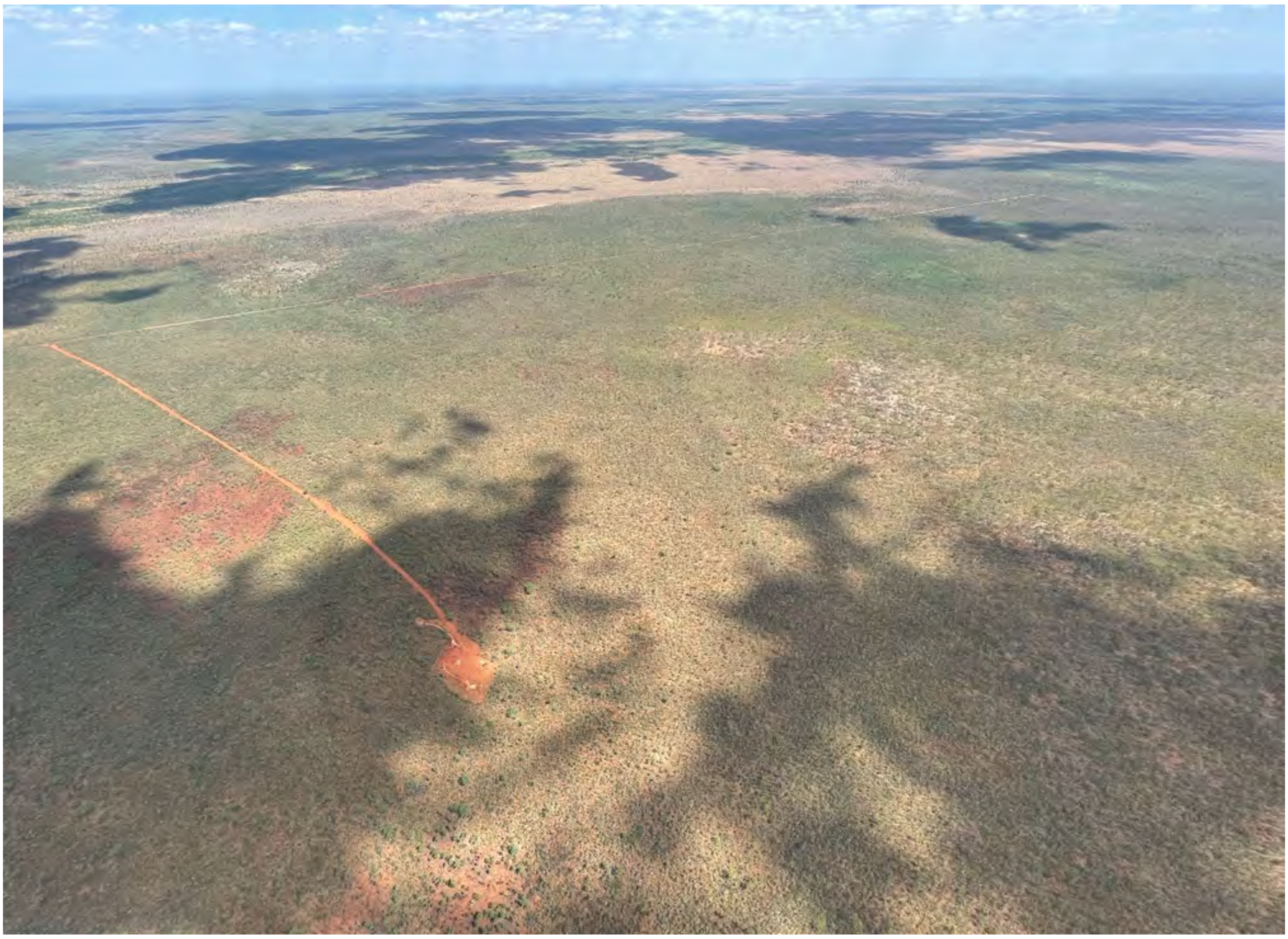
H3 Hydrogeological Assessment Napier Downs Station

Prepared for Australian Capital Equity Pty Ltd.

10th December 2021



H3 Hydrogeological Assessment
Napier Downs Station

A report prepared for Australian Capital Equity Pty Ltd.

by

Innovative Groundwater Solutions

10th December 2021

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Cover Picture

Aerial view of the Scrubby project site looking south towards the pad where the monitoring and test production bores were drilled (foreground) as well as Hawkstone Creek (background).

Disclaimer

This report is solely for the use of Australian Capital Equity (ACE) and may not contain sufficient information for purposes of other parties or for other uses. Any reliance on this report by third parties shall be at such parties' sole risk.

The information in this report is considered to be accurate with respect to information provided and at the time of investigation. IGS has used the methodology and sources of information outlined within this report and has made no independent verification of this information beyond the agreed scope of works. IGS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that the information provided to IGS was false.

