater has the potential to adversely impact groundwater dependent sacred sites, which Traditional Owners are traditionally responsible for maintaining. As noted above, if a sacred site is damaged or destroyed there is a belief that *apmerek–artwey (kirda)* may get sick or die and *kwertengerl (kurdungurlu)* who inherit the customary role of protecting sites may feel responsible for the damage, which may lead to feelings of hurt and shame, as well as mental illness and social isolation.

Fortune Agribusiness received an Authority Certificate (AC) from AAPA in 2019 for work associated with the Singleton Horticulture Project including water extraction, the use of dams, bores and watercourses and the planting of crops.[76] The AC subject land extends from the southern boundary of Singleton Station north to the Stockwell Bore area, and between the Stuart Highway and the gas pipeline (see Figure 3). This area is larger than the extraction area and much smaller, but not completely overlapped by, the drawdown area.

The current research, as well as that undertaken by AAPA for the project AC, identified no sacred sites within the immediate extraction area. C2019/083 defines ten (10) Restricted Work Areas (RWAs) covering eleven sacred sites. Within these 10 RWA:

- Seven [RWA 1, RWA 2, RWA 3, RWA 4, RWA 6, RWA7 and RWA 8] are beyond the drawdown area in the Wycliffe Creek–Swamp area associated with eight sacred sites featuring ghost gums, bloodwoods, soakages, a 'depression hollow', two sand ridges, creeks, waterholes and swamps[77]; and
- Three [RWA 5, RWA 9 and RWA 10] are within the drawdown area associated with three sacred sites featuring a creek, ghost gums, a waterhole, soakages and bean trees. RWA 10 (AAPA AC 2019/083) is very close to the western extent of the extraction area and consists of GDE features (soak and bean tree).

Of these 11 sacred sites, 10 correlate with research undertaken for the current assessment; the cluster of bloodwood trees within RWA 1 were not recorded, probably because the focus of the current research was the drawdown area and this site lies beyond it.

[76] AAPA AC 2019/083.
[77] There are two sites within RWA 1

Critically, the current assessment identified 5 sacred sites within the AC subject land, not identified in the AC or overlapped by any of the RWAs. These sites are all within the drawdown area and are all associated with GDE features; all are soakages. An additional 32 sacred sites were identified outside the AC subject land and within the drawdown zone.

This assessment also highlighted a potential duplication within the AAPA C2019/083. The status of ten of the sacred sites is described as 'recorded' whilst one is listed as 'other site'. None are 'registered'. The site listed as 'other site' [5756-32] in the AC Appendix and on the AC map is described as a site of cultural significance to Aboriginal people but not one that meets the definition of a sacred site in the NT Sacred Sites Act. The site is described in the AC Appendix as 'a small waterhole / soakage in the main channel of Wycliffe Creek'. A site with the same number is also described in the certificate as 'a small soakage and water hole' subject to RWA 6 [AC para 10]. Research for this assessment found that the soakage, waterhole and creek associated with 5756-32 are associated with the *Atherre Artweye* [=Two Men] and *Aherre* [=Kangaroo] Dreamings and are indeed sacred.

It is notable that AAPA request that the applicant 'should engage an arborist to consider the long-term health of sacred trees both within and outside of the subject land, and in particular trees located within the railway corridor.'[78] Whilst the request is not a condition of the AAPA Certificate, it indicates that AAPA are concerned about sacred sites beyond the subject land into the drawdown area, and in particular sacred features associated with trees.

Given people are spiritually connected to country, if a sacred site is damaged or destroyed the spiritual connection between Traditional Owners and the site is also damaged or destroyed. There would also be a loss or decline in the cultural connection held by the Traditional Owners to the places that are impacted. There is a strong belief that rituals and songs and stories will continue even if sites and species of cultural value are damaged or destroyed, for instance, Possum Dreaming across the region continues to be valued by Aboriginal people, despite the extinction of possums. Another example is when Traditional Owners continue to recite place names in ritual songs relating to sites that are destroyed or their location has been forgotten. Similarly, a sacred bloodwood tree on the highway within the drawdown area has died, however, Traditional Owners believe that a new one will 'spring up' nearby soon to represent the story for that place. However, songs and associated place names are more accurately etched into the minds of the next generation through visitation, by Traditional Owners hearing and feeling and smelling and seeing the site. By remembering the journey to the site and knowing the places before and after.

[78] AAPA AC 2019/083.

Whilst Aboriginal traditions are known to adapt over time to cater for ecological and demographic changes, concerns have been expressed by Traditional Owners about incremental loss. They are well aware of cultural values already lost as a result of colonisation and fear further loss into the future. The ability of Traditional Owners to maintain traditions becomes harder if paralleled to ecological destruction and site damage. Will new trees 'spring up' to replace the ones that have 'fallen'? Will the soakages be recharged with enough rainfall or will they dry out in the long term? Yes, the rainmakers can make rain and the rangers can rehabilitate the natural environment, but how sustainable is this? Kaytetye people's spiritual connections and cultural practices associated with particular sacred sites, which have endured for thousands of years, could be gradually diminished or lost forever with a reduction in groundwater.

Below is a collation of Traditional Owners' comments relevant to an expression of how this cultural value might be impacted and the extent to which site damage preys on people's minds:

> 'I get sad when I know that my uncle and father called the names of soaks they knew and they knew how to find them. I know the names they called but don't know where the sites are. It makes me sad that I'll never find these places again. What story can we leave for Wycliffe country if the sites are gone. We will know the stories and the names but there will be no sites.' *Michael Jones*

> 'Frogs live in the Wycliffe sandhill. There is a big tree standing there. A Dreamtime tree. If the frogs die, we might get sick. If the country goes down, we go down too. If they kill our country, the feeling we have for that country, for the spirits, might makes us sick.' *Karen Morrison*

> 'We are connected to country through the dreaming law. When that Ngapa tree at PANJIRRIJI got damaged the owner, Old Black Hat, he died because that tree got damaged. This happens to our people. Our Law is strong. When they took that devil's pebble away from KUNJARRA Mr Taylor died. We can get sick because the spirit in the tree is connected to our spirit, if the tree dies part of our spirit dies too. So, we try and do our best to look after country and fear the consequences if we don't. *Kirda* might die or get sick and *Kwertengerl* might feel guilty because they haven't done their job, they might get mental health no good.' *Michael Jones*

> 'When they took that KARLU KARLU rock away people got sick. The land went dry and people were having car crashes all the time. When the rock was returned people were happy. My grandmother Molly waited

for that rock to be returned before she died. She died happy. If all the water goes, forever, first we will lose our old people, then other Traditional Owners. We can't let that happen. We need to save our water forever, not lose it forever. We are not interested in money, we want our water to save our lives forever, for all the future generations. They can enjoy swimming in Wycliffe Creek too.' *Evangeline Presley*

'There is spring water at Barrow Creek at ELKEREMPELKERE. They graded too close to it so the water got shut down. The little people, the spirits living at the spring shut that water off because they were angry. They get angry if people do the wrong thing at a sacred site. We have to talk to the spirits for days so that the soil gets wet and then there will be puddles everywhere.' *Hilda Pwerle*

'If we have no soakage water, the story will still be sitting there in the country. Another tree might come up. Our Dreaming is strong and survives. We can still pass on the *Altyerre* and share the stories. That's the same for the ladies too.' *John Duggie*

'The country has spirit. It is alive. The country will get sad and sick and Traditional Owners will get sad and sick if the country dries up. We don't want to see the old people worry. We like to see our country green and the birds will be happy and the old people will be happy. I saw dad talk to the spirits at ELKEREMPELKERE. They are there. He spoke to them in Kaytetye. We belong to that place too. If kids break trees around the spring to make a humpy, they will get sick and we'd have to take them to see a witch doctor to get better.' *Selma Thompson*

Damage to sacred sites can impact Traditional Owners' spiritual connection to country as well as their social relationships. As such, protecting sacred sites is one way for Kaytetye people to maintain their spiritual identity and wellbeing.

'If we Iliyarne people let our land go dry, other people will growl at us. We need to keep the water until we die so that it can jump over to our children and their children all the way like that. The spirit people will get upset if we let that country go dry. They will make us sick, especially Rodger Tommy the main *kirda* (owner through father), and his sons and daughters. We are his *kwertengerl* (owner through mother) and we watch over that country for him.' *Heather Anderson Narrurlu*

'If the land dries up, we will not recognise it. We will not be able to find our sacred sites and soaks. The big sacred trees will fall. If water goes, country gets lost and people die. We die. Where will the animals go? Big shade trees are important too in summer for people and animals. The coolibah on the highway is called [name redacted], it represents ladies travelling when they were making rain. They were Napurrulas from Anerre country. We have to look after that tree.' *Selma Thompson*

'There is a lot of *Ngappa Wirnkara* (rain dreaming) around the Singleton area. KARLU KARLU, Wakurlpu, Warlaparnpa, all these places were made by *Ngappa Wirnkarra*. Cowboy Sandy had Ngappa Wirnkarra too and the mob at Renner Springs and Anerre in the south. All these places will be affected if there is no water. The story will still be there, still alive, the song will still be there and still be sung, but we will be sad when we get to that place all dead. The story will be weaker for younger people, it will not be as strong as it was for the people before because the places will be ruined. We take them to soakages that are gone and to country that is sick. We have lost other soakages when they put in bores. It is sad to visit these places that are lost, but we keep the story going.' *Michael Jones*

'We need to keep that big tree alive on the sandhill. That tree has a story for Iliyarne country. I paint that tree and sandhill. That's my mother's country. The spirit people are holding the tree roots underneath, they are holding on tight to keep that tree alive.' *Heather Anderson*

When sacred sites associated with people's bush names are damaged the intangible link between the person and the place is also impacted. People feel sad that they will not be allocating these names to future group members if the site is gone.

'Mpwerempwer-ange [lily] is Lindy's mother's bush name. If the land dries up, our lilies will dry out too. We want our kids to see the lilies. It is part of their country. If the lilies all die, it will just be a story from the past about how we collected lilies.' *Karen Morrison*

Figure 34 The importance of sacred sites to Kaytetye people

In summary, the importance of sacred sites to Kaytetye people are multilayered and include being a focal point for mythology and ritual; central to one's inheritance and to the inheritance of one's descendants; a source of spiritual connections and access to the powerful forces of the *Altyerre*; and an important element in the way Traditional Owners exercise their repositionability to their country and to their ancestors (Figure 34). Conversely, if a sacred soakage for instance permanently dries as a result of a reduction in groundwater on which it depends, the Kaytetye Traditional Owners are unable to fulfill their customary role in accordance with their traditional laws, and as a direct consequence senior *kirda* will be punished by *Altyerre* forces; they are likely to get sick, suffer ongoing 'bad luck' and potentially die. The group may also suffer long term and intergenerational emotional and spiritual loss.

3.3 Reduction in species required for ritual activity

A reduction in groundwater has the potential to adversely impact GDE species which Traditional Owners customarily require for ritual activity. Specific items required for ritual (e.g., bird feathers/water) may become scarce and in turn undermine ritual activity. Some ritual items are interchangeable (turkey down feathers > nappy fluff) others are not (water required from specific sacred sites). A reduction in groundwater will undoubtedly have a multitude of negative impacts on this important cultural value including altering and diminishing ritual activities into the future.

> 'We use bird feathers for ceremony; bush turkey (down) feathers, black feathers from the eagle, emu tail feathers. If these birds die or fly away, we would have to seek permission from Warlmanpa, Jingili, Mudburra and Warlpiri mob to get these things from their country. We would have to travel to this which means more work. It would make things harder because we would have to drive a long way.' *Michael Jones Jampin*

> 'We use the white cockatoo feathers for young fella business. We collect the ones that have fallen on the ground. The sons and nephews pass feathers onto their mothers and aunties. We need to look after the white gum trees where the cockatoos nest. If these trees die then the birds will have no nests for their babies and we will have no feathers for our ceremony. We need water to keep the trees and the cockies and our business alive.' *Evangeline Presley*

In regards to sacred water senior Ngappa (water) Dreaming man noted:

> 'My rain dreaming is further north. If they took the water away from my country, I'd have to close down that ceremony; it might not work. We can't let this happen. We can't live without water. Maybe they are trying to kill us.' *Dick Foster*

3.4 Diminishing natural resources required for hunting, gathering and other activities

This assessment identified the extraction area as prime hunting land. The broader drawdown area is also highly valued as a natural resource collection place. The assessment found, like other previous studies across central Australia, that Kaytetye people utilise natural resources for a variety of reasons including for sustenance, medicine, implements, ritual, and trade and exchange.

The Western Davenport Water Allocation Plan (WDWAP) acknowledges this:

> The floodouts and associated vegetation are culturally important to the Traditional Owners, particularly in relation to large trees they support (such as Eucalyptus sp. and Corymbia sp.) and the high importance of these areas to Aboriginal cultural practices and land use. Floodout are generally important hunting areas and also often have ceremonial importance…Soaks are considered one of the most important sources of water in the desert…Significant drying or lowering of the water table could adversely affect the availability of water in soaks and the health of important GDEs… (NTG 2018).

A reduction in groundwater will undoubtedly have a multitude of negative impacts on this important cultural value. Traditional Owners expressed serious concerns about the SWL potential impact to a range of cyclical ecological process which in turn are likely to negatively impact their important hunting and gathering grounds:

> 'We have to speak on behalf of the insects and animals. The insects are working hard, they all have a job to do. You are not going to see all the ants marching along with protest signs, we have to do it for them. You look at the honey bee giving life to others by pollinating flowers. There will be nothing without the bees, and no honey for us. The bees need the gum flowers to make the honey. If our bloodwoods and other gums die, the bees will have no food and can't make honey. We love our sugar bag. It makes me cry when I think of not having any more honey.' *Maureen O'Keefe*

> 'I remember seeing bilby scratching east of Neutral Junction Station and a speckled hare wallaby dead on the Alekarenge road. There should be a flora and fauna survey done across Singleton, Neutral and Warrabri ALT.' *Gladys Brown*

> 'Frogs are vulnerable to change; they might be affected by a loss of groundwater or climate change.' *David Curtis*

Because of the cyclical interrelationship between certain GDE species and places required for the native title right to hunt, gather, take and use the natural resources of the land and waters, if the current proposal reduces groundwater, there is the potential for the proposal to adversely impact GDE species and places which Traditional Owners rely on for sustenance, gaining goods and other items (see Figure 19).

Not a lot of data was collected on trade, however, there is an obvious link between a reduction in resources and people's ability to access resources for trade. Having said that, Aboriginal society has proven to be adaptable to change in regards to economic opportunities and a reduction in certain species currently valued as tradable items may lead to other items becoming more valuable in their absence.

The drawdown area, including Taylor Creek and the sand dune/floodout systems associated with Wycliffe Creek are regionally significant resource rich areas across a range of seasons. The Wauchope and Alekarenge communities in particular utilised their 'back yard' to collect natural resources and to maintain spiritual well-being. Traditional Owners take and use the natural resources across the drawdown area on a seasonal basis. There is concern that this culturally important activity will be impacted and associated knowledge lost. It is feared that the bigger animals will go to another Country to find water, and the smaller species will die out. People will feel a sense of shame and loss if they allow species to die out or find a 'new home'.

'Water is precious for life. If we have no water, we will die. Our pencil yams and bush bananas will die and the animals that can travel will go to green country.' John Duggie

Figure 35 Snail shell at MPWEREMPWER-ANGE swamp, Iliyarne ALT

Source: Photograph by Susan Dale Donaldson.

There is concern that this culturally important activity will be impacted by a reduction in groundwater and a subsequent loss of associated cultural knowledge and practice. The wellbeing of the local community who regularly access the drawdown area will also be negatively impacted given hunting and associated activities promotes a healthy lifestyle both physically and mentally. Moreover, Traditional Owners fear that the bigger animals will go to another Country to find water, and the smaller species will die out. People will feel a sense of concern, loss, sadness and shame if they allow some species to die out and others to find a 'new home'.

'When the wind blows from the east animals from the west can smell the water and come to the swamp for a drink and a rest. We worry about all the birds and animals, kangaroo and goanna, if the swamp dried up. We love collecting conkerberries, passionfruit, sugarbag, lilies, frogs and witchetty grub around MPWEREMPWER-ANGE.' *Heather Anderson*

Figure 36 Bush banana *alkwarre* (*Marsdenia australis*), Neutral Junction Station

Source: Photograph by Susan Dale Donaldson.

'In the early days spring water was drunk with grass straws. The zebra finches will take you to water. We would cover up the soak with clay so that the water didn't evaporate. The sun would suck the water up if we didn't cover it over. Old people will tell you, if there is no water in the ground, certain trees will hold water in dry times. When the water is all gone, special trees will get killed off, we are seeing this already. The animals that can't escape to find water will die. The crabs in the mud might die and the bilbies. There used to be bilbies at Greenwood when I was growing up. They live in small groups and eat witchety grubs. How will they survive without water? If there are no roos, we won't go hunting. If there is no water, it will be hard to hunt.' *Sonny Curtis Jappanangka*

'It makes me feel sad for country if country has no water. We live in a desert. We need that water.' *Cedric Tennison*

Figure 36 Conkerberry anwekety (Carissa lanceolata)

Source: Photograph by Jessica Burdon (CLC).

Kaytetye people also expressed a contextual view of the current proposal and potential impacts, with an obvious understanding of broader environmental processes:

> ‘We already have cattle messing up our creeks, so now we can’t drink from them. That makes our underground water coming up into our soaks and springs even more important. They picked the place where we need our water for the swamps and springs, it will be all sucked dry. We are going to have a water crisis. If we lose our water forever, we suffer forever, for generations to come. We are fighting for their future now. This water belongs to everyone, the plants and human beings. How cruel can the government be? You wouldn’t let your child get thirsty; they are meant to be the big daddy looking after us.’ *Maureen O’Keefe*

> ‘We have noticed some of our landmark trees drying out and dying in the hot weather. The climate is getting hotter and it will continue to get hotter into the future so we will need more water for our plants and reduce evaporation. I am not against farming or irrigation, but this water allocation is too much. The government isn’t taking into consideration climate change and the concerns of our people. Our springs and soaks will be affected, they are already being affected by the change in weather. Once the water table starts dropping, given the connections underground, all the water will head to Singleton and other current bore fields will be affected too. Our yams, bush potatoes they are in certain areas all year around, they have to depend on the groundwater. How will they be affected? Our trees in swampy areas, the witchety grubs live in them. Without the trees our food source is lost. I’d be upset to lose our bush foods. The allocation is excessive. I am against it.’ *David Curtis*

‘If we have no water, we will be very concerned about the things that can’t travel too far, like the crabs, witchetty grubs and mussels. They will die. A bird can fly away but a little crab can’t go far.’ *Michael Jones Jampin*

Figure 37 Crab (*Austrothelphusa transversa*) holes in the bank of the Wycliffe Creek

Source: Photograph by Jessica Burdon (CLC).

3.5 A loss for future generations of Kaytetye people

Because of the cyclical interrelationship between certain GDE species and the Traditional Owners’ right to maintain areas of importance for future generations, if the current proposal will have the effect of dramatically reducing groundwater, there is potential for adverse impacts to GDE species which Traditional Owners are traditionally responsible for looking after (see Figure 28).

Traditional Owners expressed that a reduction in underground water will make it very difficult for *apmerek-artwey* and *kwertengerl* to fulfill their customary obligations in relation to ensuring there is a future water supply and good hunting ground and for their descendants, just as their ancestors did:

> ‘When you add it all up, all the water they want to take out of the ground across the region, it is too much. What about our future? What about the future of our grandkids? We need to look after our water.’ *Rodger Tommy Jungarrayi*

> ‘The old people, including my father, dug water out of the soaks with coolamons and then covered them up to keep the water cool and to save the water from being ruined from kangaroos, dust and grass. They lived around Taylors Creek. That’s all Anerre country. A little bird called *Ngeymarre* lives along that creek. It is a little zebra finch. There is a story about that *Ngeymarre*.’ *Selma Thompson*

The potential for Traditional Owners to feel shamed as a result of not looking after the water upon which the plants and animals living on their country rely, was a key theme expressed during this assessment. Traditional Owners feel that a reduction in underground water will make it very difficult for *apmerek-artwey* and *kwertengerl* to fulfil their customary obligations in relation to water and the life that water sustains. What will they pass onto their grandchildren?

> 'The old people before us looked after the country proper way. They had to look after their country for us, that was their job. Things are getting harder and harder. If they take the water, how are we going to look after our country?' *Sonny Curtis Jappanangka*

> 'The rangers have a focus on prevention where wildlife and plants are concerned. This water licence isn't going to help them in the job they do. It all comes down to water. We have to preserve underground water. People can use it but not to this level. It is very irresponsible of the Northern Territory Government to do that. Small scale is not too bad. This is awful. Sucking water out of an arid zone makes no sense. We can't be certain it can be recharged and rain is not as reliable as it used to be. I can't believe the government did this. Aboriginal people should have control over water, it is part of our country. Water is for all people; no-one can live without water. Also, it is a real worry that if the underground water is removed, the ground might fall in. Sink holes. Not having control over the use of water will cause people stress and stress kills people. It will be a huge problem.' *David Curtis*

> 'It will be hard for Aboriginal people to care for their country because having no underground water is a hard problem to fix. The rangers work hard, but this will be a big problem for them. We might need water monitors so that the problem doesn't get bad. We worry about our future and the future of our grandchildren.' *Jorna Murphy Nappangarti*

Wakurlpu *kirda* Billy Boy Foster (dec.) highlighted the important role *kwertengerl* plays in looking after sacred sites and the repercussions of not:[79]

> …young men are being taught the *Ahakeye* Dreaming, they are being taught by the *kirda* and *kwertengerl, kirda* is doing the dancing, but *kwertengerl* got to do his job because that's Aboriginal Law…if *kirda* do wrong…*kwertengerl* go crook on him…The marbles are the plums…if they are damaged there would be

[79] Warumungu Land Claim, Transcript 1985:3413, 3416–17, 3441–2, 3415–8.

big trouble for the *kwertengerl*… look after the sacred *ahakeye* objects stored at [site name redacted].

Visiting country with children to teach laws and customs will also be undermined if species are reduced and sites are damaged. Summer teaching including learning how to swim, requires shade trees and water, both may be reduced.

'Allocating this much water will weaken our native title and dry up our land rights land. If certain bush tucker depends on that water, like sugar bag, the people responsible for that dreaming will be upset. My dreaming is sugar bag. I can eat sugar bag, but I wouldn't eat the last one. If the sugar bag disappears, I will still have my totem, but no sugar bag to eat and share.' *David Curtis*

'Certain people have responsibilities for the country, caring for it. If this happens, no-one has control and they can't care for their country. If they can't care for their country, they get stressed. We thought we had land rights but what good is land without water? Aboriginal people still are not safe. We are forever fighting.' *David Curtis*

'We need to look after our country, but it's like a small hose fighting a fierce bush fire…what if the rainmakers get sick and die too?' *Michael Jones*

3.6 Decline in ability to live on and travel on the land

Because of the cyclical interrelationship between certain GDE species and places and Traditional Owners' desire to continue to travel over their land and waters and to live on the land, if the current proposal will have the effect of dramatically reducing groundwater, there is the potential to adversely impact GDE species and places which Traditional Owners traditionally rely on when undertaking these important activities which they value (see Figure 31).

There is a fear that people will not attempt to travel lengthy distances in fear of getting thirsty and dying. It is thought that this right would be less enjoyable to exercise if the land is dry, and country would be accessed less often. There is a fear that people will 'stay in town' if there is no available water on country.

> ‘We are worried about how taking so much groundwater and how that will affect our water supply at Kalinjarri Outstation where our family lives. Not only Kalinjarri, but McLaren Creek, Alekarenge and Wakurlpu also. There are people living in all these places. They also go hunting around their areas and if there is not water then there will be no animals to hunt.’ *Sandra Morrison*

> ‘We have a community outstation at Wakurlpu. If the water levels drop our water goes salty and if that happens, we will not be able to live there. We would have no drinking water and wouldn’t be able to grow anything. If the water drops at Singleton, the water levels under the surrounding communities will get pulled to Singleton and reduce the water in the communities.’ *David Curtis Jungarrayi*

> ‘How can we survive without water at our outstation here at Wakurlpu. This is our country. More of our family is moving back. How can the country survive without water? We are very worried about losing our water. Our water. If we have less water our Wakurlpu community water pressure will be even less. It is already very low. Some days we have to wait half a day to get any pressure. If there is no water, it doesn’t look as though we could live there, on our country.’ *Sonny Curtis*

> ‘Don’t they see that there are people living on this land? Living off this land? It’s like when the British tested rockets at Maralinga they were blind and didn’t see that people were living there. Then they made the people sick and blind. The birds fell out of the sky. Their country was ruined. Yami Lester was blinded and he had no idea what was happening. Today we know what’s about to happen, there is about to be a water crisis. We have to stop it before it happens.’ *Maureen O’Keefe Nampijinpa*

Concerns have also been raised by Traditional Owners that if people break down in their motor vehicles when out hunting in remote areas, they might not be able to rely on their traditional ecological knowledge to survive because the landscape and its resources may be altered.

> ‘When I was eight years old, three men walked from Warrabri to Wauchope and they couldn’t find any water. One of them died of thirst. They never found the body. People need water to travel or they might die.’ *Michael Jones*

> ‘When we had no motor car, we used to walk from soak to soak, if they take the water away, we will die half way.’ *Sonny Curtis*

4.0 CONCLUSION

The drawdown area extends across Singleton PL, Neutral Junction PL, Warrabri ALT and Iliyarne ALT. These lands have been through either the Aboriginal land rights or native title process which found and/or determined that the drawdown area traditionally belongs to Kaytetye people associated with the Akwerlpe-Waake, Iliyarne, Anerre and Arlpwe groups. These four country groups have rights and responsibilities to the drawdown area in accordance with traditional laws and customs and are deeply intertwined with their neighbouring groups through ritual, mythology, kinship, trade, economic activity, language and shared historical experience.

Traditional Owners' belief in the *Altyerre* Law and the associated spiritual power imbued in the cultural landscape is the cornerstone cultural value arising from this assessment and the foundation of all other identified cultural values. Key cultural values for Traditional Owners identified in this assessment are following the *Altyerre* Law; maintaining spiritual connections and protecting sacred sites; undertaking ritual activity; upholding ecological knowledge associated with collecting natural resources; continuing customary roles and responsibilities; and being able to live on country and travel across country.

Background research combined with consultations with Traditional Owners identified 40 sacred sites associated with 20 *Altyerre* [Dreaming] mythologies within the drawdown area. Considering not all of the identified sites were visited during the assessment combined with the cultural complexities of the region, it is possible that one or two of the sites identified are actually the same place known by different names. It is also possible that other sites exist within the drawdown area that were not identified during this assessment. More time on the ground with Traditional Owners would provide further clarity on the cultural landscape in terms of the presence and significance of sacred sites.

Many of the *Altyerre* tracks traversing the drawdown area interlink with places across the broader cultural landscape. All of the sites are located beyond the immediate water extraction zone and all have features associated with GDE including *ngentye* (soakages), *elpaye* (creeks), *ilinjera* (floodouts), *artnwep* (swamps), *arrkarakw* (bloodwoods) and *atnkerre* (coolibah trees).

If there is a reduction in groundwater, Traditional Owners' feel that these important places may change forever and their ability to maintain their cultural values in accordance with their traditional laws and customs will be hindered because many culturally relevant species, sacred places and cultural practices rely on groundwater, directly and indirectly. Of particular concern to Traditional Owners are the consequences associated with breaking the Law if sacred sites are damaged; they hold a strong belief that *apmerek–artwey (kirda)* who hold the customary role of passing country onto the next generation, may get *arntetye* (sick) or *ampwarrenke* (die). Similarly, spiritual consequences for *kwertengerl (kurdungurlu)* who hold the customary role of protecting sites may feel responsible leading to feelings of *amperrnge* (sadness/unhappy) and *nyerre* (shame), and potential mental illness and social isolation or *althere* (homesickness).

The subject land for the Aboriginal Areas Protection Authority sacred sites Authority Certificate for the proposed work covers an area larger than the extraction zone but less than the estimated groundwater drawdown area (C2019/083). The current assessment identified 5 sacred sites within the AC subject land, not included in the AC. A further 32 sacred sites were identified outside the AC subject land and within the drawdown zone.

Based on in-depth discussions with Traditional Owners when undertaking this assessment, it is clear that Traditional Owners would prefer to sustain the current health of their country and maintain their custodial responsibilities to it by opposing the Singleton Water Licence, rather than the alternative scenario of seeing their country get sick, having their traditional rights and interests eroded, and holding the psychological stress and guilt associated with knowing their descendants may lose important cultural values which have been sustained by Kaytetye people for thousands of years.

Traditional Owners desire to continue their active role in managing their traditional lands and waters for the future benefit of their society and culture. They want to defend their cultural values and guard the foundation of their ancient religion. To enable this to occur, it is recommended that the broad range of cultural values identified be sustained and safeguarded in accordance with national and international cultural heritage management practice (UNESCO 2003; ICOMOS 2017).

In relation to the protection of 'cultural uses' of water, the WDWAP recognises that there are cultural values which relate to GDEs and will have additional requirements for cultural use protection such as soaks, ceremonial areas and hunting grounds, and that further work is required to ensure that these requirements are understood including ongoing monitoring to identify any changes or threats to these values being protected.[80] The plan also recognises Aboriginal people are custodians for water places and places relying on water.[81]

Good practice in the field of cultural heritage management includes working in cooperation with Traditional Owners to develop and apply an approach to cultural heritage management inclusive of a broad range of tangible and intangible cultural values. Traditional Owners' cultural values should not only be documented, Traditional Owners themselves should be empowered as active stakeholders and decision makers in matters that affect their land and waters.

[80] NTG 2018:28.
[81] NTG 2018:29.

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ATTACHMENT 1
List of plant and fungus species associated with the SWL Drawdown Area

List of plant and fungus species associated with the SWL drawdown area

This list of culturally important plant and fungus species observed or discussed within the Singleton Water Licence District and their indigenous names were collated by Jessica Burdon (CLC). The information is based on field observations, discussions with Traditional Owners, and Latz (1995 & 2018). The listed plants are referenced in Nano et al. (2021) as closely associated with sandplain and alluvial potential GDV in the Western Davenport study area. **Plants not referenced in Nano et al. (2021) are shown with an asterisk *.**

Genus	species	Family	Common name	Kaytetye	Alyawarra
Abutilon	otocarpum	MALVACEAE	lantern flower		*akeley-akeley*
Acacia	aneura	MIMOSACEAE	mulga	*artetye*	*artety*
Acacia	colei	MIMOSACEAE	Cole's Wattle, Soap wattle	*elkerte*	*alarrey*
Acacia	cowleana	MIMOSACEAE	sickle-leaved wattle	*elkerte*	*alerrey*
Boerhavia	coccinea	NYCTAGINACEAE	Tar vine		*ayep*
Capparis	umbonata	CAPPARACEAE	northern wild orange		*akerley*
Canthium	attenuatum	RUBIACEAE	native currant/bush plum		*ahakeye*
Carissa	lanceolata	APOCYNACEAE	conkerberry	*arnewetye/ perlape*	*arnwekty*

Chrysopogon	fallax	POACEAE	goldenbeard grass		*iylayemp-iylay, iylenty, lyayepelyay*
Corymbia	aparrerinja	MYRTACEAE			*Ilwemp*
Orymbia	opaca	MYRTACEAE	bloodwood		*arrkarakw*
Cymbopogon	ambiguus	POACEAE	native lemon grass	*arineng-arinenge*	*aherr-aherr/Apmwerr*
Cyperus	bulbosus	CYPERACEAE	bush onion	*erreyakwerre/ yerrakwerre*	*irreyakwerr*
Dactyloctenium	radulans	POACEAE	button grass		*apwert-arlkwenh*
Eragrostis	leptocarpa	POACEAE	love grass		*awertaw*
Eragrostis	eriopoda	POACEAE	woollybutt		*alyatywereng, antyer*
Eremophila	longifolia	MYOPORACEAE	Emu bush		*arlarterr, itnwerreng*
Eremophila	latrobei	MYOPORACEAE	Native fuchsia		*akwenthey, therrpeyt*
Erythrina	vespertilio	FABACEAE	bean tree, bats wing coral tree		*atwerety, Atjuritj*
Eucalyptus	camaldulensis	MYRTACEAE	river red gum	*aylpele*	*alperr*
Eucalyptus	victrix	MYRTACEAE			*ankerru*
Grevillea	striata	PROTEACEAE	beefwood		*irltenty*
Hakea	chordophylla	PROTEACEAE	northern corkwood	*ntyweyampe*	*ntyweyamp*
Hakea *	*macrocarpa*	*PROTEACEAE*	*Dogwood Hakea*		*andrreum*

Ipomoea	muelleri	CONVOLVULACEAE			*anaytapaytap*
Ipomoea*	*costata*	*CONVOLVULACEAE*	*Bush potato*		*anajara*
Melaleuca	lasiandra	MYRTACEAE			*dunkwerrk*
Muehlenbeckia	florulenta	POLYGONACEAE			*Inculdj*
Marsdenia*	*australis*	*ASCLEPIADACEAE*			*alkwarrer*
Pisolithus*	*tinctorius*	*SCLERODERMATACEAE*			*arrank-arrank, irrkweng*
Podaxis *	*pistillaris*	*TULOSTOMATACEAE*			*pwenkapw, pwengapweng*
Pterocaulon	serrulatum	ASTERACEAE			*inteng*
Rhyncharrhena	linearis	APOCYNACEAE	bush bean	*werrpe*	
Santalum	lanceolatum	SANTALACEAE			*alkwa*
Senna	artemisioides	FABACEAE			*apwen, arey-arey, areyawarr*
Solanum	chipendalei	SOLANACEAE			*akatyerr*
Streptoglossa	bubakii	ASTERACEAE			*inteng*
Tinospora	smilacina	MENISPERMACEAE			*atnwerl*
Triodia	pungens	POACEAE	soft spinifex	*alatyite*	*alatyeyt*
Ventilago	viminalis	RHAMNACEAE			
Yakirra	*australiensis*		Bunch Panic, Bilby grass		*alwepenh, yakerr*

ATTACHMENT M:

ADDENDUM: ABORIGINAL CULTURAL VALUES
SINGLETON WATER LICENCE

Prepared by Susan Dale Donaldson, Anthropologist
7 February 2023

ADDENDUM

Aboriginal cultural values impact assessment

Singleton Water Licence Drawdown Area

Singleton Pastoral Lease, Neutral Junction Pastoral Lease, Warrabri Aboriginal Land Trust and Iliyarne Aboriginal Land Trust, Northern Territory, Australia.

SUSAN DALE DONALDSON

ANTHROPOLOGIST

Environmental & Cultural Services

7 Feb 2023

WARNING: THIS REPORT CONTAINS REFERENCE TO ABORIGINAL PEOPLE WHO HAVE DIED

Contents

Executive summary

The Singleton Horticultural Project proposal has been referred to the Northern Territory Environment Protection Authority (NT EPA) for consideration as a 'proposed action' under section 48 of the NT *Environment Protection Act 2019* (NT EP Act). The Singleton Horticultural Project relies on the Singleton Water Licence (SWL). The Central Land Council (CLC) requested Susan Donaldson prepare an addendum to the Aboriginal Cultural Values Assessment report (Donaldson 2021) to specifically address whether the Singleton Water Licence will have a *significant impact* on Aboriginal cultural values identified across the Singleton Water Licence Drawdown Area (SWLDA).

The Singleton Water Licence Drawdown Area (SWLDA) extends across Singleton Pastoral Lease (PL), Neutral Junction PL, Warrabri Aboriginal Land Trust (ALT) and Iliyarne ALT. These lands traditionally belong to four Kaytetye speaking landholding groups, Akwerlpe-Waake, Iliyarne, Anerre and Arlpwe, who have recognised native title rights to the SWLDA. These four Aboriginal groups have localised rights and responsibilities to the drawdown area in accordance with traditional laws and customs which give rise to their cultural values which are of high significance. Akwerlpe-Waake, Iliyarne, Anerre and Arlpwe people are structurally interrelated with the other Kaytetye landholding groups and their Warumungu, Alyawarr, Warlpiri, Anmatyerre and Warlmanpa speaking neighbours all of whom culturally connect to the SWLDA and share many of the identified cultural values.

Traditional Owners' belief in the *Altyerre* Law is the cornerstone value arising from the cultural values assessment and the foundation of all other values including maintaining spiritual connections and protecting sacred sites; undertaking ritual activity; upholding ecological knowledge associated with natural resources; continuing customary roles and responsibilities; and being able to live and travel on country (Donaldson 2021).

These values primarily relate to social and spiritual themes linked to surface water, groundwater dependent ecosystems (GDEs) and other features across the SWLDA. The values relate to cultural places within the SWDLA, as well as cultural practises and traditions directly associated with the SWDLA. The cultural values across the SLWDA are maintained by the Traditional Owners today and are deeply rooted in their heritage and form the framework for their future.

Additional analysis has shown that the likely consequences (the 'impact') to each of the identified Aboriginal cultural values (the cultural aspects of 'environment' present on the selected site) caused by a reduction of groundwater (the 'action' and major 'impact source') will be significant.

A massive reduction in groundwater across the SWLDA will trigger major negative consequences to cultural places and values held by Akwerlpe-Waake, Iliyarne, Anerre and Arlpwe people and their neighbouring tribal groups impacting culture and heritage; human health; community and economy; aquatic ecosystems; hydrological processes; and terrestrial ecosystems.

The potential impacts will likely or almost certainly result in highly significant cultural values to be lost, degraded and damaged, as well as notably altered, modified, obscured or diminished. The planned action, in my view, is likely to alter the existing use of a number of cultural and ceremonial sites, causing their values to notably diminish over time. The action is also likely to permanently diminish the cultural value of places for Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people to which its values relate and permanently damage ceremonial features with cultural value. It is my view that the likely impact that this proposal may have on the identified cultural places values as linked to Groundwater Dependant Ecosystems (GDEs) across the SWLDA is significant.

Whilst Aboriginal Areas Protection Authority (AAPA) approval has been granted and aims to avoid harm to a number of identified sacred sites, the substantive risk of damage to, or interference with sacred sites on or in the vicinity of the AAPA subject land is highly likely (even if they are covered by Restricted Work Areas). Another highly likely consequence of harming sacred site in this matter is the distress caused to the Traditional Owners. In my view both of these potential impacts are significant and not adequately addressed by approvals received under the Northern Territory Aboriginal Sacred Sites Act 1989.

I am not aware of impact management measures aimed at avoiding, mitigating or reducing the potential adverse impacts to the identified cultural values beyond the AAPA Authority Certificate process. Accordingly, the duration and extent of the significant impact to the cultural values is unknown at this stage. Significant cumulative impacts of the proposal are also uncertain but likely given the changes to the climate, the existing and historical use of the site for agricultural activity, and the proposal to remove a large quantity of groundwater. Similarly, the 'end of life' plan for the proposal is undefined, so the ongoing or residual impacts to the cultural values is also uncertain.

1.0 INTRODUCTION

The Singleton Horticultural Project proposal has been referred to the Northern Territory Environment Protection Authority (NT EPA) for consideration as a 'proposed action' under section 48 of the NT Environment Protection Act 2019 (NT EP Act). The Singleton Horticultural Project relies on the Singleton Water Licence (SWL).

The Central Land Council (CLC) requested Susan Donaldson prepare an addendum to the Aboriginal Cultural Values Assessment report (Donaldson 2021) to specifically address whether the Singleton Water Licence will have a significant impact on Aboriginal cultural values identified across the Singleton Water Licence Drawdown Area (SWLDA).

A deeper analysis of the existing consultation data was carried out and considered in relation to the project's potential 'significant impact' as defined by the Northern Territory's *Environment Protection Act 2019* (NT EP Act), with consideration of the *Environment Protection Biodiversity Conservation Act 1999* (Cth) (EPBC Act), the Burra Charter (Australia ICOMOS 2013) and the Burra Charter Practice Note on Intangible Cultural Heritage and Place (Australia ICOMOS 2017).

In preparing this addendum, further engagement with Traditional Owners did not occur.

1.1 Definitions

The SWL proposal has been referred to the NT EPA for consideration as a 'proposed action' under section 48 of the NT EP Act because the proposed action has the potential to have a 'significant impact' on the environment.

> The meaning of 'action' under the NT EP Act includes a project; a development; an undertaking; an activity or series of activities; works, and a material alteration of any of these things.

The meaning of ‘impact’ (of an action) under the NT EP Act is an event or circumstance that is a direct consequence of the action; or an event or circumstance that is an indirect consequence of the action and the action is a substantial cause of that event or circumstance. An impact may be a cumulative impact and may occur over time.

The NT EP Act defines ‘significant impact’ as an impact of major consequence having regard to the context and intensity of the impact; the sensitivity, value and quality of the environment impacted on, and the duration, magnitude and geographic extent of the impact.

The meaning of ‘environment’ under the NT EP Act is all aspects of the surroundings of humans including physical, biological, economic, cultural and social aspects.

The meaning of ‘environmental values’ under the NT EP Act is aspects of the environment that are important or serve an important function, such as a river that provides beneficial uses to ecological and human communities, a site that is sacred to Aboriginal people, or an animal or plant species that is threatened.

Further to the criteria outlined in the NT EP Act, in determining whether a proposal is capable of having a ‘significant impact’ on the environment the NT EP Act may have regard to various matters including (NT 2021: 19):

1. objects of the NT EP Act or other NT environmental legislation
2. value (e.g., effects on environmental factors and objectives), sensitivity and quality of the environment which is likely to be impacted
3. extent (intensity, duration, magnitude, frequency and geographic footprint) of likely impacts
4. consequence of likely impacts (or change)
5. resilience of the environment to cope with the impacts or change
6. cumulative impact with other proposals
7. connections and interactions between parts of the environment to inform a holistic view of impacts to the environment

8. level of confidence in the prediction of impacts and the success of proposed mitigation.

The decision about whether a potential impact is considered 'significant', for the purpose of the NT EP Act, is one for the Northern Territory Environmental Protection Authority.

The term 'significant impact' has been adopted in other jurisdictions, and most notably in relation to the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), which requires Ministerial approval if an action will have a significant impact on matters of national environmental significance (MNES). Although the EPBC Act Significant Impact Guideline (2013) (EPBC Guideline) is not directly relevant to Singleton Station as it deals with MNES, there is useful information in relation to how proposals with potential impacts on Indigenous heritage values are considered against the significant impact test.

Under the EPBC Act a 'significant impact' is an impact which is important, notable, or of consequence, having regard to its context or intensity. Whether or not an action is likely to have a significant impact depends upon the sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts. Most of the national criteria are incorporated into the NT EP Act criteria listed above.

The EPBC Guideline contains useful information in relation to how proposals with the actions likely to cause impacts on Indigenous heritage values associated with World Heritage properties and National Heritage places are considered against significant impact criteria.

<u>Significant impact criteria for World Heritage properties and National Heritage places with Indigenous heritage values</u>

An action is likely to have a significant impact on the Indigenous heritage values of a place if there is a real chance or possibility that it will cause (EPBC Guideline 2013:16, 19):

- one or more of the values to be lost
- one or more of the values to be degraded or damaged, or
- one or more of the values to be notably altered, modified, obscured or diminished.

Examples of actions likely to have significant impact on World Heritage properties and National Heritage places associated with Indigenous heritage values

Examples of how an action is likely to have significant impact on Indigenous heritage values of a place include if there is a real chance or possibility that the action will (EPBC Guideline 2013: 18, 22):

- restrict or inhibit the existing use of a place as a cultural or ceremonial site causing its values to notably diminish over time;
- permanently diminish the cultural value of a place for a community or group to which its values relate;
- alter the setting of a place in a manner which is inconsistent with relevant values;
- remove, damage, or substantially disturb cultural artefacts, or ceremonial objects, in a place, and
- permanently damage or obscure rock art or other cultural or ceremonial features with heritage value.