CONTENTS

1. Introduction

This H3 hydrogeological assessment was undertaken to support the application by Napier Corporation Pty Ltd. on 4 December 2018 for a licence to abstract 6,000,000 kilolitres per annum (i.e., 6.0 gigalitres per annum) of groundwater under section 5C of the *Rights in Water and Irrigation Act 1914* from the Canning-Kimberley, Canning-Grant aquifer. The project site 'Scrubby' is located on Napier Downs Station (NDS) approximately 80 km west of Derby where the current land use is pastoral cattle grazing for primary production. It does not fall within any specific management zone or area of special licensing rules in the proposed Fitzroy water allocation plan (WA Govt. 2020). The proposed purpose of the groundwater abstraction is to irrigate fodder crops via eight 40-hectare centre pivots with each pivot having a total water demand of 750 megalitres per annum to meet crop water requirements.

The contents of this report fully address the requirements of *Operational Policy no. 5.12 – Hydrogeological reporting associated with a groundwater licence* (DOW, 2009). The WA Department for Water and Environmental Regulation (DWER), representing the key regulatory agency assessing the water licence application, has stipulated this report must also address the additional requirements of *Interim Guidance – H2 & H3 Level of Assessment methodology for groundwater abstraction from groundwater resources within the Fitzroy water allocation plan area* (DWER, 5 April 2019). Specifically, to include chapters 5 (cultural values), 6 (environmental and social values), 7 (risk assessment) and 8 (referral to other agencies) herein, even though these are not explicitly defined in DOW (2009). Accordingly, the methodologies employed in this H3 hydrogeological assessment were carefully developed and refined through close consultation with DWER staff between February 2019 and August 2021, particularly the Regional Hydrogeologist North West Region.

1.1. Background

Innovative Groundwater Solutions Pty Ltd. (IGS) has been engaged by Australian Capital Equity Pty Ltd. (ACE) to explore groundwater and surface water development opportunities on Napier Downs Station and nearby pastoral leases since late 2018. Key steps in this process can be summarised as follows:

1. The first body of work explored groundwater opportunities and identified the regional Grant Group aquifer as being highly prospective (IGS, 2018a; Appendix A). This assessment was largely based on outcomes of the WA Government Water for Food initiative, which included results from drilling and testing of the Grant Group aquifer nearby, as well as a regional-scale Airborne Electromagnetic (AEM) geophysical survey (Brodie, 2016). Interpretation of the latter by IGS was instrumental in identifying 100-300-metre thick sequences of Grant Group extending across the south-western portion of Napier Downs Station (refer to Appendix A in particular Figure 3 and Appendix B therein). The Devonian reef limestones were also identified as potential groundwater targets; however, these were later discounted on the basis that they host significant cultural and environmental values.
2. The second body of work explored surface water opportunities in the form of rainfall, runoff and river flow (IGS, 2018b; Appendix B). For Napier Downs Station, the Lennard River and its tributaries in the Richenda River, Barker River and Hawkstone Creek offer

significant volumes of fresh surface water every wet season. However, high inter-annual variability in wet season rainfall means that river flow reliability is low, which, when coupled with the challenges of harvesting high flows and storage off-stream, means that actual opportunities are limited (IGS, 2019a; also included in Appendix B). Analysis of flood inundation mapping also revealed that areas where surface water may be most available did not correlate with areas of best soil type for irrigation (IGS, 2019b; also included in Appendix B).

3. The above studies led ACE to the decision to explore groundwater opportunities in further detail, focussing on the Grant Group aquifer at three potential sites: moving from east to west the 'Lennard', Hawkstone' and 'Scrubby' sites (Figure 1). Napier Corporation Pty Ltd. lodged an application on 4 December 2018 for a licence to abstract 6.0 gigalitres per annum from the Canning-Grant aquifer. The Lennard site was preferred on the basis that it had suitable soils, year-round access via the Gibb River Road and was close to existing infrastructure, albeit was adjacent the Lennard River and offered the smallest window of Grant Group aquifer of the three options. Exploratory drilling at the site in May 2019 resulted in confirmation that a productive zone of the Grant Group aquifer exists below 100 m depth and thus a permanent stock/monitoring bore was constructed (IGS, 2019c).
4. Following advice from DWER, a Preliminary groundwater Risk Assessment (PRA) report was prepared for the Lennard site (IGS, 2019d; Appendix C) detailing existing knowledge of the hydrogeology and identifying any risks of irrigation development to environmental and cultural values. This report was supported by a desktop environmental (biological) review of both the Lennard and Hawkstone sites (Phoenix, 2019). DWER's response to the PRA report (2 October 2019) requested clarification on a number of issues and outlined areas of further work required for the H3 hydrogeological assessment, most notably the need for studies to better understand groundwater dependent ecosystems (GDEs) associated with permanent pools in the Lennard River and riparian vegetation.
5. IGS conducted a run-of-river pool survey of the Lennard River on 13 November 2019, measuring radon-222 activities and field water quality parameters to determine the level of groundwater dependence (IGS, 2019e; Appendix D). The results indicated that pools adjacent the Lennard site had a high likelihood of groundwater input; thus, further work would be required to understand whether the pools were connected to the water table of the Grant Group aquifer or some shallower alluvial system. Radon results for one of two pools south of the Hawkstone site also indicated a high level of groundwater input. However, two pools sampled more than 10 km south of the Scrubby site revealed a low level of groundwater dependence.
6. A meeting between ACE, IGS and DWER on 19 December 2019 acknowledged the next step to progress the Lennard site was to install shallow monitoring bores adjacent the river to understand connectivity. ACE subsequently consulted with Warrwa traditional owners to request cultural heritage clearance to drill the monitoring bores and approval was granted in June 2020. Drilling of two shallow monitoring bores occurred in July 2020, followed by surveying of the bores and nearby river pools in August 2020. This work concluded the Lennard River is most likely connected to the regional water table in the Grant Group aquifer. Accordingly, all future plans for the Lennard site were discontinued and the focus changed to Hawkstone and Scrubby