The EPBC Guideline notes that the above are general examples and their application will depend on the individual values of each place, and that an alteration or disturbance which is small in scale may have a significant impact if a feature or component of a place embodies values that are particularly sensitive or important (2013:18).

Moreover, the EPBC Guideline also notes that to have a significant impact on Indigenous heritage values, it is not necessary for an action to impact upon the whole of the place, all of the values of a place, or a whole value of a place (2013: 18). It is sufficient if an action is likely to have a significant impact on a part, element, or feature of a place which embodies, manifests, shows, or contributes to the values of that place.

Identifying places with 'Indigenous heritage values' and levels of cultural significance is required in order to determine the level of any impacts. The concept of cultural significance is used in Australian heritage practice and legislation to encompass all of the cultural values and meanings that might be recognised in a place. Cultural significance is the sum of the qualities or values that a place has, including the five values—aesthetic, historic, scientific, social and spiritual, for past, present and future generations (Article

1.2 of the Burra Charter 2013). Of particular relevance to this matter are the social and spiritual values which form cultural significance for Traditional Owners.

Social value refers to the associations that a place has for a particular community or cultural group and the social or cultural meanings that it holds for them (Burra Charter 2013). Examples include places that are:

- important as a local marker or symbol
- important as part of community identity or the identity of a particular cultural group
- important to a community or cultural group because of associations and meanings developed from long use and association

Spiritual value refers to the intangible values and meanings embodied in or evoked by a place which give it importance in the spiritual identity, or the traditional knowledge, art and practices of a cultural group (Burra Charter 2013). Spiritual value may also be reflected in the intensity of aesthetic and emotional responses or community associations, and be expressed through cultural practices and related places. The qualities of the place may inspire a strong and/or spontaneous emotional or metaphysical response in people, expanding their understanding of their place, purpose and obligations in the world, particularly in relation to the spiritual realm. Spiritual values can include:

- places that contribute to the spiritual identity or belief system of a cultural group
- places that are a repository of knowledge, traditional art or lore related to spiritual practice of a cultural group
- places that are important in maintaining the spiritual health and wellbeing of a culture or group
- the physical attributes of a place which play a role in recalling or awakening an understanding of an individual or a group's relationship with the spiritual realm
- spiritual values of the place that find expression in cultural practices or human-made structures, or inspire creative works

1.2 Summary of the Aboriginal cultural values

Donaldson (2021) identified six Aboriginal cultural values associated with surface expressions of groundwater as well as groundwater dependent ecosystems (GDEs) across the SWDLA[1]. These Aboriginal cultural values are:

- Following the Altyerre Law and cultural obligations
- Maintaining spiritual connections and protecting sacred sites
- Undertaking rituals
- Upholding ecological knowledge associated with natural resources
- Continuing customary roles and responsibilities
- Being able to live and travel on country

These tangible and intangible cultural values are held by the members of four Kaytetye speaking landholding groups; the Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe. Whilst these values are found in various forms across Aboriginal Australia, it is the Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people who observe these values in the specific, localised context of the SWLDA. Accordingly, these six cultural values are highly significant to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people. Aspects of these cultural values are also shared by members of other Kaytetye speaking landholding groups as well as the members of the neighbouring Warumungu, Alyawarr, Warlpiri, Anmatyerre and Warlmanpa language groups.

For further details about these cultural values and the groups to which they relate refer to Donaldson (2021).

[1] A groundwater dependant ecosystem (GDE) is the natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis so as to maintain their communities of plants and animals, ecological processes and ecosystem services. More specifically, aquatic GDE (Type 2) are ecosystems dependent on the surface expression of groundwater (wetlands, springs, soaks) and terrestrial GDE (Type 3) are ecosystems dependent on subsurface presence of groundwater (groundwater is not visible from the earth surface and the water table is within the root zone of the plants, either permanently or episodically) (Richardson et al., 2011).

2.0 ANALYSIS OF CULTURAL VALUES

This section provides a deeper analysis of the data presented by Donaldson (2021) in order to present a more detailed description of the identified cultural values and to determine the level of impact the proposed action may have to those values and associated places (as presented in section 3).

As noted above the Kaytetye speaking Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people observe each of the six identified values (listed in section 1.4) in the specific, localised context of the SWLDA. The critical point here is that the connection to the SWLDA held by these people are unique. Accordingly, these cultural values are highly significant to the members of the Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe groups. Additionally, aspects of these six cultural values are also shared by members of other Kaytetye groups as well as the members of the neighbouring Warumungu, Alyawarr, Warlpiri, Anmatyerre and Warlmanpa language groups.

2.1 Types of sacred sites and their inherent cultural value

Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people and their tribal neighbours maintain these six key cultural values across the SWLDA in relation to 40 sacred sites (Ihangkele) associated with surface expressions of groundwater, aquatic GDEs and terrestrial GDEs. Whilst there are additional sacred sites across the SWLDA that do not depend on groundwater (e.g., a few rocky outcrops and other rock formations), approximately 95% of sacred sites present across the SWLDA are groundwater dependant. Accordingly, the majority of sacred sites across the SWLDA are vulnerable or sensitive to changes to groundwater levels.

Sacred sites featuring surface expressions of groundwater (soakages, springs, wetlands including swamps) are highly valued by Aboriginal people in the desert region where it is common for Ancestral activity to indicate water sources and the pathways between them (Berndt 1976:141).

Soakages dominate the cultural environment across the SWDLA; over half of the sacred sites identified across SWLDA are soakages which continue to be highly significant to the Traditional Owners as critical source of water and a guide for travelling through country. Across the SWLDA 28 sacred soakages (ngentye) have been identified[2].

According to Peterson, soakage waters are the most important water sources under all but the worst conditions and are relied upon by Aboriginal people when other surface water sources diminish (Peterson 1976: 26). Across the SWLDA, soakages are the spiritual embodiment of Ancestral activity and direct subsistence patterns relative to environmental conditions across the region (Peterson 1976:25). Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people are culturally obliged to protect soakages, as well as undertake rituals and maintain spiritual connection to them. In doing so the Altyerre Law is followed. It is also critical that they uphold ecological knowledge associated with soakages in order to live and travel on country (Bell 2002:92).

One sacred swamp (artnwep) was also identified within SWLDA[3]. The presence of swamps in a desert environment supports an abundance of life forms. Swamps are often the focus for Aboriginal ritual activity because they can sustain large gatherings of people over an extended period of time. The swamp supports the growth of multiple aquatic GDEs including water lilies. The swamp is the foci of an important Iliyarne increase ritual aimed at generating an abundance of lilies to feed the people and appease the Ancestors dwelling at the site. Lilies are highly culturally significant and are specifically associated with this locality and in this region specifically associated with Iliyarne country. Water lilies growing at this swamp are the cornerstone identification feature for Iliyarne people and country. Lilies are the Iliyarne 'trade mark' celebrated by Ileyarne people through traditional songs, dance and painting.

For these reasons, the sacred soakages and the sacred swamp within the SWLDA are highly significant to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people and their tribal neighbours.

Additionally, the interrelationship between these sites and places in the surrounding landscape is very important. For instance, WILYANINYE is a permanent spring on Wakurlpu country, 5km to the north of the SWLDA on Singleton Station. WILYANINYE is sacred due to its association with bush plum and baby dreaming[4]. The place is also highly valued as a place to live in the hot dry months when other water sources are depleted. According to Nungarrayi, 'in the olden days we lived off the spring water. When all

[2] A soakage is a location where shallow groundwater can be accessed by digging (Box et al 2008:1399).
[3] A swamp is a shallow waterbody with emergent vegetation or a vegetated area with saturated soil (Box et al 2008:1399).
[4] Koch, K., G. Koch, P. Wafer and J. Wafer (1981: 35).

the soakages dried up that was where we lived, at Wilyaninye, because of the permanent spring water…' (Bell 2022:121).

Sacred sites with root systems dependant on groundwater are also highly significant to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people. Six sacred sites classified as terrestrial GDEs have been identified across the SWLDA; three bloodwood trees (arrkarakw), one coolibah tree (atnkerre), one supplejack tree and one ghost gum tree. Each of these groundwater dependant trees is highly significant to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people because, like soakages, they are the spiritual embodiment of Ancestral activity and the basis for specific ritual activity. These trees dominate the cultural landscape due to their longevity and offer a seemingly everlasting array of reliable natural assets; medicine, good shade, food, habitat for fauna. Whilst the sacred tree species within the SWLDA individually offer specific natural resources (sap, bark, food etc), the high significance of these trees is primarily due to their intangible religious associations.

The three sacred creeks (elpaye) and two sacred floodouts (ilinjera) identified across the SWLDA are also highly significant to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people[5]. These features represent spiritual Ancestral activity and also attract an abundance of natural resources associated with important cultural practices undertaken by Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people. The sacred creeks are highly significant because they are a source of water and are a place to gather for cultural teachings. The sacred floodout is highly significant because it is an important hunting ground at certain times of the year.

Each of the 40 sacred sites within the SWLDA, regardless of their natural features, are the foci for Kaytetye people following the Altyerre Law and undertaking cultural obligations including activities associated with protecting them. These places enable Kaytetye people to maintain spiritual connections and undertake rituals associated with groundwater and GDEs. Each of the 40 sacred sites within the SWLDA, regardless of their natural or physical form, are deeply valued by Kaytetye people because they are the source of spiritual essence and ongoing religious sustenance. The cultural significance of each of these 40 sacred sites is high; these places are highly valued. The majority of sacred sites across the SWLDA serve important functions for Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe and their tribal neighbours.

[5] Whilst their dependence on groundwater can vary both between sites and for an individual site throughout the year or longer periods, creeks and floodouts are a mixture of Type 2 and Type 3 GDEs, depending on how the water table interacts with them (pers. comm. Ryan Vogwill 25.01.2023).

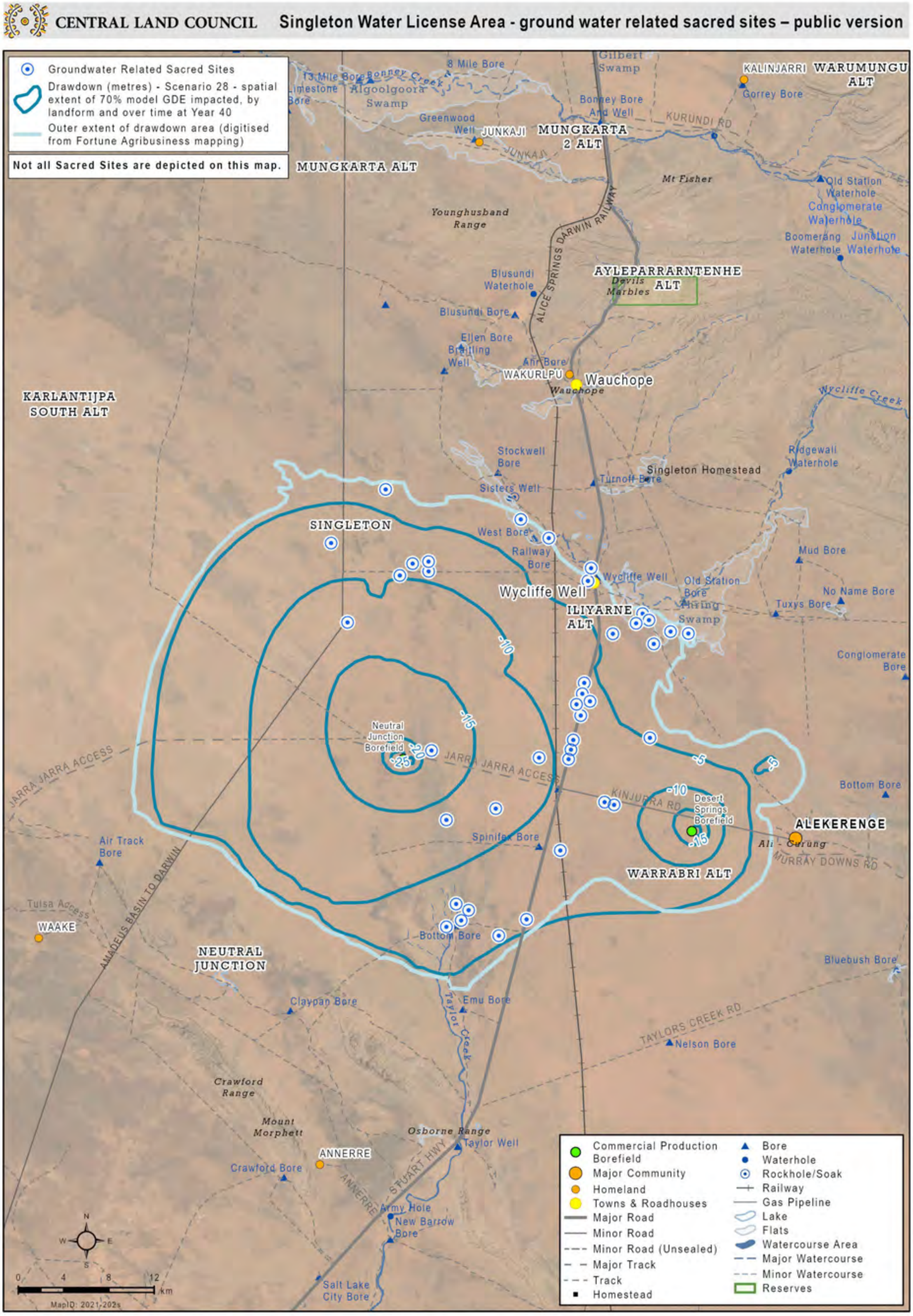

Figure 1 Groundwater related sacred sites SWLDA (CLC 2022)

2.2 The present condition of the sacred sites and their relative value

Traditional Owners are part of a dynamic and complex system designed to sustain their physical, biological, economic, cultural and social environment. Whilst the overarching Dreamtime Law is a constant, the system enables changes within it. For instance, lost cultural knowledge can be regained through dreams and replaced back into the country, for future generations (Bell 2022: 92 – 93); a sacred tree may be re-established by a sapling of the same species at the same location; a person inadvertently entering a sacred place can be punished by internal systems of controlling order (Berndt 1996: 348); and a group may have to temporarily rely on a neighbour's permanent water source in times of serve drought.

These are examples of how Aboriginal society perpetuates and adapts when faced with isolated incidents of change and disorder. Berndt argues that deviations (as distinct from minor variations) by Aboriginal people from their own social norms attract sanctions implemented by senior members of the group which can lead to the death of perpetrators (Berndt 1996: 338 – 344).

What happens today when a sacred site is lost or degraded as a result of major external influences?

Changes to the Aboriginal social system caused by more severe activities have been documented across the region over the past century and a half and include the depletion of critical waterholes by explorers and their stock, massacres of people whose detailed knowledge of country was lost forever, and the raping of women (Bell 2022:62-63). According to Bell the impact caused by these types of actions were 'dramatic' and led to 'carefully managed resources destroyed by persons with whom they couldn't communicate and to whom the Law did not apply…. their ability to care for their country and their dependants was immediately jeopardised, no longer was knowledge of country enough for survival' (2022:62).

As alluded to by Bell, punishment can be difficult if the perpetrator or perpetrators are not part of Aboriginal society, that is, they are beyond the control or influence of the senior members of the group who make decisions about the punishment.

Whilst some sacred sites across the SWLDA have already suffered partial damage as a result of agricultural activity (use of bore water, construction of fences) and environmental factors (drought, fires), the majority of sacred sites surveyed for this assessment were intact and ranged from moderately healthy to very healthy. Some of the soakages visited were dug out by hand and water was collected.

The few sacred sites observed in poor condition were considered by the Traditional Owners to have the ability to regain good health by way of human or spiritual action (regrowth or replanting). One bloodwood tree which had been burnt to the ground, seemingly in poor condition, was survived by fresh shoots rising from its base. One Bean Tree (*Bauhinia cunninghamii*) marking a soakage appeared very dry and possibly dead. Traditional Owners maintained that the bean tree was planted by their human Ancestors as a land mark to assist people to locate the soakage and that it is now the customary role of the present generation to replant another bean tree to serve the same function.

Traditional Owners have maintained these cultural practices and beliefs for generations but now fear that a reduction in the groundwater, for the duration and magnitude proposed, will undermine these cultural and environmental management techniques.

Does the cultural value of a sacred site alter if a site is harmed (by any action) or the quality (environmental condition) of the site is poor?

Yes and no. The value of the <u>place</u> remains significant to Aboriginal people because the spiritual essence endures in the country, waiting to remerge at some point in the future in the same location. The songs, designs and dances are also retained in Aboriginal people's repertoire of <u>cultural practices.</u> The loss occurs at the point of <u>cultural connection</u> between Traditional Owners and the place; given the place may no longer be evident or visible, the intangible cultural values of cultural connection are broken. The loss is felt in the sphere of <u>cultural obligation</u> between Traditional Owners, the place and their Laws; the intangible cultural values invoked when fulfilling customary roles and responsibilities are absent. The consequences of the loss also impact ritual activity, being able to live and travel on country and being able to protect sacred sites; the intangible and tangible cultural values associated with these activities are severely undermined.

Does a reduction in the number of sacred sites in one's country mean that the remaining sites become more precious?

Each sacred site is important for Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people and their tribal neighbours. A scarcity in water resources would trigger a reliance on the remaining water resources, consequently increasing the significance of the remaining resource. In this context the remaining sacred sites have an increased cultural value.

A reduction in the quantity of sacred sites over time over the geographical extent of one's country will result in severe sanctions within Aboriginal society aimed at the senior members of the group responsible for maintaining a healthy country. So, whilst the remaining sites increase in value, the Traditional Owners will likely undertake death and mourning rituals in response to seeing country dry out and sacred sites suffering permanent harm. Whilst the remaining sites might become the focus for cultural and ritual activity, the places that are lost will never be forgotten and the trauma associated with the loss will endure.

2.3 Geographical extent and the Kaytetye land tenure system

In the present matter, to understand how the geographical extent of the proposed works might impact the identified cultural values, it is essential to understand the localised way in which Kaytetye people connect to the land according to their traditional laws and customs.

The SWLDA lies in the mid north western extent of land owned by Kaytetye speaking people (Figure 2). Kaytetye country comprises at least 15 landholding or estate groups, each group being responsible for all aspects of their respective traditional lands. Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe country is within the SWLDA, with Jarra Jarra to the west, Arrawatyen to the north east, Lyentyawel Ileparranem to the east, Warlekerlange to the south west, and Alapanpe, Akalperre, Arlekwarr, Ertwerrpe, Thangkenharenge, Kwerrkepentye and Entengele to the south[6]. A large portion of Kaytetye country is affected by this proposal.

[6] Turpin and Ross 2004: 20

Figure 2 Kaytetye country (Tindale 1940).

Each group holds the traditional responsibility to appease and maintain connections with the spiritual Ancestors residing in their respective lands; Anerre people, for instance, hold the traditional responsibility to appease and maintain connections with the spiritual Ancestors residing in Anerre land and to protect the sacred sites on their country. Similarly, the Waake-Akwerlpe, Iliyarne and Arlpwe people are charged with upholding the same laws and customs on their respective lands. Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people have recognised native title rights under Australia law across the SWLDA, specifically:

- Iliyarne people have associations to the north east extent of the SWLDA in relation to 19 sacred sites (nine of which they share responsibility for with other groups);
- Arlpwe people have associations to the central and eastern extent of the SWLDA in relation to six sacred sites (three of which they share responsibility for with other groups);
- Anerre people have associations to the north central and southern extent of the SWLDA in relation to 23 sacred sites (12 of which they share responsibility for with other groups); and the
- Waake-Akwerlpe people have associations to the western and northern extent of the SWLDA in relation to five sacred sites (two of which they share responsibility for with other groups).

Viewing each group's connection to the SWLDA at a localised level allows us to understand the potential impact, from a Kaytetye perspective, in relation to the cultural value associated with following the Altyerre Law by undertaking certain rituals, fulfilling cultural obligations including the protection of sacred sites, and maintaining spiritual connections. Each sacred site is important to each of these groups, in particular, and serve an important function for Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people and their tribal neighbours. A large and important extent of Iliyarne country and Anerre country will be affected by the proposal (and in turn the identified cultural values), and important parts of Waake-Akwerlpe country and Arlpwe country (and their cultural values) will also be affected.

2.4 Context in relation to focal sacred sites

In relation to context of the proposal and the value of places (sacred sites), it is critical to understand how most desert groups relate to a focal sacred site or cluster of sites, being the loci of religious powers for their particular group and the basis for the group's name. Whilst all sacred sites are important, focal sites hold another layer of import by virtue of their high religious significance and point of group identification. Focal sacred sites are particularly sensitive and culturally important for the associated Traditional Owning group.

Within the SLWDA a focal complex of sacred sites exists for the Iliyarne group; ILIYARNE ILPAIYE, a creek and associated ghost gum trees interlinked with the highly significant MPWEREMPWER-ANGE, a swamp and large coolibah tree. This highly significant site complex, within the SWLDA, is the foundation of Iliyarne people's cultural identity as the basis of the group's name, as the focal mythological place for this group and as the primary food source for the group. It is irreplaceable. This focal site complex is the basis for Iliyarne Law, physical wellness, ritual and spiritual wellbeing. Thus, in the context of the local cultural landscape, compared with the other groups whose focal sacred sites lay beyond the SWLDA, the SWLDA has additional layers of cultural meaning to Iliyarne people and commensurately greater sensitivity to impact. The Iliyarne focal sacred sites across the SWLDA serve an important function for Iliyarne people and how they relate to their tribal neighbours.

2.5 Context and sacred sites as boundary markers

In accordance with the traditional Kaytetye land tenure system, there are multiple sacred sites within the SWLDA where two or more of the traditional Aboriginal landholding groups converge, that is, their respective countries share boundary zones. Traditional boundaries in this region are usually marked by sacred sites, which are often shared by the neighbouring groups. Whilst all sacred sites are important due to their spiritual value, sacred sites that are also boundary markers hold an additional value to the respective groups because of their function to organise how people are located within the cultural landscape. These boundary sites act as navigational markers and are integral to cultural educational practices and intergroup relations. It is understood that these boundaries were established in the Altyerre and Kaytetye people today are obliged to abide by them.

The anthropological research for this investigation identified 12 sacred sites within the SWLDA that are important boundary markers and of high cultural value to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people. Two of these boundary markers indicate locations where three landholding groups come together (both large ghost gum trees). The other 10 sacred sites indicate boundaries for two neighbouring groups (nine soakages and one large ghost gum tree). The sacred sites on Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe country which indicate tribal boundaries between each of the groups are deeply important and particularly sensitive to change. Negative impacts to these culturally prominent sites could lead to long-term problems in terms of how Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people relate to themselves and each other, and may affect their ability to undertake cultural obligations according to traditional laws and customs. Sacred sites that indicate tribal boundaries serve an important function for Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people and their tribal neighbours.

2.6 Connections and interactions across the landscape

Consideration of the connections and interactions between parts of the environment needs to be considered in the context of the Kaytetye land tenure system. According to traditional laws and customs this system of land tenure is fundamentally localised whilst concurrently deeply interconnected with the broader cultural landscape associated with the neighbouring Warumungu, Alyawarr, Warlpiri, Anmatyerre and Warlmanpa speaking people.

Another way to inform a holistic view of the environmental and cultural landscape is to consider connections and interactions between the land and people directly associated with the SWLDA in relation to the surrounding land and people. So, whilst the Kaytetye groups Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe are the Traditional Owners of the area covered by the SWLDA, other Kaytetye landholding groups as well as Warumungu, Alyawarr, Warlpiri, Anmatyerre and Warlmanpa speaking people, maintain a different type of association to the SWLDA involving kinship, trade, historical experiences, social obligation, resource collection and ritual co-operation.

In particular, those parts of the SWLDA where there are no identified sacred sites are highly valued by Warumungu, Alyawarr, Warlpiri, Anmatyerre and Warlmanpa people as hunting grounds and as sources of natural resources of cultural value. In these areas multiple groups maintain ecological knowledge associated with collecting natural resources, continuing customary roles and responsibilities and undertaking rituals, and are able to live and travel on country. The natural environment, including the seasons, dictates Aboriginal land use practises. Many Aboriginal residents of nearby communities and outstations, including Alicurung, regularly visit the SWLDA on a seasonal basis, to 'go hunting' in their 'back yard'. These activities are valued and are an integral part of what it means to be an Aboriginal person in Central Australia.

Understanding these regional connections and seasonal interactions allows a greater appreciation of how the SWLDA contains important cultural values for Aboriginal people well beyond the immediate SWLDA. Lands rich in natural resources in a desert environment serve an important function for Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people and their tribal neighbours. Changes to the cultural landscape directly within the SWLDA will potentially impact people and country across the region.

2.7 Geographical extent of each value

The geographical extent of each cultural value needs to be considered from an Aboriginal ontological perspective where all living things are interconnected and interact with the spiritual world.

Whilst the deep and powerful spiritual essence is found at 'sacred sites' which are treated with respect and reverence, spiritual Ancestors are also located across the broader landscape and are part of everyday activities such as hunting and swimming and preparing a camping place.

The 40 sacred sites across the SWLDA do not exist in isolation from each other, but rather they are interconnected to form the core of the Aboriginal cultural landscape held together by the identified cultural values. There are no unimportant spaces or places not associated with Aboriginal laws and customs or the recognised native title rights and interests[7]. All aspects of Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe country are important to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people and their tribal neighbours.

[7] The recognised native title rights across the SWLDA include the right to access and travel over any part of the land and waters; the right to live on the land, and for that purpose, to camp, erect shelters and other structures; the right to hunt, gather, take and use the natural resources of the land and waters, including the right to access, take and use natural water resources on or in the land; the right to access, maintain and protect places and areas of importance on or in the land and waters; and the right to engage in cultural activities.

3.0 ANALYSIS OF DATA CONSIDERING LEVEL OF IMPACT

This section aims to determine the likely consequences (the 'impact') to the identified Aboriginal cultural values (the cultural aspects of 'environment' present on the selected site) caused by a reduction of groundwater (the 'action' and major impact source). Consideration is then given to the level of impact (major/ minor) in terms of the context and intensity of the impact, the sensitivity, value and quality of the environment impacted on and the duration, magnitude and geographic extent of the impact.

3.1 The action – available data and existing opinions

It is acknowledged that whilst there is a current lack of region-specific groundwater drawdown impact criteria (and data) and an absence in the assessment of the risks to aquatic GDEs (Hydro Geo Enviro 2021:7), it is understood that 'water drawdown presents a potential risk to sacred sites that include features dependent on groundwater (i.e., soaks and culturally significant trees)' (GHD 2022:92). It has been argued that a reduction in groundwater can have 'severe negative impacts on GDEs' (Nano et al. 2021:1).

GHD also highlighted that groundwater pumping will lower the water table beneath and surrounding the bore field and because some sacred sites including trees are dependent on access to the groundwater, lowering the water table may reduce the trees' access to water which in turn could impact their health (2022: 126). GHD recognise that 'some soaks are part of sacred sites' and that depending on the connection between the soaks and the groundwater being pumped for irrigation, it is possible that pumping could reduce the water available to soaks (2022: 126). GHD also acknowledge the relationship between the health and wellbeing of Aboriginal people and the health of country (GHD 2022: 126).

Despite recognising these key factors, GHD found that there was only a *medium* residual risk associated with the proposal in relation potential impacts to sacred sites or Aboriginal cultural values from water drawdown and a *low* residual risk associated with direct impacts to sacred sites (GHD 2022:129).

Impacts to Aboriginal cultural values caused by actions undertaken during the course of a development project are usually considered as either direct or indirect. The NT Environmental Impact Guidance for proponents (NT Guide 2021) defines 'impact of an action' as an event or circumstance that is:

- a direct consequence of the action; or
- an indirect consequence of the action and the action is a substantial cause of that event or circumstance.

According to this definition an action is quite broad in that it can include a project, a development, an undertaking, an activity or series of activities or works (NT 2021). According to GHD, direct impacts to Aboriginal cultural values are not anticipated as part of the proposal (2022: 126).

Utilising the available albeit limited data concerning standard consequences relating to a reduction in groundwater, Donaldson (2021) identified a number of likely impacts to Aboriginal cultural values associated surface water, groundwater dependent ecosystems (GDEs) and other features within the SWLDA:

  - Aboriginal people's sacred sites will be harmed
  - Aboriginal people will suffer from emotional and physical stress
  - Flora and fauna species required by Aboriginal people for ritual activity will be eradicated or diminished
  - Natural resources required by Aboriginal people for hunting and gathering will be eradicated or diminished
  - Aboriginal people's ability to live on and travel across their traditional lands will be hindered
  - Future generations of Aboriginal people will suffer from a loss of cultural practices and cultural identity

The next sections outline the severity of these consequences against NT guidelines and other relevant criteria, to assess whether or not the impacts should be considered 'significant'.

3.2 NT EPA environmental factors

It is clear that a range of important tangible and intangible Aboriginal values relating to cultural aspects of the environment are present across the proposed development area (Donaldson 2021; GHD 2022; Bell 2002; CLC 2008; Koch & Koch 1993; Turpin 2003).

The NT EPA's pre-referral screening tool outlines the NTG's environmental factors and objectives and the indicative values associated with them. The framework is useful for the present assessment in that it provides a thematized structure within which to consider areas where the proposal may have the potential to have a significant impact on the environment (limited here to factors relating to cultural aspects of the environment).

The relevant factors that relate to the identified cultural values across the SWLDA are culture and heritage, human health, community and economy, aquatic ecosystems, hydrological processes, and terrestrial ecosystems, as detailed below.

Potential effects on NT EPA's environmental factors, objectives and indicative values (NT 2021: 25 – 30)		
NT EPA Factor	**Objective**	**Indicative environmental value**
Culture and heritage	Protect sacred sites, culture and heritage.	Sacred sites
Human health	Protect the health of the Northern Territory population.	Drinking water Recreational water Bush tucker
Community and economy	Enhance communities and the economy for the welfare, amenity and benefit of current and future generations of Territorians	Dwellings, homelands, communities, towns and suburbs where people live Livable environment (access to natural resources including bush food, recreational use of the natural or built environment e.g. fishing, cycling, sports, picnics)

		Healthy lifestyles (sense of wellbeing and good mental health) Vulnerable sectors of the community Connections to culture and community (Aboriginal rights and interests, including right of access; cultural practices; sense of belonging, inclusion, connectedness and cohesion; healthy social relationships).
Aquatic ecosystems	Protect aquatic habitats to maintain environmental values including biodiversity, ecological integrity and ecological functioning.	Groundwater dependent ecosystems Species of social, cultural, livelihood and/or economic significance Biological and functional diversity
Hydrological processes	Protect the hydrological regimes of groundwater and surface water so that environmental values including ecological health, land uses and the welfare and amenity of people are maintained.	Culturally important water features or other features affected by water level Present and future uses, and users of water
Terrestrial ecosystems	Protect terrestrial habitats to maintain environmental values including biodiversity, ecological integrity and ecological functioning.	Species of social, cultural, livelihood and/or economic significance

These factors and associated objectives and indicative (environmental / cultural) values have been incorporated into this impact assessment (3.3).

3.3 Impact assessment

3.3.1 AAPA

As outlined by GHD the Authority Certificate C2019/083 covers portions of property parcel NT Por 653 (Singleton Station) and most of, but not all of, the groundwater extraction drawdown area (2022:126). GHD note that harm to sacred sites is not permitted under C2019/083, including due to water extraction, and the proposal is being planned to avoid harm. Similarly, harm to sacred sites outside of the C2019/083 subject land must also be avoided, according to GHD (2022:126).

The project AAPA Authority Certificate (AC) (2019/083) stipulates work restrictions aimed at protecting three sacred sites within the drawdown area (RWA 5, RWA 9 and RWA 10 associated with a creek, ghost gums, a waterhole, soakages and bean trees) and eight sacred sites beyond the drawdown area (RWA 1, RWA 2, RWA 3, RWA 4, RWA 6, RWA7 and RWA associated with ghost gums, bloodwoods, soakages, a 'depression hollow', two sand ridges, creeks, waterholes and swamps).

Unfortunately, not all of the 40 sacred sites identified by Donaldson (2021) were identified by AAPA as being present in the AC subject land and are thus not covered by any of the 10 RWAs in the AAPA Authority Certificate (AC 2019/083) outlined above. Additionally, a large number of sacred sites were identified by Donaldson within the drawdown area beyond the AC subject land, as described below:

> '…Critically, the current assessment identified five sacred sites within the AC subject land not identified in the AC or overlapped by any of the RWAs. These sites are all within the drawdown area and are all associated with GDE features; all are soakages. An additional 32 sacred sites were identified outside the AC subject land and within the drawdown zone…' (Donaldson 2021:70).

A direct impact to a sacred site is often thought of as occurring as a result of a physical and highly visible disturbance, such as when a grader knocks down a sacred tree or backfills a sacred soakage. These forms of direct impact causing harm to sacred sites are usually avoided by ensuring the AAPA Restricted Works Area (RWA) process is applied.

Drilling multiple bores to extract groundwater is proposed as a key activity in the current development. In my view activities that are critical to the proposed development with likely negative consequences to the identified cultural values should be considered within the 'direct impact' framework. Having said that, it is my view that even if the extraction of groundwater is classified as causing an 'indirect impact', the removal of groundwater will still be the substantial cause of events that follow, that is, harm to sacred sites and distress for the Traditional Owners.

In my view whilst a RWA may protect a sacred site from the direct impact of a drilling rig, for example, but it will not protect a sacred sites from the impact of a reduction in groundwater on which the existence of the sacred site depends. Accordingly, all of the identified GDE sacred sites, be they covered by a RWA or not, have the potential to be harmed by a reduction in groundwater which in my opinion equates to significant impact. The consequences of significant impact to sacred sites are outlined in the table below.

3.3.2 IMPACT SUMMARY TABLE

SWL ABORIGINAL CULTURAL VALUES IMPACT ASSESSMENT (NT EP Act 2019 criteria)				
ABORIGINAL CULTURAL VALUES PRESENT ON SWLDA	CULTURAL SIGNFICANCE	IMPACT CAUSED BY REMOVAL OF GROUNDWATER	POTENTIAL FOR IMPACT	LEVEL OF IMPACT
Maintaining spiritual connections and protecting sacred sites, specifically in relation to the 40 identified GDE sacred sites (Ihangkele) within the SWLDA.[8]	High	Within the SWLDA Iliyarne people have the localised responsibility in accordance with their traditional laws and customs to protect 19 sacred sites (nine of which they share responsibility for with other groups); Arlpwe people have the same local responsibility to protect six sacred sites (three of which they share responsibility for with other groups); Anerre people have the same local responsibility to protect 23 sacred sites (12 of which they share responsibility for with other groups); and the Waake-Akwerlpe people have the same local responsibility to protect five sacred sites (two of which they share responsibility for with other groups). The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect sacred sites, culture and heritage* in the following ways: • Harm to sacred sites (Ihangkele) will lead to the punishment of the senior Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people, by	Likely	Significant

[8] See pages 29 - 36 of Donaldson (2021) for identification of these cultural values and pages 69 -74 of Donaldson (2021) for the impact of disruption to them.

		Ancestral Spirit beings, for not protecting the sacred sites within their respective countries. • Harm to sacred sites (Ihangkele) will cause major negative consequences to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people's spiritual connection to country because they maintain that their etnwenge (a person's spirit) is deeply connected to one's country (apmere), sacred sites (Ihangkele) especially to water (arntwe). • Harm to sacred sites will subsequently cause distress to the Aboriginal custodians of the sacred sites that have been damaged or destroyed. • Given the identified sacred sites are the source of spirituality and ongoing religious sustenance, harm to the sacred sites will have enduring and sever consequences to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people's spiritual health and well-being. • Harm to a sacred site could interrupt the spiritual connection Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people have to that place and inhibit the spiritual connections if the place no longer exists or is permanently damaged.		

		• Harm to sacred sites is an offence under the *Northern Territory Aboriginal Sacred Sites Act 1989* According to the significant impact criteria for places with Indigenous heritage values (EPBC Act), there is a real possibility that the removal of groundwater under the SWL will: • restrict or inhibit the existing use of cultural or ceremonial sites causing the values to notably diminish over time • permanently diminish the cultural value of places for Traditional Owners		
<u>Following the Altyerre Law and cultural obligations</u> across the SWLDA	High	For Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people, abiding by the Altyerre Law and undertaking important cultural obligations for kin and country appeases the creator spirits and is a deeply important societal foundation. The system is balanced to ensure the environment sustains future generations who in turn will maintain the Altyerre Law and undertake cultural obligations to perpetuate society. On a regional scale, a large portion of Kaytetye country is affected by this proposal. Locally (within the SWLDA), large portions of Iliyarne country and Anerre country, will be affected by the proposal. Important parts of Waake-Akwerlpe country and Arlpwe country will also be affected.	Likely	Significant

12 sacred sites within the SWLDA are important tribal boundary markers and of high cultural value to Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people. Two of these boundary markers indicate locations where three land holding groups come together (both large ghost gum trees), the other 10 indicate boundaries for two neighbouring groups (nine soakages and one large ghost gum tree).

These tribal boundary sites act as navigational markers and are integral to cultural educational practices and intergroup relations. It is understood that these boundaries were established in the Altyerre and Kaytetye people today are obliged to abide by them. Sacred sites that represent tribal boundaries are deeply important and particularly sensitive to change.

The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective *to enhance communities and the economy for the welfare, amenity and benefit of current and future generations of Territorians* in the following ways:

- The desertification of country and in particular homelands and communities where people live, will have major negative consequence for senior Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people who are responsible for sustaining country for the future. They will suffer shame and blame which will affect their

		emotional and physical state, potentially including, the Kaytetye believe, severe illness resulting in death. • The liveability of the environment including access to natural resources, access to bush food, the recreational use of the natural environment will be diminished. • The ability to maintain a healthy lifestyle for an already vulnerable sector of the community, including attaining a sense of wellbeing and good mental health will be diminished. • Connections to culture and community including exercising Aboriginal rights and interests associated with access, cultural practices, sense of belonging, connectedness and healthy social relationships will be negatively altered if not permanently damaged. The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect aquatic habitats to maintain environmental values including biodiversity, ecological integrity and ecological functioning* in the following ways: • Damage to Groundwater dependent ecosystems (GDEs)		

		• Species of social, cultural, livelihood and/or economic significance will be disturbed including culturally important localised species (lilies). The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect the hydrological regimes of groundwater and surface water so that environmental values including ecological health, land uses and the welfare and amenity of people are maintained* in the following ways: • Culturally important water features or other features will likely be affected by a reduction in water level including culturally prominent boundary marking sites. Permanent damage to these landmarks could lead to major consequences including long-term problems for Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people in terms of how they relate to themselves and each other, and their ability to undertake cultural obligations according to traditional laws and customs. • Species of social, cultural, livelihood and/or economic significance will be diminished.		

		According to the significant impact criteria for places with Indigenous heritage values (EPBC Act), there is a real possibility that the removal of groundwater under the SWL will: • permanently diminish the cultural value of places for Traditional Owners • inhibit the existing use of cultural sites causing the values to notably diminish over time		
Undertaking rituals requiring GDE species sourced from within the SWLDA across the SWLDA[9]	High	The spiritual connection Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe have with their apmere (country) is strengthened by ritual activity which is also linked to the powerful forces of the Altyerre. Many of these ritual activities require specific flora and fauna species obtained across the drawdown area, some of which directly or indirectly relate to GDE. The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect terrestrial habitats to maintain environmental values including biodiversity, ecological integrity and ecological functioning* in the following ways:	Likely	Significant

[9] See pages 37 - 42 of Donaldson (2021) for identification of these cultural values and pages 75 of Donaldson (2021) for the impact of disruption to them.

		• A reduction in species of social, cultural, and economic significance required by Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people for ritual activity. This will lead to the need for Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people to seek permission from neighbouring tribal groups to obtain the required ritual items from them. Having to seek permission from neighbours for resources that used to be obtained on their own country may cause Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe to feel shamed about their degraded country and cultural loss. • A reduction in shade trees and water sources, which in turn may hinder Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people's ability to the gather in large groups to undertake ritual activities that require shade and water on their land across the SWLDA. The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect the hydrological regimes of groundwater and surface water so that environmental values including ecological health, land uses and the welfare and amenity of people are maintained* in the following ways: • Culturally important water features or other features affected by water level		

		• Present and future uses, and users of water for ritual activity • the cultural practices associated with ritual activity are diminished if site visitation is not possible, that is, if the site is permanently destroyed and over time locationally lost or forgotten. This is another major consequence indirectly related to the act of removing groundwater. According to the significant impact criteria for places with Indigenous heritage values (EPBC Act), there is a real possibility that the removal of groundwater under the SWL will: • permanently diminish the cultural value of places for Traditional Owners • inhibit the existing use of ceremonial sites causing the values to notably diminish over time		
Upholding ecological knowledge associated with collecting natural	High	The geographical extent of impacts to this value is to be understood with a consideration of the seasonal way in which Kaytetye, Warumungu, Alyawarr, Warlpiri, Anmatyerre and Warlmanpa people exploit the SWLDA.	Likely	Significant

<u>resources</u> across the SWLDA.[10]		Upholding cultural knowledge and practices associated with ecological processes linked to the collection of natural resources for sustenance and trade is an important cultural value associated with the entire SWLDA. The SWLDA is prime hunting ground used by Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people, as well as other Kaytetye people and their Warumungu, Alyawarr, Warlpiri, Anmatyerre and Warlmanpa neighbours, at different times of the year. Many Aboriginal residents of the nearby Alicurung community regularly visit the SWLDA on a seasonal basis, as their 'backyard'. The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect the health of the Northern Territory population* in the following ways: . • A reduction in drinking water • Damage to recreational water • A reduction in bush tucker and medicines The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect terrestrial habitats to maintain environmental values including biodiversity, ecological integrity and ecological functioning* in the following ways:		

[10] See pages 42-49 of Donaldson (2021) for identification of these cultural values and pages 76-80 of Donaldson (2021) for the impact of disruption to them.

		• Species of social, cultural, livelihood and/or economic significance including the altering of cyclical ecological process which may indirectly diminish important natural resources utilised for hunting, gathering and other activities across the SWLDA for Aboriginal people across the region who value and utilise the area. • loss of associated cultural knowledge and practice associated with soakage water. • The wellbeing of the local community who regularly access the drawdown area will also be negatively impacted, given hunting and associated activities promote a healthy lifestyle both physically and mentally. • Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people fear that the bigger animals will leave Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe country to find a better, well-watered home, and that the smaller species unable to travel far will die out. Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe will feel a sense of concern, loss, sadness and shame if they allow some species to die out and others to find a 'new home'. According to the significant impact criteria for places with Indigenous heritage values (EPBC Act), there is a real possibility that the removal of groundwater under the SWL will:		

		• permanently diminish the cultural value of places for Traditional Owners • restrict the existing use of cultural sites causing the values to notably diminish over time		
Continuing customary roles and responsibilities across the SWLDA[11]	High	According to traditional laws and customs, Traditional Owners see themselves as custodians of their land and waters (on behalf of all others) and they have customary roles and responsibilities to maintain and protect their country and the things that live there. Looking after country in a broad sense relates to sustaining the biodiversity through regular burns, cleaning out/covering up soakages and other activities. These cultural activities relate to preserving all aspects of the cultural landscape, including water sources, for future generations so that culturally valued natural resources can be sustained and sacred sites protected. The geographical extent of impacts to this value is to be understood with a consideration of the Kaytetye land tenure system which, according to traditional laws and customs, is fundamentally localised whilst concurrently deeply interconnected with the broader cultural landscape associated with Warumungu, Alyawarr, Warlpiri, Anmatyerre and Warlmanpa people	Likely	Significant

[11] See pages 50 - 53 of Donaldson (2021) for identification of these cultural values and pages 80 -82 of Donaldson (2021) for the impact of disruption to them.

		Within the SLWDA a focal complex of sacred sites exists for the Iliyarne group; ILIYARNE ILPAIYE, a creek and associated ghost gum trees interlinked with MPWEREMPWER-ANGE, a swamp and large coolibah tree. This highly significant site complex is the foundation of Iliyarne people's cultural identity (as the basis of the group's name, contains the primary food source for the group, and is the focal mythological place for this group) and is irreplaceable. This focal site complex is the basis for Iliyarne customary practices guiding their roles and responsibilities. Thus, in the context of the local cultural landscape, compared with the other groups whose focal sacred sites lay beyond the SWLDA, the SWLDA has additional layers of cultural meaning to Iliyarne people and commensurately greater sensitivity to impact. The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect the hydrological regimes of groundwater and surface water so that environmental values including ecological health, land uses and the welfare and amenity of people are maintained* in the following ways: • Culturally important water features or other features affected by water level may cause Iliyarne to feel shamed, leading to social isolation and physiological ill health.		

		• Members of the group may suffer long term, intergenerational emotional and spiritual loss and even death. For Ileyarne people, these consequences are catastrophic. • the unleashing of power (punishment) held by the Ancestral spirits residing at these places can have long lasting negative emotional and physical effects, mainly for the senior Iliyarne people. • If Iliyarne people are seen by other Kaytetye groups as allowing their 'main country' to get sick, Iliyarne people will also suffer the consequences of societal shame which can lead to psychological ill health. Kaytetye people have terms for these particular consequences including arlatnarrerane (crying), ampwarrenke (dying), amperrnge (sad/unhappy), nyerre (shame), arntetye (sick), athamarrerange (worried), and atere (scared). • A reduction in groundwater will make it very difficult for Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people to fulfil their customary obligations in relation to looking after water and the life that the water sustains. If GDE species diminish, the impact may be experienced by future generations of Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people.		

		According to the significant impact criteria for places with Indigenous heritage values (EPBC Act), there is a real possibility that the removal of groundwater under the SWL will: • permanently diminish the cultural value of places for Traditional Owners		
<u>Being able to live and travel on country</u> across the SWLDA.[12]	High	The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *enhance communities and the economy for the welfare, amenity and benefit of current and future generations of Territorians* in the following ways: • Dwellings, homelands, communities, towns and suburbs where people live • Liveable environment (access to natural resources including bush food, recreational use of the natural or built environment e.g. fishing, picnics) • Healthy lifestyles (sense of wellbeing and good mental health) • Vulnerable sectors of the community	Likely	Significant

[12] See pages 53-64 of Donaldson (2021) for identification of these cultural values and pages 82 - 83 of Donaldson (2021) for the impact of disruption to them.

The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect the hydrological regimes of groundwater and surface water so that environmental values including ecological health, land uses and the welfare and amenity of people are maintained* in the following ways:

- Damage to the 28 soakages (ngentye) which are critical sources of water and are relied upon when travelling through country.

- Culturally important water features or other features affected by water level will be reduced thus hindering Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe people's ability to live and travel across their lands.

- Present and future uses, and users of water will also be diminished if not permanently destroyed. A decline in available water in soakages will hinder Aboriginal people's ability to live on and travel across their traditional lands. Without the availability of water, travel is more difficult and even dangerous for people's lives. There is a concern that people will not attempt to travel lengthy distances in fear of getting thirsty and dying.

- Traditional Owners feel responsible for looking after their Kaytetye kin and Warumungu, Alyawarr, Warlpiri, Anmatyerre and

		Warlmanpa neighbours and the residents of nearby communities and outstations who utilise the area and rely on the natural resources across the SLWDA. The removal of groundwater during the operation of the project has the potential to transgress the NT EPA's objective to *protect terrestrial habitats to maintain environmental values including biodiversity, ecological integrity and ecological functioning* in the following ways: • Species of social, cultural, livelihood and/or economic significance According to the significant impact criteria for places with Indigenous heritage values (EPBC Act), there is a real possibility that the removal of groundwater under the SWL will: • permanently diminish the cultural value of places for Traditional Owners • restrict the existing use of cultural sites causing the values to notably diminish over time		

3.4 Managing significant impacts

3.4.1 AAPA

Whilst Aboriginal Areas Protection Authority (AAPA) approval has been granted and aims to avoid harm to a number of identified sacred sites, the substantive risk of damage to, or interference with other sacred sites on or in the vicinity of the AAPA subject land is highly likely or almost certain. Another highly likely consequence of harming sacred site in this matter is the distress caused to the Traditional Owners of the sacred sites.

In my view both of these impacts are significant and not adequately addressed by approvals received under the *Northern Territory Aboriginal Sacred Sites Act 1989*.

3.4.2 Other measures and uncertainties

There has been extensive community engagement with Traditional Owners and other affected Aboriginal community members in relation to the proposal. The overwhelming community response is one of concern for future generations given the unknowns in relation to how the significant impacts will be managed in order to avoid catastrophic consequences (for people and country).

Impact management measures beyond the AAPA Authority Certificate process (3.3.1) aimed at avoiding, mitigating or reducing the potential adverse impacts to the identified cultural values have not been identified by the proponent. Accordingly, the duration and extent of the significant impact to the identified cultural values is unknown at this stage and the level of community confidence in predicting potential significant impacts of the proposal is low due to the absence of relevant (local and current) information, which fosters uncertainty.

Cumulative impacts of the proposal are also uncertain but likely given the changes to the climate, the existing and historical use of the site for agricultural activity, and the proposal to remove a large quantity of groundwater. The culmination of historical impacts and project driven impacts lead to significant impact to the identified cultural values. Similarly, the 'end of life' plan for the proposal is undefined, so the ongoing or residual impacts to the cultural values is uncertain.

The capacity of affected community members to access and understand information about the proposal and the management of potential significant impacts is hindered by a lack of information required to enable informed decision making. As such, the level of community confidence in predicting and managing potential significant impacts to sacred sites and other important cultural values is low.

4.0 CONCLUSION

The proposed reduction in groundwater relating to the Singleton Water Licence for the Singleton Horticultural Project has the potential to cause significant impact to Aboriginal cultural values across the Singleton Water Licence Drawdown Area (SWLDA) which extends across Singleton Pastoral Lease (PL), Neutral Junction PL, Warrabri Aboriginal Lands Trust (ALT) and Iliyarne ALT.

This analysis has shown that the proposed reduction in groundwater across the SWLDA will trigger major negative consequences to cultural places and values held by Akwerlpe-Waake, Iliyarne, Anerre and Arlpwe people and their neighbouring tribal groups including factors associated with culture and heritage; human health; community and economy; aquatic ecosystems; hydrological processes; and terrestrial ecosystems. The potential impacts will likely or almost certainly result in highly significant cultural values to be lost, degraded and damaged, as well as notably altered, modified, obscured or diminished.

Whilst Aboriginal Areas Protection Authority (AAPA) approval has been granted and aims to avoid harm to a number of identified sacred sites, the substantive risk of damage to, or interference with sacred sites on or in the vicinity of the AAPA subject land is highly likely (even if the sacred sites are covered by Restricted Work Areas). Another highly likely consequence of harming sacred site in this matter is the distress caused to the Traditional Owners. In my view both of these potential impacts are significant and not adequately addressed by approvals received under the Northern Territory Aboriginal Sacred Sites Act 1989.

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ATTACHMENT N:

REVIEW OF THE SINGLETON HORTICULTURE PROJECT'S WATER ENTITLEMENT PROVISION COSTS, BENEFITS AND EMPLOYMENT IMPACTS

Released 12 July 2022

Prepared by Professor Jeffrey Connor, Daniel Hill, Dr Daniel Gregg and Dr Kamaljit Sangha

University of South Australia,
Centre for Markets, Values and Inclusion

Review of the Singleton Horticulture Project's water entitlement provision costs, benefits and employment impacts.

University of South Australia

Centre for Markets, Values and Inclusion

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Executive Summary

The Singleton Horticulture Project (henceforth 'Singleton') proposed south of Tennant Creek in the Northern Territory by Fortune Agribusiness has published a business case outline in publicly available form. The case outlines an ambition to develop 3,500 hectares of 'high value irrigated horticulture', primarily comprised of permanent crops (e.g. mandarins, grapes, avocados) with the remainder as annual horticulture (e.g. melons, onions and fodder). **To support the development, the Northern Territory Government has agreed to provide an entitlement to 40,000 megalitres of groundwater to be drawn annually for 30 years, free of charge.**

Whilst, the proponents have put forward a business case, it is short on publicly available detail. Additional rigour would be required to validate the claims in that business case that very large regional economic and employment benefits will result. This review challenges the business case and implicit assumptions that the project would provide net benefit to the NT by applying "reference case" analysis, (reference to similar past and ongoing projects) to realistically forecast potential performance of Singleton with respect to outcomes that count for the NT. The objectives are to:

1. Assesses the true economic costs of Singleton by considering the value of natural resources (namely water) that are currently not included in the business case for this project. This publicly owned asset has been allocated at no charge to Singleton.
2. Considers assumptions around employment and value generation for Singleton using data on agricultural employment and real-world business performance statistics from similar projects/cases.
3. Describe a range of other economic, social, environmental, and cultural impacts that may be substantial but are not considered within the Singleton business case.

Summary of findings

The key findings with respect to the Singleton business case are that:

1. The business case includes a large, unstated, subsidy in the form of a transfer of water owned by the NT public to Fortune Agribusiness, with a value of between $70 million to more than $300 million.

2. The economic benefit claims by Singleton seem overstated compared with reported industry performance in similar enterprises, especially when likely local and NT as opposed to outside of NT distribution of benefit is considered. The nature of this overstatement relative to best available real world reference data is summarised in the table below.

Economic benefit from Singleton.	**Claims made by Fortune Agribusiness and NT Government**	**Findings from our analysis.**
Value of the water entitlement.	Provided free of charge by the NT Government.	The entitlement is worth between $70 million and over $300 million.
Employment for local communities and Northern Territory residents.	110 permanent jobs and 1350 seasonal jobs, with opportunities for local employment.	A large proportion of NT agricultural jobs go to overseas workers and interstate fly-ins. Seasonal jobs are only available for short contracts over a few weeks or months. We estimate that only 26-36 full time equivalent jobs will likely be filled by residents of the Northern Territory, of which only 5-8 full-time equivalent jobs are expected to be from proximate Aboriginal communities in the Barkly region.
Economic activity through operating expenditures.	$110 million a year, much of this spent within the Northern Territory.	Operating costs appear to be inflated by between 10%-35%. The true expenditure figure is likely to be only between $70-$100 million per year, of which only $13-$28 million is expected to be spent in the Northern Territory.

The proposed project is also likely to generate large social and ecological costs that will result from substantial impacts on other users of the resources including groundwater-dependent ecosystems. Yet, social or environmental costs have not been accounted for in any publicly available Singleton business case reporting.

We conclude that the gift of water, valued at between $70 million and more than $300 million, from the NT public to a private enterprise headquartered outside of the NT is extraordinary. Especially given the lack of detail on the case for this transfer, and the potential for major social and environmental impacts associated with this water allocation. There is no evidence of a clear social benefit-cost analysis to justify a transfer of such value from the public to a private enterprise. Indeed, considering that as few as 26-36 full time equivalent jobs could be filled by Northern Territory residents and only $13-$26 million per year will be spent within the Northern Territory, if performance is similar to reference projects, the public value of this project appears to be highly questionable.

Also concerning is that, despite the NT Government's stated focus on development processes that are inclusive of Aboriginal people and communities, the Singleton project approval process has provided no substantive opportunity for Aboriginal communities with a clear stake in this project to participate in the water allocation decisions related to Singleton.

Recommendations

This review raises serious concerns about the process of approving water entitlements in the NT. A lack of publicly available information demonstrating thorough and creditable assessment of project benefits and costs suggests that the Northern Territory Government (NTG) is unlikely to have robustly assessed the high social and economic costs involved in the Singleton water entitlement or the return on the large gift of publicly owned water. In the absence of publicly available assessment demonstrating otherwise, we can only conclude that the NT Government appears to have decided to gift a public asset worth between $70 and more than $300 million for a project likely to create very limited NT employment and likely adverse impacts on the social and economic wellbeing of Aboriginal traditional owners, residents of neighbouring remote communities and the environment.

The main recommendation arising is that the NT Government should reform the processes of water entitlement application review, evaluation and charging. A revised process backed by legislation and regulatory frameworks should:

a) Require Commonwealth and State water infrastructure and dam investments and private proponent proposals for water allocations such as the Singleton water allocation to include an independent and peer-reviewed social benefit cost analysis process;

c) Strengthen processes and policy that support Aboriginal participation in water entitlement applications in order to make resource allocation decisions that are consistent with Aboriginal cultural practices, cultural values protection, and employment and development objectives; and

d) Introduce an appropriate charging regime for transfer of public water assets to private interests.

About this report

The Central Land Council (CLC) is a Commonwealth corporate entity established under the *Aboriginal Land Rights (Northern Territory) Act 1976* (ALRA). It is also a native title representative body under the *Native Title Act 1993*. It is led by a representative body of 90 Aboriginal people elected from communities in the southern half of the Northern Territory, which covers almost 777,000 square kilometres and has as Aboriginal population of more than 24,000.

The CLC has statutory responsibilities to ascertain, represent, and protect the rights and interests of Aboriginal people living in the CLC region. It also has specific statutory functions with respect to Aboriginal land. One of the CLC's central roles is to protect the interests of Aboriginal people with an interest in Aboriginal land, by assisting constituents to make land claims, negotiate agreements with third parties, protect sacred sites and use land and other financial resources for the benefit of their communities. Many Indigenous communities and outstations are located on Aboriginal land owned under the ALRA, and thus the CLC had a direct interest in, and responsibility for, the administration of land in those communities and outstations.

In addition to these functions, the CLC administers a range of programs for the benefit of constituents in relation to environmental management, community development, governance, cultural heritage, and customary practices. The CLC also plays a strong role in advocating for the interests of our constituents, the majority of which reside in remote communities.

The CLC, on behalf of local traditional owners and native title groups, requested a team of economists led by University of South Australia Business School Professor Jeff Connor to review the economic case put forward by Fortune Agribusiness in their Singleton Water Licence application for a 3500 hectare irrigation development south of Tennant Creek in the NT.

1. Introduction

The Singleton Horticulture Project proposed by Fortune Agribusiness on Singleton pastoral station south of Tennant Creek in the Northern Territory has published a business case in publicly available form. The case outlines an ambition to develop 3,500 hectares of 'high value irrigated horticulture', primarily comprised of permanent crops (e.g. mandarins, grapes, avocados) with the remainder as annual horticulture (e.g. melons, onions and fodder). **To support the development, the Northern Territory Government has agreed to provide an entitlement to 40,000 megalitres of groundwater to be drawn annually for 30 years, free of charge.**

The proponent's business case, whilst short on publicly available detail, claims that very large regional economic and employment benefits will result. Good governance would require transparent review of costs, and benefits from the perspective of the NT public including accounting for large implicit subsidy and high costs from groundwater level decline.

Taking a public good benefit cost perspective the analysis considers the costs and benefits likely to accrue to the people of the Northern Territory who will implicitly subsidise the project. This review applies a "reference class analysis" approach where performance of documented similar projects is used to estimate performance, cost and benefit assumptions.[1] The approach is particularly important in evaluation of large irrigation and water resource projects because it can correct for the enduring optimism bias around performance and costs typical in large project evaluations.[2]

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[1] Ansar, A., Flyvbjerg, B., Budzier, A., Lunn, D., 2014. Should we build more large dams? The actual costs of hydropower megaproject development. Energy policy 69, 43-56. Flyvbjerg, B., Bester, D.W., 2021. The cost-benefit fallacy: Why cost-benefit analysis is broken and how to fix it. Journal of Benefit-Cost Analysis 12, 395-419.

[2] Higginbottom, T.P., Adhikari, R., Dimova, R., Redicker, S., Foster, T., 2021. Performance of large-scale irrigation projects in sub-Saharan Africa. Nature Sustainability 4, 501-508. Petheram, C., McMahon, T., 2019. Dams, dam costs and damnable cost overruns. Journal of Hydrology X 3, 100026.

Objectives

The objective of this review was to test assumptions about benefits and costs in the Singleton business case published by Fortune Agribusiness (henceforth 'the Singleton Project Report') against published data on comparable projects and contexts with a view to:

i. Consider the validity of business case assumptions and the case for possible adjustments to more accurately reflect experience with projects facing similar circumstances to Singleton.
ii. Consider implicit assumptions about subsidy, true economic costs and values at risk for the NT from the Singleton proposal that are not stated in the Singleton business case.
iii. Provide a recalibration of the skeletal business case detail made publicly available for Singleton including evaluation of distribution of benefits and costs within and outside of the NT using data on actual outcomes from a range of cases that are comparable in at least one dimension to Singleton.

Three key aspects of the business case from the NT public perspective examined analysis were:

1. The value of natural resources (namely water) that are currently not included in the business case or charged to the project proponent and yet should be counted as cost to the citizens of the NT.
2. Assumptions about employment and value generation from Singleton for the NT. These are tested with data on agricultural employment and business performance statistics from similar projects/cases.
3. The range of other economic, social, environmental, and cultural impacts that are likely substantial, but are not considered in the Singleton business case.

Report structure

The report begins (Section 2) with a brief review of key facts that can be discerned from the publicly available Singleton business case reporting. Section 3 provides an analysis of the value of water provided to Singleton. Section 4 considers explicit and implicit assumptions in the Singleton business case and how calibration using reference case analysis leads to different conclusions about outcomes. Additional economic, environmental and social values that are likely to be impacted upon by Singleton but could not be quantified in dollar terms in this study are provided in Section 5. Finally, a brief set of conclusions are provided in Section 6.

2. Key facts of the Singleton business case

Key facts underpinning the business case provided publicly by the project proponent and the NT Government are minimal. They state only that:

- Up to 40,000 megalitres of water is proposed to be allocated to the project on a 30 year basis.
    - The groundwater for this project comes from the Lake Surprise Sandstone, Arrinthunga Formation, Chabalowie Formation, and Dulcie Sandstone aquifer types of the Wiso and Georgina basins underlying the Central Plains Management Zone.
    - This allocation of water is, by far, the biggest groundwater allocation license ever given to any development project in the NT.
    - This allocation also represents a very large allocation in comparison to other horticultural operations in Australia.
    - The 30 year period of the lease is three times longer than the normally granted 10 years.
- The proposed area for the development is 3,500 hectares.
    - While irrigation is to be entirely on the Singleton property, water table drawdown from this project is expected to substantially and adversely impact very large areas where groundwater levels will decline. The impacted area extends well beyond the Singleton property boundaries and into the lands of four independent estate groups (the Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe).
    - The drawdown area includes a range of ecologically and culturally significant sites that are likely to be negatively impacted by the project with little hope of recovery if water levels are lowered.

Additionally, the Singleton business case includes assumptions about project costs and employment levels, but it doesn't describe NT based employment including Aboriginal employment expected for nearby communities. Ecological and cultural impacts are mostly ignored in Fortune Agribusiness' own statements. Section 4 provides insights into expectations for these outcomes.

3. The value of water provided for Singleton

Natural water bodies and waterways that have not yet been allocated to individual users, are public assets. The allocation of water owned in common to individual users comes at an opportunity cost (see text box below) to others who are no longer able to access the resource or the benefits that derive from its non-extractive management. In recognising this opportunity cost, unallocated water is typically only made available for individuals through tenders or water markets. Charging for the water ensures that the resource is allocated to the highest value use, with reserve prices set to reflect the opportunity cost to the public of no longer owning the water entitlement.

Opportunity Cost

Opportunity cost is the forgone benefit that would have been derived from an alternative option (that was not actually chosen). To properly evaluate economic costs, the costs and benefits of the next best available option should be compared to a proposed course of action. In many cases, market prices or other equivalent values are used to provide a basis of comparison for the 'next best available option'. Opportunity costs that are positive (i.e. when the alternative option is more valuable) should typically be justified on the basis of other benefits.

3.1. How valuable is the ground water provided to Singleton by the NT public?

The NTG has not undertaken a tender process for the water allocated to Singleton. It allocated Singleton an entitlement to extract up to 40 gigalitres of groundwater *each year* for 30 years from the Central Plains Management Zone. No price has been applied against this water even though a groundwater resource in the arid zone is unlikely to be renewable on any normal economic timeframe. As a comparison, the 40 gigalitres allocated to Singleton is more water than what is consumed in Darwin annually, and over 30 years the project will extract the equivalent of 2.4 times the volume of water contained in Sydney Harbour. **In providing this entitlement free of charge, the NT Government is providing an implicit subsidy to Singleton.**

Whilst there is a lack of a tender process, or water sales data for the NT, the water resource allocated to Singleton can be valued by applying water entitlement market values from other jurisdictions in Australia. A range of potential comparison values can be used. For example, Class 3 SA River Murray (high security) entitlements are traded in a mature water market and are typically used for high value tree crops like those proposed for Singleton. The volume-weighted average price (VWAP)[3] for Class 3 SA River Murray (high security) for the 2020/21 water year was $6,710/megalitres.[4] At this price the entitlement gifted to Singleton implies a subsidy of up to $268 million.

For groundwater systems, water entitlement prices from other states that allocate and trade Great Artesian Basin water represent appropriate proxies for Central Plains Management Zone groundwater resource. Across 466 trades in the Great Artesian Basin groundwater system between 2008 and 2021 the volume weighted average price was $7,878/megalitres.[5] The *minimum* groundwater volume weighted average price across *all* groundwater resources in Queensland over this period was $2,216/megalitres. This includes groundwater resources where secure surface water is also available and is made available for lower value irrigation. At this price, a minimum or lower bound implicit subsidy for groundwater for the Singleton proposal is valued at $89 million for 40GL of high-security groundwater.

The table below summarises the implied values of the groundwater resource made available to Singleton. The table also includes the volume-weighted average price for all water traded in Australia since 2007 (where prices are available), and recent successful bids for unallocated groundwater in the Great Artesian Basin (in Western Queensland).

[3] The volume weighted average price is the average value (dollars per megalitre) of the water traded where each trade is weighted proportionally by the volume of water (in megalitre) involved in the sale. This provides a more accurate representation of the price (i.e. high-volume trades generally attract a 'bulk discount').
[4] Available from the BOM interactive dashboard - http://www.bom.gov.au/water/dashboards/#/water-markets/map
[5] Also available from the BOM interactive dashboard - http://www.bom.gov.au/water/dashboards/#/water-markets/map

Table 1 – Value of entitlements for different water resources across Australia, and implied value for the Singleton Horticulture Project water entitlement

Water resource	Implied value per megalitre of entitlement	Opportunity cost for Singleton Horticulture Project 30-year lease (40 gigalitres)[6]
Price paid by Fortune Agribusiness for Singleton for water entitlement	$0	$0
All water traded in Australia since 2007/08 (where prices are available)	$1,772	$70.89 million
Class 3 SA River Murray (high security) water entitlements (Southern Connected Murray Darling Basin - 2020-21 VWAP)	$6,710	$268.40 million
Recent bids for Great Artesian Basin unallocated water (for horticulture)	$3,001	$120.04 million
Minimum VWAP across all groundwater resources in Queensland since 2007/08 (where prices are available)	$2,216	$88.64 million
Great Artesian Basin groundwater VWAP since 2007/08 (where prices are available)	$7,878	$315.12 million

[6] The Singleton Horticulture Project has been granted a 30-year lease, meaning that values of entitlements in perpetuity might overvalue the lease for Singleton Horticulture Project. However, it is likely that the lease would be renewed after 30 years.

The values in the table are a good indication of the value of the high security groundwater resource provided to Singleton. Using these prices, the opportunity cost of the water entitlement provided to Singleton ranges between $70.89 million and $315.12 million, with evidence to suggest that the value is towards the higher end of this range. **The subsidy provided as unpriced groundwater thus likely represents foregone revenue for the NT public of up to $300 million**. For context, the total major works budget for the 2020-21 NTG Budget in the Barkly Region was $200 million, and after excluding transport infrastructure was only $28.9 million[7]. In addition, the NTG has incurred significant expenses in conducting investigations on water availability and extraction in the region.

4. Comparing Singleton business case assumed costs, benefits and employment impact to reference cases

Singleton estimates a yearly operating cost of $110 million across the 3500 hectares of productive land. It is claimed that this expenditure and development will support 110 permanent staff and up to 1350 seasonal jobs.

4.1. Operating costs of production are likely overstated

Singleton reports that much of the estimated yearly operating cost of $110 million will be spent locally. There is evidence to suggest this is a substantially higher operating cost than similar horticulture systems in Australia. Using standard farm budgets published by Australian state governments, annual operating costs for the proposed crops on Singleton range from approximately $20,000 per hectare for mandarin to $28,500 per-hectare for table grapes. Using these per hectare estimates of operating costs, this would indicate that the total operating costs for 3500 hectares would be in the range of $70 million to $100 million. These values are documented in the table below.

[7] NT Government Budget Barkley fact sheet - https://budget.nt.gov.au/__data/assets/pdf_file/0008/1000412/Barkly.pdf

Table 2 – Estimated operating costs for the crops proposed under the Singleton Horticulture Project

Operating costs	**Operating costs/Ha**	**Operating costs for 3500 Ha**	**Source**
Avocado	$26,065	$91,225,955	Howard Hall and CDI Pinnacle Management Pty Ltd, 2015, *Australian Avocado Benchmarking Program Development*, a report prepared for Horticulture Innovation Australia.
Table grapes	$28,563	$99,971,574	Department of Agriculture and Fisheries (QLD), 1998, *Gross Margin for Table Grapes (inland under trickle irrigation) North QLD*.
Mandarin	$20,090	$70,315,614	Falivene S and Creek A, 2018, *NSW citrus farm budget handbook 2018*, A report prepared for the Department of Primary Industries (NSW).
Onion	$26,220	$91,768,424	Department of Primary Industries (NSW), 2013, *Gross margin budget – Onions.*
Rockmelon	$22,770	$79,694,413	Department of Primary Industries (NSW), 2013, *Gross margin budget – Rockmelon.*
Expected operating costs for Singleton	$24,803	$86,811,141	Based on the expected split of crops - 75% tree crops and 25% annual crops.

Whilst the reported operating costs for Singleton may include additional costs associated with new supply chains and for operating in a remote area, **the data presented above suggests that the operating costs are potentially inflated for the project by between approximately 10%-35%**. There is an absence of documentation on why Singleton expects superior performance to similar past projects. These higher than 'reference class' cost estimates appear to be an optimistic forecast and thus likely to overestimate the true Singleton project contribution to economic activity and jobs. As this forecast has been used to gain support for the project from investors and the NTG, there have been strong incentives for the project proponent to overstate operating costs and the economic contribution of the project[8]. For example, there is evidence to suggest the royalty-free access of groundwater has been granted due to expectations around permanent and seasonal jobs that will be provided by the project.

Overstating operating costs has implications for the true distribution of benefits from the project. Holding revenue constant, lower actual operating costs would result in higher profits for Singleton. This would result in fewer jobs and benefits for the local community, and instead increase the profits and returns for interstate and overseas investors.

4.2. The majority of non-labour operating costs will not be spent in the Barkly region or in the NT

There is further evidence to suggest that a large proportion of non-labour operating costs will not be spent locally, and instead will be spent interstate or overseas. Using the same state government farm budgets from

Table 2, we are able to disaggregate operating costs for the different crops proposed for Singleton. For each crop, the annual operating costs per hectare are disaggregated between different categories of farm expenses and are summarised in *table 3*.

Large agribusinesses typically do not use local providers for non-labour inputs as local providers do not have the capacity to provide for production of this scale. While the Singleton business case provides no detail on how their operating costs have been calculated, for each cost item it is possible to make highly plausible assumptions about whether each cost will involve spending within the NT or more likely involve spending interstate and overseas:

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[8] Denicol, J., Davies, A., Krystallis, I., 2020. What are the causes and cures of poor megaproject performance? A systematic literature review and research agenda. Project Management Journal 51, 328-345. Higginbottom, T.P., Adhikari, R., Dimova, R., Redicker, S., Foster, T., 2021. Performance of large-scale irrigation projects in sub-Saharan Africa. Nature Sustainability 4, 501-508.

- Fertiliser, chemical and packaging materials are typically sourced from interstate and overseas providers for large horticulture businesses.
- Fortune Agribusiness propose to use intermediaries for distribution. Expenditure for these intermediaries will primarily be in interstate and overseas export markets.
- Services such as administration and marketing are likely to be conducted at Fortune Agribusiness' head offices outside of the region, or through external providers in key domestic and overseas markets.
- It is assumed that the majority of freight, nursery, fuel, and electricity inputs will be spent in the NT although these are also likely to be largely sourced from interstate. For example fuel for a project the size of Singleton is more likely to be bought in bulk with dedicated tankers from bulk fuel sellers (interstate). Similarly, freight may be provided by interstate freight companies.

Table 3 – Operating costs per hectare for proposed crops (detailed breakdown)

Operating costs/Ha	Avocado	Table grapes	Mandarin	Onion	Rockmelon
Seeds and nursery inputs	$0 (0%)	$0 (0%)	$0 (0%)	$1,563 (6.0%)	$1,463 (5.6%)
Fertiliser and chemical inputs	$2,220 (8.5%)	$4,146 (15.9%)	$2,277 (8.7%)	$2,212 (8.5%)	$1,911 (7.3%)
Fuel & electricity	$585 (2.2%)	$0 (0%)	$0 (0%)	$719 (2.8%)	$480 (1.8%)
Water (pumping and treatment)	$0 (0%)	$0 (0%)	$554 (2.1%)	$334 (1.3%)	$267 (1.0%)
Fixed labour inputs	$7,488 (28.7%)	$3,449 (13.2%)	$3,985 (15.3%)	$645 (2.5%)	$970 (3.7%)
Seasonal labour inputs	$246 (9.5%)	$4,084 (15.7%)	$5,736 (22.0%)	$8,931 (34.3%)	$2,646 (10.2%)
Packaging materials	$3,004 (11.5%)	$2,360 (9.1%)	$836 (3.2%)	$1,004 (3.9%)	$4,521 (17.3%)
Freight	$2,514 (11.5%)	$7,261 (27.9%)	$4,079 (15.7%)	$5,359 (20.6%)	$4,127 (15.8%)
Other costs - marketing, admin etc.)	$7,785 (29.9%)	$7,261 (27.9%)	$2,620 (10.1%)	$5,448 (20.9%)	$6,381 (24.5%)
Total non-labour costs per Ha	**$18,331 (61.9%)**	**$21,030 (73.6%)**	**$10,370 (51.6%)**	**$16,644 (63.5%)**	**$19,154 (84.1%)**
Total labour costs per Ha	**$7,734 (38.1%)**	**$7,533 (26.4%)**	**$9,720 (48.4%)**	**$9,576 (36.5%)**	**$3,616 (15.9%)**
Total operating costs per Ha	**$26,065**	**$28,563**	**$20,090**	**$26,220**	**$22,770**

Table 4 provides a summary of the percentage of non-labour costs likely to generate activity in that NT or interstate/overseas. Depending on the final mix of crop types, Singleton will likely only spend between 19-45% of total non-labour costs in the NT. **Assuming an operating cost of $110 million a year, best available information suggests that in total only $13-28 million a year will be spent in the NT for non-labour inputs.**

Table 4 – Distribution of non-labour operating costs

Non labour costs	**Location majority of cost item likely to be spent**	**Percentage of non-labour operating costs**
Seeds and nursery inputs	Northern Territory	0% - 9.4%
Fertiliser and chemical inputs	Interstate and overseas	10.0% – 22.0%
Fuel & electricity	Northern Territory	0% - 4.3%
Water (pumping and treatment)	Northern Territory	0% - 5.4%
Packaging materials	Interstate and overseas	6.0% - 23.6%
Freight	Northern Territory	15.6% - 39.3%
Other costs - marketing, distribution, admin etc.)	Interstate and overseas	25.3% - 48.3%
Proportion of non-labour costs spent locally in the NT		**19-45%**
Proportion of non-labour costs spent interstate or overseas.		**55-81%**

4.3. Employment opportunities for NT residents

Singleton proponents claim the project will support 110 permanent jobs and up to 1350 seasonal jobs when at full production capacity. This employment relates to the primary production of horticultural products, with additional employment to support the labour force, freight, and administration. Much like the non-labour inputs costs, it is likely that a majority of labour costs and employment opportunities will not be available for the NT population overall, less so for Barkly region towns and Aboriginal communities.

A report by Ernst and Young[9] estimates labour shortages of over 25% during the high intensity harvest periods across Australia. These labour shortages are more severe in remote locations where living conditions are less attractive, where there is time-sensitive harvest, and harvest conditions are hotter. Larger producers in remote regions, such as Singleton, typically rely on overseas or interstate workers through labour hire companies as working holiday workers and Australian residents prefer locations closer to larger towns and cities.

The NT Farmers Association reported that in 2019 only 11% of total horticultural labour was supplied locally. Overseas workers represented 63% of total labour, particularly during the harvest season, and the remaining 28% was supplied from interstate workers.[10] Many producers find it difficult to attract Australian workers due to the seasonal nature of the roles offered, remote locations and lack of contract security. Evidence of this can be seen on mango plantations in the NT, where producers report nearly no local seasonal workers[11].

The above evidence raises serious doubts about the true employment impacts of Singleton for the NT and Barkly region economy. Given the significant labour shortages for horticulture in Australia, it is likely that a large proportion of the permanent and seasonal work will be from overseas or interstate. Seasonal workers will most likely be sourced from the existing pool of

[9] Ernst and Young, 2020, Seasonal horticulture labour demand and workforce study, a report prepared for Horticulture Innovation Australia, https://ausveg.com.au/app/uploads/2020/10/20200928_Hort-Innovation_Workforce-study_Final-Report_Public-Extract_vF2.pdf

[10] NT Farmers Association, 2019, *NT Plant Industries Workforce Development Plan 2020-25,* https://ntrebound.nt.gov.au/__data/assets/pdf_file/0003/930027/5.-NT-Farmers-WorkforceDevelopmentPlan2020_Final_Small-compressed.pdf

[11] Ernst and Young, 2020, Seasonal horticulture labour demand and workforce study, a report prepared for Horticulture Innovation Australia, https://ausveg.com.au/app/uploads/2020/10/20200928_Hort-Innovation_Workforce-study_Final-Report_Public-Extract_vF2.pdf

employed seasonal workers in the NT economy. In the absence of Singleton, these workers would find alternative opportunities in the NT or elsewhere.

Using the farm budget information in *table 5*, we are able to derive expected labour costs for permanent and seasonal staff and derive our own estimates of employment for the project consistent with actual experience with similar businesses. To compare permanent jobs with seasonal jobs, we adjust seasonal jobs to *full time equivalents* (FTEs). Given Singleton expects 1350 seasonal workers to be used across the 3500 hectares, we calculate from the labour costs in the farm budgets that the average term of employment for these 1350 seasonal workers is 8.8 weeks. As each FTE involves 46 weeks of employment, we can expect only around 258 FTE jobs from seasonal work. This is in addition to the 110 FTE jobs for permanent positions in the Singleton Business case.

Table 5 – Estimated FTEs from the Singleton Horticulture Project

Calculation	Figure	Method and source
Estimated total seasonal labour cost per ha	$4,519	Farm budgets from Table X, based on the expected split of crops - 75% tree crops and 25% annual crops
Estimated seasonal labour cost for 3500 Ha	$15,816,742	Cost per Ha multiplied by 3500 Ha
Expected number of seasonal labour days for 3500 Ha	59,617 days	Total cost for seasonal work, divided by the minimum daily wage for seasonal work in NT (with 30% on-costs)
Expected number of labour days per worker	44 days	Number of labour days, divided by the 1350 seasonal workers expected by Fortune Agribusiness
Expected number of labour weeks for seasonal worker	8.8 weeks	Number of labour days divided by 5 working days a week
Expected number of FTEs from seasonal work	258 FTEs	1350 seasonal workers, working on average 8.8 weeks a year.
Expected number of FTEs for permanent positions	110 FTEs	Expected number of permanent positions by Fortune Agribusiness
Expected number of FTEs filled from the local population	41 FTEs	368 total season and permanent FTEs, multiplied by 11% (percentage local employees as reported by NT Farmers Association, 2019)
Expected number of FTEs filled by local Aboriginal people	8-9 FTEs	21% of local FTEs (from proportion in the Ord River Irrigation Project – WA Auditor General 2016)

When considering that only 11% of those employed in horticulture are NT residents, we can expect a total NT employment outcome of only 41 FTE jobs (including seasonal workers). Also important is the number of people employed from Barkly region Aboriginal Communities. For an appropriate benchmark we can use the total Aboriginal employment outcomes from the Ord River Irrigation Scheme near Kununurra, WA. Kununurra has a similar proportion of Aboriginal people as the Barkly region in NT, where the WA Auditor General found that 21% of Ord irrigation project labour was provided by Aboriginal people in the initial stages of irrigation development and production.[12] Assuming this proportion for Singleton, we can expect, optimistically, only around 8-9 FTE jobs to be available for the local Aboriginal communities. **Taking into account the apparent over-statement of operating costs of 10-35% and assuming a similar overstatement of labour demand (Section 4.1), the total employment of NT residents could be as little as 26-36 FTE jobs and as few as 5-8 full-time equivalent jobs for local Aboriginal people.**

4.4. Economic and employment benefits have been limited in other horticultural projects

The promised employment outcomes of Singleton have strong parallels with other major irrigation projects in Northern Australia. The most notable of these is the Ord River Irrigation Scheme. The WA Auditor General reported that employment relating to the recent Ord River Irrigation Scheme expansion was 61 people plus 10–15 seasonal workers.[13] This was for an additional 1,600 hectares of irrigated crops and was substantially fewer jobs than what was expected. More details on Ord River Irrigation Scheme are provided in Box 1.

Box 1 – Ord River Irrigation Expansion Project

The Ord River Irrigation Expansion Project is a large scale, publicly funded development that has sought to develop irrigated land for intensive horticulture. The first stage of the Ord River Irrigation Area was completed in 1971 and services 14,000 hectares of farming land. In 2011 the WA and Commonwealth Government committed $220 million to the Ord River Irrigation Expansion project to:

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[12] WA Auditor General, 2016, *Ord-East Kimberley Development*, https://audit.wa.gov.au/reports-and-publications/reports/ord-east-kimberley-development/auditor-generals-overview/

[13] Ibid

- deliver water and road infrastructure to service about 8,000 hectares of land at Goomig
- subdivide and sell off the 8,000 hectares in up to 25 lots.
- scope for land at Mantinea (4,000 hectares), Ord West Bank (1,300 hectares) and Packsaddle (1,380 hectares), and work to consider land at Knox (8,000 hectares), Victoria Highway, Carlton Hill, Bonaparte Plain and the Keep River Plain (NT).

The economic case for Ord River and its later expansions have been debated for decades. The consensus is that while the irrigation has provided some economic benefits for the local community, the costs of the scheme have far outweighed the benefits. Kununurra comes closest to being a town created and sustained by a remote irrigation scheme in Australia, but its growth appears to have relied more on tourism and mining than agriculture.[14]

In 2015 The Western Australian Office of the Auditor General reviewed the Ord River Project. The review found that:

- The original time and cost to deliver the irrigation expansion was unrealistic. This was due to severe underestimation of the time and investment needed to develop the irrigated land.
- A result of this was significantly less land under crop than what was previously planned at the time of the review. Although the area with irrigated crops has increased since, governance and economic constraints still exist for irrigators.[15]
- Whilst employment for the local population increased during the development stages, total employment relating to the expansion since dropped to 61 people plus 10–15 seasonal workers. This number is substantially fewer than what was expected at this stage of the scheme expansion.

[14] Wittwer G and Banerjee O, 2014, *Investing in irrigation development in North West Queensland, Australia*, Australian Journal of Agricultural and Resource Economics, 59, pp. 189–207
[15] For example, see Australian Broadcasting Corporation, June 21 2019, *Ord River irrigators say bureaucracy stifling agricultural development in WA's far north*, Available from - https://www.abc.net.au/news/rural/2019-06-21/ord-river-irrigators-red-tape-stifling-agricultural-development/11222494

There have been several economic evaluations of irrigated developments in Northern Australia undertaken by the academic community. The consensus conclusion from this literature is that while agricultural production can be feasible from a technical perspective, significant economic and social barriers have often prevented large scale developments from being viable and providing welfare benefits for local communities.

For example, Wittwer and Banerjee[16] undertook a computable general equilibrium model of horticulture development in remote NW Queensland. They found that the irrigation development provided welfare losses for the Queensland community, even under different climate change, productivity, and demand scenarios. They concluded that there is limited evidence to suggest that irrigated agriculture has provided local jobs or made a substantial contribution to regional development.

In 2018, the CSIRO analysed a number of agricultural development schemes in Northern Australia.[17] The study found that nearly all large-scale developments have faced significant challenges in scaling up and providing the promised economic outcomes. A common factor across the schemes was the significant underestimation of the time required to expand irrigated production, and a lack of appreciation of input and output markets. Financial plans tended to overestimate early production, returns on capital and economies of scale. This typically resulted in severe cash flow problems for developers. **As a consequence, the areas of development and welfare outcomes for local communities were usually much less than the original expectations. Overstatement of the gains from private capture of public resources appears to be a common feature of large development projects in Northern Australia.** This can be seen in *Figure 1* from the CSIRO report, which contrasts the proposed area of development against the area actually developed.[18]

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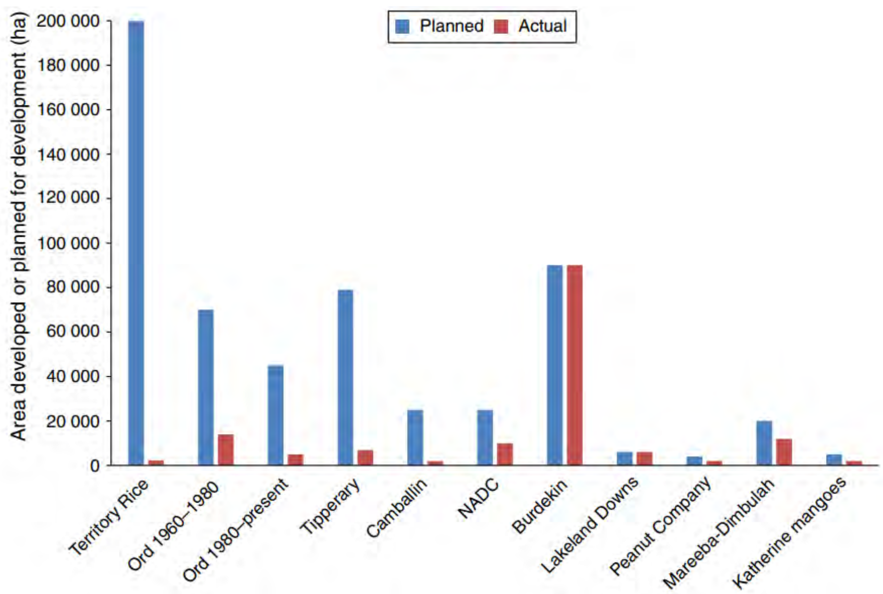
[16] Wittwer G and Banerjee O, 2014, *Investing in irrigation development in North West Queensland*, Australia, Australian Journal of Agricultural and Resource Economics, 59, pp. 189–207
[17] Ash A and Watson I, 2018, *Developing the north: learning from the past to guide future plans and policies,* The Rangeland Journal, 40, 301–314
[18] Ibid, pg. 310

Figure 1 - Areas (ha) of land planned for development, and actually developed



5. Environmental and cultural values

Whilst the proposed water extraction zone (development wells / bores) is located on the Singleton pastoral lease, the groundwater drawdown from the bores is expected to impact an area several orders of magnitude larger. Even the hydrology assessment by Fortune Agribusiness suggests that a drawdown area with a diameter in the order of 50 km will extend well beyond the water extraction points themselves to impact large areas of the lands of four Kaytetye speaking groups (Anerre, Waake-Akwerlpe, Iliyarne and Arlpwe). 23 additional Aboriginal groups across the broader Western Davenport District also hold kinship and ritual ties to the groups with traditional lands in the drawdown area.

5.1. Unquantified environmental values

A comprehensive cultural values assessment undertaken by anthropologist Susan Donaldson on behalf of Aboriginal land owners found that "if the current proposal reduces groundwater, there is the potential for the proposal to adversely impact GDE species and places which traditional Owners rely on for sustenance, gaining goods and other items."[19] The assessment found that,

[19] Dale-Donaldson, Susan (2021) *Singleton Water Licence Aboriginal Cultural Values Assessment*, PUBLIC REPORT TO THE CENTRAL LAND COUNCIL, 1 September 2021. p 77

many Kaytetye rituals require specific flora and fauna species that are currently obtained across the drawdown area but could be at risk of disappearing with the planned drawdown. These potential changes concern the current generation of Traditional Owners, they fear the consequences of not following their ancient Law. The extraction and drawdown areas have been identified as prime hunting ground by Traditional Owners. A vast array of flora and fauna species utilised by Traditional Owners were documented during this assessment, many of which depend on groundwater.[20]

5.2. A lack of consideration of cultural values

The Wakurlpa and Alekarenge communities in particular use their ‘back yard’, within the drawdown area, to collect natural resources. Hunting and collecting “are vital to the maintenance of good mental, physical and spiritual health for Aboriginal people and an important way to transmit cultural knowledge and practices to younger generations.”[21]

Conceptually, economic measures of cost could be developed for the broad array of potential damages to cultural values, including costs of:

- emotional and physical responses;
- damage to sacred sites;
- reduction in species required for ritual activity;
- diminishing natural resources required for hunting, gathering and other activities;
- a loss for future generations of Kaytetye people; and
- a decline in the ability to live on and travel on the land.

While the work required to creditably assign economic values to such damages are beyond the scope of what is possible for this study, there is no good reason, a priori, to believe that they wouldn’t involve values of similar or larger magnitude to direct benefits expected from irrigated production.

[20] Ibid, p. 80
[21] Ibid, p. 43

Further, significant losses of environmental values, that are in addition to cultural value losses, are likely as a result of groundwater table decline associated with Singleton. One potentially very large loss would be damaged potential to store carbon in perennial vegetation biomass, roots and soil. While this potential cost has not been assessed, the scientific basis for such assessment is available and considerable evidence demonstrates that once the groundwater level declines below key threshold levels, high carbon storage potential trees don't survive and potential for storage of hundreds to thousands of tonnes of carbon storage in biomass, roots and soil per hectare is lost[22]. Again, methods to value the cost to the Australian people and the Government in terms of increased costs compliance to meet Commonwealth emissions targets are available. **While the work required for such valuation is beyond the scope of this report, there is no reason, a priori, to believe that such cost might not be similar or greater than the direct benefits from horticultural production that the project would create.**

5.3. The process of approval of the Singleton Horticulture Project appears to be in contradiction to the NTGs own policy statements on Aboriginal development and inclusion

One common view expressed by traditional owners is that the drawdown that Singleton will cause will preclude fulfilling obligations required by Altyerre (Dreaming) law. The need to follow this law is a core of cultural identity and represents a failure to meet cultural obligations, even if the failure is a result of actions by others. This failure has severe consequences for traditional owners: "Taking care of country into the future according to ancient laws and customs appeases the creator spirits residing at important places. If traditional roles and responsibilities are not carried out by traditional owners, and if country is damaged as a result of the actions of traditional owners or others, punishment is imposed on senior traditional owners by Altyerre forces resulting in sickness, injury and even death. Spiritual punishment can lead to psychological stress and guilt linked to people's sense of internal moral failure associated with being responsible for damaging the country belonging to their spiritual ancestors, their actual ancestors, the current generation of kin and their descendants. Social sanctions may also result;

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[22] Qiu, J., Zipper, S., Motew, M., Booth, E., Kucharik, C., Loheide, S., 2019. Nonlinear groundwater influence on biophysical indicators of ecosystem services. Nat Sustain 2: 475–483.

traditional owners can be forced into temporary or permanent isolation from their traditional group"[23].

There is no evidence to indicate that the NTG have adequately considered Traditional owners' perspectives despite statements that outline inclusivity as a core procedural element of NT Government decision making with respect to developments:

> *"Developing and strengthening structures [should be undertaken] to ensure the full involvement of Aboriginal and Torres Strait Islander peoples in shared decision making at the national, state and local or regional level and embedding their ownership, responsibility and expertise to close the gap." Priority Reform statement for the NT Government in their implementation plan for the Closing the Gap program (https://aboriginalaffairs.nt.gov.au/our-priorities/closing-the-gap)*

More recent policy development platforms, such as the Everyone Together 2019-2029 Strategy published by the NTG (NTG 2019) includes statements that clearly indicate a focus on integrating Aboriginal perspectives into policies about natural resource development, and explicitly placing Aboriginal people at the centre of decision-making:

> *"The NT Government accepts that decisions are best made closer to the communities affected and will lead a regional approach that places Aboriginal people and communities at the centre of decision making." (p7 NTG 2019)*

In addition, in 2008 the NT Government, along with all other states and territories, agreed to the National Water Initiative. Modules supporting the NWI outline a process to ensure "i) inclusion of Indigenous representation in water planning wherever possible; and ii) water plans will incorporate Indigenous social, spiritual and customary objectives and strategies for achieving these objectives wherever they can be developed (COAG 2017, p7).

The allocation of groundwater to Singleton represents incoherency in NT Government policy. Our analysis shows that the NT Government, in approving the Singleton water

[23] Ibid. p.67

licence, has not heeded their own commitments under Closing the Gap nor in the 'Everyone Together 2019-2029 Strategy'.

6. Conclusions

This report sought to consider:

1. the true economic costs of Singleton by considering the value of natural resources (namely water) that is currently not included in the business case for this project;
2. how assumptions around employment and value generation likely from the Singleton change based on data on agricultural employment and business performance statistics from similar projects/cases;
3. the range of other economic, social, environmental, and cultural impacts that may be substantial but are not considered within the Singleton Project Report.

In all cases we find substantial inconsistencies and omissions that indicate a substantial gap between the stated economic benefits of Singleton and those expected to be realised. Specifically, the review above indicates that, in all cases considered, economic benefits have likely been overstated (using reference case comparisons) and major known or potential costs have been omitted.

The key findings with respect to the Singleton business case are that:

1. The business case is critically dependent on an unstated subsidy associated with the transfer of water owned by the NT public to Fortune Agribusiness with a value of between $70 million and $300 million plus.
2. The stated economic benefits of Singleton are overstated:
    a. Operating costs appear to be inflated by between 10-35%.
    b. Local Aboriginal and non-Aboriginal employment levels implied within the project are much smaller than the forecast employment figures. Whilst exact employment outcomes can't be known ahead of project implementation we estimate that in the order of only between 26 and 36 FTE NT based jobs and as few as 5-8 jobs from neighbouring Aboriginal communities are likely if performance is like similar projects.

c. Implied expenditures are likely to be primarily outside of the NT. Our analysis suggests the likely amount to be in the vicinity of $13-28 million a year for non-labour input expenditures will be local if the project proceeds. This compares to an estimated operating cost figure in the Singleton business case of $110 million.

a. The proposed project is likely to generate substantial social and ecological costs that have not been accounted for. The resulting reductions in groundwater levels through extraction can best be considered as unsustainable and will generate substantial impacts on other users and groundwater-dependent ecosystems. The latter are considered to be at high risk.

In addition to these findings, the study identifies a concerning lack of detail around the business case that has led to the NTG approving the water licence for this project. The lack of detail extends to monitoring of environmental and cultural outcomes, and how any provision to curtail rights of withdrawal will be guaranteed should the project fail to substantively deliver on claimed benefits or cause unforeseen harm. It is concerning that there appears to be no formal social benefit cost assessment of the proposed project given the size of the public water resources allocated to this project, publicly-funded efforts to quantify water resources in the area and the potential associated environmental and cultural impacts.

ATTACHMENT O:

PEER REVIEW BY PROFESSOR R. QUENTIN GRAFTON OF UNISA'S ECONOMIC ANALYSIS REPORT OF THE SINGLETON HORTICULTURE PROJECT

March 1 (updated 7 July) 2022

Peer Review by Professor R. Quentin Grafton of UniSA's Economic Analysis Report of the Singleton Horticulture Project

March 1 (updated 7 July) 2022

The authors of the report have undertaken a hydrological-economic review of the costs and benefits of the proposed Singleton Horticultural Projects, south of Tennant Creek in the Northern Territory (NT). This planned development would be based on access to and extraction of up to 40,000 million litres per year of 'free' groundwater over a thirty-year period.

Business Case

The business case for the Singleton Horticultural Projects rests on access to the groundwater in the form of a licence from the NT government. The authors have used alternative water entitlement prices from other locations to estimate the implicit subsidy to the Singleton Horticultural Projects.

In my judgement, given the lack of any other water source for this project, a reasonable estimate of the market value of this water is likely to be in the higher end, or some $6,710 per million litres. At this market value, the implicit subsidy to Singleton Horticultural Projects could be in the order of $250 million. As a consequence of this subsidy, the NT government - the legal owner of the groundwater, will forgo this revenue that could be used for worthy purposes and, instead, it will accrue to a private enterprise rather than the 'public purse'.

Implicit Subsidy

It appears the primary justification for the large implicit subsidy to the Singleton Horticultural Projects is to generate local employment. Much of this employment would occur at harvest times. As the authors of the report note: "The Northern Territory Farmers Association report that in 2019 only 11% of total horticultural labour was supplied locally. Overseas workers represented 63% of total labour, particularly during the harvest season, and the remaining 28% was supplied from interstate workers." What the actual local additional employment with the development would be impossible to know with certainty in 2022 but it would seem highly unlikely to be more than a few dozen FTEs.

Accountability

In September 2021, the NT Department of Parks, Environment and Water Security prepared a public report entitled 'Northern Territory Strategic Water Plan: Directions Paper'. One of the espoused principles in the Directions paper is: "Fair and Accountable - Decisions will be based on clear roles, responsibilities and processes. Decisions will maximise public benefits, recognising that water has social, economic, cultural and environmental, as well as intrinsic values.". In my view, providing an implicit subsidy of the order of $250 million to a commercial enterprise in the form of 'free' water, does not satisfy this key principle.

Importantly, the NT Government is a signatory to the National Water Initiative (NWI). In paragraph 65 of the NWI, Australian governments (including the NT Government) agreed to; "full cost recovery for water services to ensure business viability and avoid monopoly rents, including recovery of environmental externalities, where feasible and practical" and in paragraph 66; "full cost recovery for all rural surface and groundwater based systems". In paragraph 72, the NWI further states that in the provision of unallocated water it should: "To the extent practicable, releases should occur through market-based mechanisms" The only exception to the 'user-pay principle' is in relation to community services obligations but that does *not* apply in this case as the benefits accrue to a commercial operation and is *not* the provision of water to a community.

Free, Prior and Informed Consent of First Nations

It would also seem that there has not been 'free, prior and informed consent' (FPIC) in relation to all the First Nations communities that may be affected by the development and the groundwater extractions. This is contrary to both the Aboriginal and Torres Strait Islander Studies (AIATSIS) Code of Ethics and the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP). It is also contrary to a key finding of The Productivity Commission (2020, p. 13) 'National Water Reform Inquiry' that: “Much more needs to be done to include Traditional Owners’ interests in water in jurisdictional planning and the management of water.”

Summary

I concur with the authors of the report that the business case of providing a large subsidy of ‘free’ water to Singleton Horticultural Projects is not justified from either a public interest or a cost-benefit perspective. Nor does it support water justice. These is because:

(1) An implicit subsidy in the order of $250 million in the form of ‘free’ groundwater to a commercial enterprise does *not* maximise public benefits, and is contrary to the National Water Initiative to which the NT Government is a signatory;

(2) It fails to adequately consider the consequences of social, economic, cultural and environmental values associated with large groundwater extractions over a thirty-year period. Thus, it also does not meet the NT government’s own guidelines in relation to water security; and

(3) It is inconsistent with free, prior and informed consent of First Nations communities in the vicinity of the proposed groundwater extraction. Thus, it is contrary to the United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP).

ATTACHMENT P:

SINGLETON PROJECT ECONOMIC IMPACT ANALYSIS: REVIEW IN REFERENCE TO THE *CONNOR ET AL. (2022)* CRITICAL REVIEW

Prepared by Professor Jeffrey Connor, Dr Daniel Gregg and Dr John Kandulu

Singleton Project Economic Impact Analysis: Review in reference to the Connor *et al*. (2022) critical review

Executive Summary

This document provides findings from a critical review of an Economic Impact Assessment (EIA) supporting the business case for the Singleton Horticulture Project conducted by GHD Pty Ltd (GHD) on behalf of Fortune Agribusiness Funds Management Pty Ltd (FAFM) on 25 October 2022. In an earlier report, Connor *et al.* (2022), provided an initial critical review of the proposed Singleton Horticulture Project business case based on information that FAFM made publicly available at that time.

The authors of this report have been requested by the Central Land Council to provide an updated review of the proposed Singleton Horticulture Project to inform a rigorous Environmental Impact Assessment process, considering that new reporting on the Singleton Business case has now been made available by FAFM. The questions guiding this additional review are:

1. What new information has been provided since we published Connor *et al.* (2022) specifically through the FAFM EIA and SIA referral documents?
2. Does the new material lead us to change the conclusions provided in Connor *et al.* (2022)?
3. Does the new material raise any additional concerns about the accuracy, methodology, assumption, data, or interpretation of data that warrant further investigation?
4. What tier of assessment is appropriate from an EIA perspective?

We found that GHD provided significant additional information and analysis, including further details on assumptions and methods used to estimate project costs and benefits. However, we also found that many of the assumptions used to estimate costs and benefits remain implausible, with minimal evidence provided to support the assumptions based on the performance of past similar enterprises. We also found that the EIA failed to satisfy a number of the NTG's own guidelines for benefit cost analysis for this type of project. We conclude that the bulk of additional information does not change the conclusions provided in Connor *et al*. (2022). Indeed, there are clear incentives for optimism bias in the EIA through implausible assumptions that bias project benefits upward, and this finding supports the key conclusion from Connor *et al*. (2022) that the project will provide substantially less benefit than FAFM contends and involve significant public costs that are not accounted for. We, therefore, submit that GHD's EIA does not meet the NT and Commonwealth governments' standards expressed in its benefit cost analysis guidelines for EIAs of proposed projects.

We found that costs to the environment and local Aboriginal wellbeing were not adequately accounted for, and a large, unstated, subsidy in the form of a transfer of water owned by the

NT public to Fortune Agribusiness was neither acknowledged nor quantified in the assessment. This leads us to believe that the FAFM EIA referral documents, in their current form, are not consistent with the NT's own guidelines for best practice in EIA.

Further, a major proposed benefit of the project is associated with job creation for Barkly Region residents. This claim is unrealistic and cannot be expected to be fulfilled if this project were to progress. This is primarily because the work force in the region is limited, with few appropriately skilled people currently unemployed or under-employed. All evidence indicates that regional labour shortages are generally not filled by regional residents as indicated by reporting on labour constraints by the NT Farmers' Association (2019). Furthermore, the Social Impact Assessment (SIA) for this project indicates a material likelihood that the project would displace employees from other businesses more than it would create new jobs in the region. This is likely to generate negative social and economic development outcomes by reducing the ability of locally-owned businesses to grow.

The reported data basis for the model is neither sufficient nor transparent enough to enable a critical review of the assumptions used. Unsubstantiated assumptions about unlimited labour supply in the region are likely to exaggerate job creation impacts. This deficiency should be addressed by using appropriate modelling methods that regional economics regularly uses to adjust for small region limited labour supply contexts. The EIA was also devoid of scenario analysis, probabilistic calculations and other widely applied tools typically employed when conducting a social benefit cost analysis of a proposed project. Most importantly, not all of the modelling assumptions and results seem to be available for public review.

Furthermore, whilst FAFM proposes that adaptive management will be used for this resource there is no provision for independent assessment of negative impacts over the course of the project. Nor is there provision for ensuring appropriate governance around that adaptive management. It is unlikely that self-regulation would work in this context where cost of sustainable management will be experienced by local NT citizens not FAFM, who stands to gain financially from the implicit subsidies. Therefore, self-regulation should be rejected as an option. Several corporate behavioural studies have showed that liability threats and pressures from consumers, investors and the public are more effective than self-regulation when it comes to adaptive environmental management, particularly when there is a significant financial disincentive (e.g. Anton *et al*. 2004). Therefore, if this project were to proceed, the adaptive management strategies proposed by FAFM should be enforced through an independent (not associated with FAFM or the NTG) body conducting annual impact reviews, making all impact results public, and retaining decision making power over continuation of the irrigation development plan for Singleton.

The concerns outlined in this report, similar to those outlined in the original Connor *et al*. (2022) review, lead us to question FAFM's seriousness about seeking to provide a clear, and unbiased, analysis of project impacts particularly regarding regional environmental, cultural, and economic development outcomes. Given these concerns, we can only conclude that the most detailed possible review for the Environmental Impact Assessment (i.e. a Tier 3 assessment) is required. To comply with the NT's own requirements, this would require accounting for the large public subsidy in the order of \$70-\$300 million dollars of the NT public's assets implicitly paid to FAFM, and a much more serious effort to value environmental and social costs currently omitted in the EIA documents. In addition, further evidence is required to support assumptions, methods and input data used to forecast project costs and benefits to enable credible estimation of the net benefit of the project, including social and environmental impacts. Given repeated concerns around unrealistic assumptions applied to current FAFM project reviews, any future reviews for Environmental Impact Assessments should be undertaken by an entirely independent body with models and results provided for public review.

Key findings from our review of the GHG EIA are:

1. The EIA does not meet the NT and Commonwealth governments' standards, nor does it adhere to guidelines for EIAs of proposed projects
2. Optimistic assumptions were used in estimation of public benefits, leading to overstated public benefit forecasts
3. The assessment omits social costs, including potential loss of groundwater-dependent cultural and spiritual benefits, thereby effectively assigning them a value of 'zero'
4. The EIA did not account for the value of water entitlements that would be provided free of charge to FAFM
5. The EIA uses unsubstantiated assumptions about potential flow-on benefits, which suggests exaggerated flow-on impact estimates
6. The EIA overstates employment benefits, which questionably assumes that there is, currently, a large pool of available skilled labour in the Barkly Region
7. The assessment contains vague statements about the project's public service and benefit provision without providing any financial commitment to support the claims

Report overview

Organisation of reporting is as follows. First, key findings from Connor *et al.* (2022) are summarised, then a description of new material included in the EIA is provided. Next, key findings from a critical review of the EIA are outlined in reference to NT (and Commonwealth) Government economics assessment standards, particularly, the NTG Environmental Protection Authorities own Guidelines for the Preparation of an Economic and Social Impact Assessment V2.0 (2013)

Key findings from Connor *et al*. (2022)

Key findings provided by the Connor *et al.* (2022) review of the business case for the Singleton Horticulture Project show that first, there is a large implicit subsidy to FAFM who would extract groundwater for the project free of charge and second, estimates of economic benefits, operating costs of production and local expenditure and employment are overstated.

Nonadherence to the NTG Environmental Protection Authority's own Guidelines

It is evident that the assessment flouted the NTG Guidelines, which stipulates, for example, that:

"*investment* ***should provide the highest net benefit of all options available to increase access to water, taking into account economic, social and environmental impacts****; Projects should ..* ***provide a demonstrable public benefit and address a community need****; Projects should align with the National Water Initiative principles including appropriate* ***cost recovery*** *and, where full cost recovery is not deemed feasible,* ***any subsidies are fully transparent to the community****"*.

Most notably, the EIA of the proposed Singleton Horticulture Project is inconsistent with NTG Guidelines, having significant implicit (in-kind water allocation) and a cash subsidy that is not counted as a cost despite the NT's own guidance indicating that it should be.

Large implicit subsidy to FAFM

The business case includes a large, unstated, subsidy in the form of a transfer of water owned by the NT public to Fortune Agribusiness, with a maximum value of over $300 million. In other states, consistent with NWI principles, the project proponent would have to incur this cost. In this case however, it is an implicit subsidy that should be represented as a cost in a social benefit cost analysis (BCA). Implications of public subsidisation of a private entity's groundwater extraction activities may include over extraction of scarce groundwater resource with multiple competing uses due to absence of an effective incentive to use water efficiently and a missed opportunity to recover costs for improved governance and resource management.

Overstated economic benefits

The claimed economic benefits of Singleton are overstated when compared with reported industry performance in similar enterprises. For example, the EIA found that the project would create 110 new permanent local jobs and 1,350 seasonal jobs (Pp 16 Section 2.3.2). Considering current labour market conditions in the Barkly region are characterised by a tight local skilled labour market, the project would more likely displace local labour from other competing sectors than create new jobs. Especially considering that the EIA does not provide a detailed plan for training the unemployed subpopulation, which is, in itself, limited.

Overstated operating costs of production

Based on comparisons with findings from assessments of similar horticultural enterprises in the region, it is likely that the project's operating costs of production are overstated by 10%-35% (Connor *et al*. 2022, p12)

Overstated local expenditure values

Expenditures on local and regional inputs are likely to be substantially overstated, noting that FAFM has not provided any new information, grounded in empirical evidence, to justify applying a greater than typical assumption in relation to local expenditure.

Overstated local employment forecasts

Local and regional employment estimates are likely to be grossly overstated. For example, the business case estimates that the project would employ 1,350 seasonal workers and create 110 FTE positions. These estimates are not consistent with calculations provided in Connor *et al*. (2022), which suggest that the expected contribution of the Singleton project, in terms of **local** job creation, would in-fact, be much lower than suggested in the business case, noting that Connor *et al*. (2022) based their calculations on data from the NT Farmers Association average proportions of local versus seasonal international and FIFO labour in the sector (2019).

Table 1 provides a summary of key findings from our review of the business case for the Singleton Horticulture Project.

Table 1. Omitted public cost and potentially overstated benefits identified in Connor *et al*. (2022)

Purported economic benefits from the Singleton Horticulture Project	Estimates from the GHD business case	Findings from our own analysis
1. Value of the water entitlement	Provided free of charge by the NT Government	The entitlement is worth between $70 million and over $300 million
2. Employment for local communities and Northern Territory residents	110 permanent jobs and 1,350 seasonal jobs, with opportunities for local employment	A large proportion of NT agricultural jobs go to overseas workers and interstate fly-ins. Seasonal jobs are only available through short-term contracts, ranging between one to three weeks and a few months. We estimate that only 26-36 full time equivalent (FTE) jobs will likely be filled by residents of the Northern Territory, of which only 5-8 FTE jobs would be expected to go to Aboriginal communities in the Barkly region.
3. Economic activity through operating expenditures	$110 million a year, much of this spent within the Northern Territory	Operating costs appear to be inflated by between 10%-35%. The true expenditure figure is likely to be between $70-$110 million per year, with $13-$28 million expected to be spent in the NT.

Based on the limited information available, and with plausible adjustment to reflect past performance in similar projects, we conclude that scaling up may be more difficult and limited than suggested and that:

Taking into account the apparent over-statement of operating costs of 10-35% as applying equally to the labour force (Section 4.1) the total employment of NT residents could reasonably be expected to be only 26-36 FTE jobs of which only 5-8 jobs are expected to include local Aboriginal people.
Connor et al. (2022, p21)

Updated information provided by FAFM

We note that since our original analysis, which was based on limited publicly available information, FAFM commissioned GHD to produce a detailed EIA on 25 October, 2022.

The EIA provides further detail and more clarity about calculations behind benefit and cost estimates than we had access to when we released Connor *et al*. (2022), including data and assumptions underpinning the business case as summarised in Table 2.

Table 2: New material included in the EIA of the Singleton Horticulture Project

Item	**Section**
EIA overview of methods, results, assumptions, limitations and the scope of evaluation. Details of accommodation, extraction staging, and development work steps	Section 1, Table 1
A profile of the regional economy	Section 2
indirect flow-on economic impact assessment with input-output (IO) modelling assumptions	Section 3
Indirect flow-on economic impact results	Section 4
Combined direct and indirect economic impact assessment results	Section 5
A crop attractiveness and market analysis selection, based on factors such as horticultural suitability, market capacity to take up more without adverse price collapse and returns per ha	Appendix D

Apparent contradictions, poorly validated assumption and other issues that require further attention

To judge the quality and adequacy of the information provided, we evaluated the EIA in reference to NTG Environmental Protection Authority's own Guidelines for the Preparation of an Economic and Social Impact Assessment V2.0 (2013) (hereafter, *NTG Guidelines*).

NT (and Commonwealth) governments' economics assessment standards

The objectives of the NTG Guidelines are to:

- *document the economic and social impacts of a proposed development on the locality and region;*
- *mitigate negative economic and social impacts on the locality and region;*
- *encourage development of new and/or expansion of existing businesses in the locality; and*

- *foster sustainable development and community wellbeing* (NTG, 2013).

The intent and content of this guidance is very similar and related to national guidelines such as the Commonwealth White Paper on Irrigation (2015), which states that agri-water "*investment* ***should provide the highest net benefit of all options available to increase access to water, taking into account economic, social and environmental impacts****; Projects should ..* ***provide a demonstrable public benefit and address a community need****; Projects should align with the National Water Initiative principles including appropriate* ***cost recovery*** *and, where full cost recovery is not deemed feasible,* ***any subsidies are fully transparent to the community****; If providing capital,* ***a consistent robust analysis of costs and benefits is used*** *and assessment is undertaken by Infrastructure Australia or similar experts."*

Similarly, the NTG Guidelines state that *Accelerated development places a premium on provision of accurate and comprehensive impact assessment and where appropriate mitigation of project specific economic and social risks.* (page 1). In addition, Section 5 of the NTG Guidelines provides specific requirements for what should be included in economic impact assessments including:

5.1.1 Contribution to the NT and Australian Economy

a) estimated total project revenue for the planned project duration (to provide the economic scale of the project)
b) expected project duration
c) value of any value-adding in the NT and Australia
d) estimated overall tax and royalty payments, showing the NT proportion, if available
e) expected value of exports and any imports
f) estimated capital expenditure for the whole project, identifying construction cap ex
g) expected annual operational expenditure, showing the proportion in the NT
h) impacts if any of neighbouring businesses or projects (costs and benefits)
i) any overall direct and indirect economic impact data if available
j) specific regional resources, constraints and opportunities
k) historical and current economic trends in the Territory/regional economy including projects being developed or to be developed in the near future
l) previous resources or other major development in the region and their effects including long and short term incomes and employment, business development, and estimates of lost and gained opportunities and landscape services e.g. reduction in the quality of the water supply.

5.1.2 Contribution to Business Development

a) expected value of NT/Australian business supply and service participation during construction and operations
b) Contribution through an agreed industry participation plan if required (usually required for all projects over $5m in value which receive 'substantial' NT government assistance).

5.1.3 Contribution to Employment and Training

a) expected direct and indirect project employment during construction and operations
b) estimated workforce/contractor numbers by occupational classification if available
c) overall employment training proposed during commencement, construction and operations

d) *planned Indigenous employment, training and other project participation*
e) *expected level of overseas recruitment*

5.1.4 Contribution to Regional Development

a) *value of the proposed Community Benefit arrangements (already included)*
b) *estimated overall regional economic benefits*
c) *other contributions to local communities, including Indigenous traditional owners community value of any residuals infrastructure, such as roads, camps, lakes, etc*
d) *assessment of deficiencies / issues that require further attention in Economic impact*

The highlighted text draws attention to the items that, in our assessment, do not meet the NT and Commonwealth governments' standards for economic impact assessments of proposed projects in the EIA prepared for FAFM by GHD. Most notably, the EIA of the proposed Singleton Horticulture Project is inconsistent with NTG Guidelines, having significant implicit (in-kind water allocation) and potentially other subsidy that is not counted as a cost despite the NT's own guidance indicating that it should be.

In the following sections, we provide further description of how the EIA is inconsistent with NTG Guidelines due to overstated public benefit estimates, arising from errors or purposeful misrepresentation of economic assessment methods, data and assumptions. The two main potential sources of error discussed include use of optimistic assumptions that overstate public benefit estimates and omission of social costs of the project.

1. *Optimistic assumptions that create overstated public benefit estimate remain*

The essence of points 2 and 3 in Table 1 from our original critique still hold. The new detailed EIA provides further detail on estimates of local input spending and employment. However, as in the previous publicly available information we based Connor *et al.* (2022) on, the proportion of highest value crops assumed in the business case's crop mix exceeds what has been achieved in similar past projects on a sustained basis. Input use expenditure also remain higher than is suggested by data for similar projects from publicly available information sources. This implies that the public is being asked to provide hidden cash subsidies for less public benefit than is stated and that the public benefit cost ratio for the project would likely be overstated based on this information.

The potential to create local employment seems particularly overstated as noted in Connor *et al*. (2022)

> *"The NT Farmers Association reported that in 2019 only 11% of total horticultural labour was supplied locally. Overseas workers represented 63% of total labour, particularly during the harvest season, and the remaining 28% was supplied from interstate workers. Many producers find it difficult to attract Australian workers due to the seasonal nature of the roles offered, remote locations and lack of contract security. Evidence of this can be seen on mango plantations in the NT, where producers report nearly no local seasonal workers.*
>
> *The above evidence raises serious doubts about the true employment impacts of Singleton for the NT and Barkly region economy. Given the significant labour shortages for horticulture in Australia, it is likely that a*

large proportion of the permanent and seasonal work will be from overseas or interstate. Seasonal workers will most likely be sourced from the existing pool of employed seasonal workers in the NT economy. In the absence of Singleton, these workers would find alternative opportunities in the NT or elsewhere."
Connor et al. (2022, p19)

The updated assessment assumes high proportions of local labour supply and input expenditures. This is contradictory with evidence showing low unemployment in the regions' small work forces, especially in appropriately skilled categories. This issue is evident in the GHD's EIA regional economic profile (Page 16), which provides graphs that contradict some of the reported numbers and census data. GHD's graph shows that 10.8% of the work force in the Barkly local government area (LGA) are technicians and trades workers, 16% are labourers in a total work force population of 2,700, with only a small fraction available for employment, or not fully employed. Further, there are significant contradictions between assumptions, data and comments by other concerned regional businesses in the SIA carried out by GHD about the potential for "crowding out" of local existing demand. Our submission is that a Tier 3 assessment is needed, including calibration of impact estimates such as expected local employment outcomes based on empirical evidence, to test/check forecasts provided in GHD (2022).

2. *Failure to include social cost despite purported public net benefit in assessment*

There is vague discussion/acknowledgement of potential loss of cultural and spiritual benefits for First Nations groups, but not serious effort to evaluate the scale of these values at risk, nor is there meaningful evaluation of investments required to mitigate or avoid these negative impacts on wellbeing of NT citizens. Though, as outlined in Connor *et al* (2022) Sections 5.1 and 5.2, estimating the value of potential losses in cultural, spiritual and environmental values of water is difficult, potential negative impacts of groundwater extraction on flow and flood-dependent cultural and spiritual values must still be recognised as a cost. Further, implications of omitting potential negative cultural and spiritual impacts should be made clear and transparent in discussion of EIA limitations and interpretation of EIA outcomes, consistent with best practice guidelines (DoFA, 2006; DTF, 2008) to ensure that limited water resources are distributed equitably and justly (Nikolakis & Grafton, 2022). Failure to acknowledge these values at risk from the project effectively assumes that they have a value of 'zero' in the EIA.

The plan suggests that an adaptive management approach will be taken, involving reduced water extraction and production scale (a traffic light approach), yet no probabilities of this kind of outcome or financial planning with contingencies for such eventualities is offered (e.g. how any potential risks of environmental damage from groundwater extraction will be mitigated). This leads us to question the robustness of the economic analysis and whether there is a serious intention to scale back should it prove environmentally and socially unsustainable.

3. *Failure to account for the value of water entitlements provided free of charge to FAFM*

This is a cost to the people of the Northern Territory. The Northern Territory does not charge when it allocates water because it assumes there will be significant economic development benefits and the "trade-off is worth it". However, the NT government's own BCA guidelines require that all public and implicit subsidy costs should be acknowledged.

4. *Unsubstantiated assumptions about flow-on benefits, suggesting exaggerated flow-on impact estimates*

GHD use the Input-Output (IO) methodology to estimate impacts of the project for the regional economy. As stated in the GHD report itself, IO analysis assumes:

"that the economy has no supply-side constraints. That is, it is assumed that extra output can be produced in an area without taking resources away from other activities, thus overstating economic impacts. The actual impact is typically dependent on the extent at which the economy is operating at or near capacity" (GHD 2023 p20)

Evidence from both the regional economy profile (EIA section 2) and the SIA provided by GHD illustrate that this assumption is not valid in the context of Barkly LGA, which is characterised by low unemployment rates (PP 16), particularly in the absence of a plan to offer training to the already limited unemployed subpopulation.

5. *Overstated employment benefits*

Despite a tight and small local skilled labour market in the Barkly LGA, the EIA claims that large job creation benefits are expected (Pp 16 Section 2.3.2). SIA comments by other local businesses, and empirical economic evidence from similar small local labour force settings, suggest displacement or poaching from other local employers is more likely than creation of new local jobs.

The following statement, which is the core basis for the use of the IO methodology to estimate economic impacts, is clearly contradicted by several sources, but most notably by the NT Farmers Association itself:

> *"The NT Farmers Association reported that in 2019 only 11% of total horticultural labour was supplied locally. Overseas workers represented 63% of total labour, particularly during the harvest season, and the remaining 28% was supplied from interstate workers. Many producers find it difficult to attract Australian workers due to the seasonal nature of the roles offered, remote locations and lack of contract security. Evidence of this can be seen on mango plantations in the NT, where producers report nearly no local seasonal workers.*
>
> *The above evidence raises serious doubts about the true employment impacts of Singleton for the NT and Barkly region economy. Given the significant labour shortages for horticulture in Australia, it is likely that a large proportion of the permanent and seasonal work will be from overseas*

or interstate. Seasonal workers will most likely be sourced from the existing pool of employed seasonal workers in the NT economy. In the absence of Singleton, these workers would find alternative opportunities in the NT or elsewhere."

Connor et al. (2022, p19)

This contradiction indicates that the application of the IO methodology in this case is deeply inappropriate and is highly likely to substantially overstate the value of the Singleton project given major and unavoidable supply chain constraints that characterise production in northern Australia, and more so in regional areas of northern Australia.

This concern is magnified by the fact that IO methodologies are not typically regarded as appropriate for 'small' regions – where 'small' refers to the size and scope of economic activity. The Barkly region, in this context, would typically be considered as falling in the 'very small' category, indicating that the IO methodology is not a valid method for estimating regional economic impacts in this case (ABS, 2023).

It is unclear how the IO is applied. It appears to be applied to the Barkly region based on IO specification appropriate to larger regions, and not to the Barkly region but this is not explicitly stated. Nor is there any explanation of how the issue of limited local respending opportunity and employable workforce in very small regions is treated methodologically. We suspect improper application of the model and resultant interpretation of results and suggest the issue should be further clarified in Tier 3 assessment.

6. *Vague statements without any commitment to public service and benefit provision*

In the information provided we see no budget items that focus on any form of social benefits, no committed funding to training or employee wellbeing. While infrastructure is vaguely discussed, there is no budgeted investment in broader public benefit. It seems to be implied that public subsidy should provide significant benefit to FAFM and that others will benefit as well. If there is a public subsidy provided to FAFM in any form it should be costed to determine true net public benefit in line with NT guidance.

7. *Inadequate consideration of climate liability*

Inadequate consideration of climate liability of the project as stipulated in Australian Prudential Regulation Authority (APRA)'s Prudential Practice Guide - CPG 229 Climate Change Financial Risk (APRA, 2021)

APRA has recently ruled that company directors and by extension ministers cannot plead ignorance of significant adverse greenhouse gas impacts of their business plans and risks that this creates. Carbon cost and liabilities for Australia in meeting its UN net emission reduction targets would likely arise from this project, as has been found in similar large horticultural operations for example Martin-Gorriz *et al.* (2020). The NT and FAFM are aware of these and should include, at a minimum, the cost of covering this liability with carbon credits if not the broader social cost of the emissions.

Table 3. R**eview details and comparisons**

Attribute	Original	Updated (GHD EIA)	Details	Significance
Operating costs	Operating costs were estimated at $110 million AUD per year.	Updated operating costs are estimated at 'over $94 million' AUD per year.	The lower end of the updated operating costs ($94 million) is ~15% lower than the original estimate. This accounts for the lower end of over-estimation of operating costs described by Connor *et al*. (2022) being estimated at 10%-35% over-estimation of operating costs. NT expenditures are broken down by category into percentage of expenditure within the NT in Table 15 (page 25 of GHD report) as follows (percentages reflect stated percent of all expenditure that will be spent in the NT). Bracketed [%] values indicate the percentage of all costs that each category is calculated to be (i.e the cost share): Crop variable costs: 70% [78%] Permanent employee costs: 80% [15%] Management fees: 50% [1.6%] General repairs and maintenance: 50% [<1%] Sundries/contingencies: 70% [<1%] Electricity: 100% [<1%] Insurance: 50% [<1%] Vehicle operating costs: 100% [<1%] Plant and equipment: 50% [1.7%] Overheads: 80% [1.7%]	Estimates for overall operating costs have been substantially reduced to be within a potentially reasonable range based on other farming activities. The new estimates remain at the upper end of expectations for operating costs, based on similar projects, and are likely to be lower than stated, possibly substantially lower. This indicates that there is a strong likelihood that the total operating cost of the project will be substantially lower than stated. Crop variable costs make up the highest proportion of operational costs of the project at 78% of all costs. This cost estimate includes seasonal labour for crop production activities. Average total expenditures estimates add up to over $75 million per year over 30 years. The percentage of crop variable costs forecast to be expended in the NT is estimated at 70%
Local procurement	No clear statement	Clear statement on locally-focused procurement: "procurement preference is clearly local Barkly region first, Territory second, elsewhere third. Where firms outside the Territory may be needed, FAFM will actively encourage these to function as close to the site as possible and to employ locally" (EIA page v)	There is no detail available on how this procurement preference will be applied. Given limitations facing local procurement there is no evidence that the Singleton project will be able to achieve substantial local, or even Territory, procurement for either the investment or operational phases.	There is no additional evidence that changes the results outlined by Connor *et al*. (2022).

Attribute	Original	Updated (GHD EIA)	Details	Significance
Revenues and gross margins	Not reviewed in Connor *et al*. (2022)	Stated to be an expected final revenue of $200 million AUD per year.	This represents a $100 million annual gross profit (EBITDA) on operating costs of approximately $100 million – or a margin of 50% on all costs.	This assumption represents an extraordinary divergence from any existing horticultural project known. For example the NSW DPI estimates that rockmelons have a 14% margin while seedless watermelons have a 9% margin not including interest, tax, depreciation and amortization. Taking out water costs only changes the margin by 1-2%. There is no detail on the source of these differences but some basic calculations indicate a very large over-estimation of expected revenues. For example, the expected revenue per hectare on the basis outlined within the GHD EIA report is equal to an average of over $57,000 revenue per hectare. Even taking a high estimate of gross margins from revenues at 20%, and retaining the high operating cost estimates for Singleton (at $100 million AUD) these values indicate a revenue expectation of $125 million AUD – an over 35% reduction in stated margins. If operating costs, and likely associated revenues, were strongly overstated (as indicated as a possibility) these values would be even lower at approximately $90 million AUD total revenue (or over 50% lower than stated in the GHD EIA documents). Given the extraordinary overstatement of expected revenues per hectare, combined with no evidence provided to justify such an expectation, there is a strong indication that total economic values would be substantially lower than stated – possibly half of what has been stated.
Employment (operating)	Connor *et al*. (2022) calculated that the project statements indicate that a total of 368 FTE positions would be created comprising of 110 true	The GHD EIA review indicates a substantial increase in expected employment levels to a total of 426 FTE positions	The GHD report uses FTEs as a measure instead of statements of seasonal and permanent positions making comparisons to standard farm models and data more direct.	This is a dramatic increase on estimated FTEs from the original proposal details (as calculated by Connor *et al.* 2022). It represents an increase of 15% on those original employment expectations – employment expectations that were shown to be likely to be inflated compared to labour usage

Attribute	Original	Updated (GHD EIA)	Details	Significance
	FTE positions and 1350 seasonal places (average employment length assumed at 8 weeks).		The composition of employment is described in the GHD EIA as: • 122 direct farm full time equivalent positions • 37 full time equivalent seasonal positions • 170 indirect full time equivalent positions • 97 indirect supply chain full time equivalent positions The IO analysis of GHD implies an employment multiplier of over 100% for operating activities – 159 FTEs generate 170 additional (indirect) FTE positions in the broader economy. For the construction phase the multiplier is lower, but still large (80%) for indirect jobs.	expectations for intensive horticulture in areas with greater labour availability, even with the original lower detail. These new estimates represent an inflation factor of over 50% compared to rockmelon labour use as estimated by the NSW Department of Primary Industries at 0.12 FTE per hectare (compared to 0.077 FTE per hectare for rockmelon in NSW). There is no detail to support these estimated labour usage data for Singleton whilst existing comparisons, in areas with high labour availability, indicate substantially lower labour usage (over 50% lower than stated per hectare for the Singleton project).
Construction estimates	Total construction value only provided	Detailed construction value across a number of activities provided along with a percentage allocation to expenditure within the NT. No detail provided that can support claims on % NT expenditures.	Total capital expenditure is estimated at ~ $252m AUD. Of this ~$167m is stated to be spent within the Northern Territory (66% of all capital expenditures).	It is not possible to consider the validity of the total expenditure estimates with available data. However, the proposed proportion of expenditure in the Northern Territory of 66% of total capital expenditures, amounting to $167 million appears highly optimistic. For each category, other than land clearing, the expectation that the Singleton project would seek to purchase capital inputs from the Northern Territory, a region with a small, and declining manufacturing sector, is unrealistic. Other indicators also raise questions over this assumption – for example the 3.3% unemployment rate in greater Darwin and 4.8% in regional areas of the Northern Territory are strongly indicative of an economy that is at capacity. In combination with the small size of the economy and population, this indicates substantial difficulties in the capacity of the NT economy to provision services/inputs to the construction phases of the Singleton project.

Authors' biographies

Professor Jeffery Connor

Jeff Connor specialises in quantitative economic, environmental and social integrated systems modelling often working closely with governments at local, state, national and international levels to provide economic policy advice based on rigorous economics. Jeff worked as an economist and group leader at CSIRO from 2001-2016 where he provided research and advise to the Murray Darling Basin Authority, natural resource management boards and state departments for water, agriculture and natural resource management in South Australia, Victoria, and Western Australia and in Bangladesh, Indonesia, China and Laos. He has secured and/or managed over $6 million worth of externally funded research and published over 60 peer reviewed articles and book chapters in water resource and environmental economics.

Dr Daniel Gregg

Daniel Gregg is Principal Economist at Heuris. Daniel has led several reports into farming systems risks and strategic initiatives, including a recent report for the OECD on agro-food systems resilience in which price and input risks were reviewed alongside market and other risks. This report focused on the importance of price risks in the COVID era and due to the emergence of geo-political tensions such as from the Russian invasion of Ukraine. Daniel has ongoing work with the OECD focusing on farm productivity measurement, leads the economic analysis of a large national sustainable farming initiative, and is an Associate Editor of the Australian Journal of Agriculture and Resource Economics focusing on farm analysis efforts.

Dr John Kandulu

John Kandulu is a Senior Research Economist at the School of Economics and Public Policy at the University of Adelaide. John has over 15 years of work experience as an applied economist in education, not-for-profit and government sectors focusing on natural resource management policy design and evaluation. He has contributed to projects addressing aid for development programs, policy-, program- and project impact evaluation, food and water security and water quality management. John applies various analytical techniques to inform policy- and investment decisions, including evaluating the effectiveness of new policy-, program- and project options, and the expected net return on prospective investment options. John's current research area of interest is design and evaluation of effective diversity and inclusion policies to inform inclusive natural resource management.