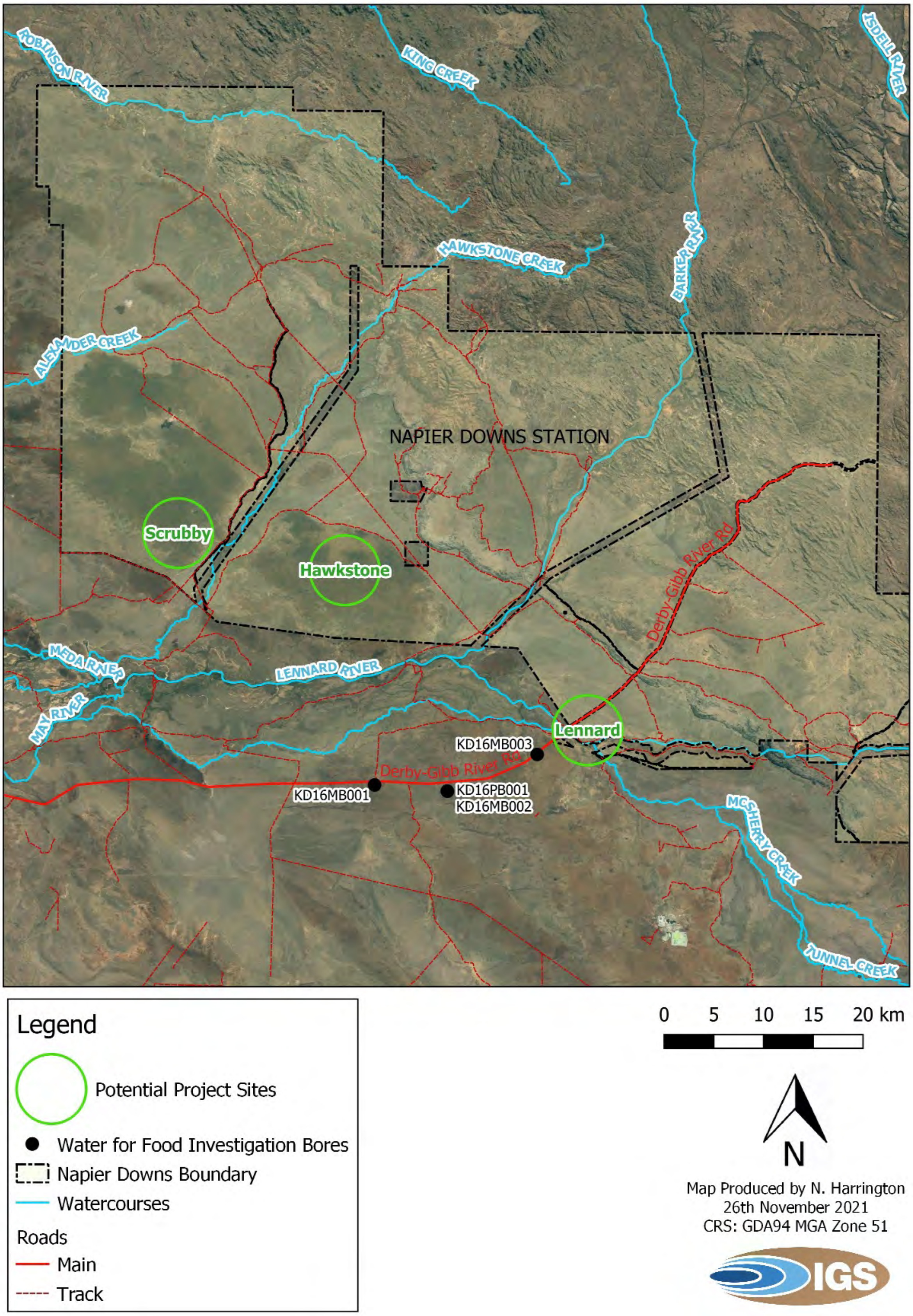


Figure 1. Location of potential irrigation project sites on Napier Downs Station relative to previous investigation bores drilled as part of the WA Government Water for Food initiative.

sites where there are considerably larger setback distances from Lennard River to avoid potential drawdown impacts to permanent pools.

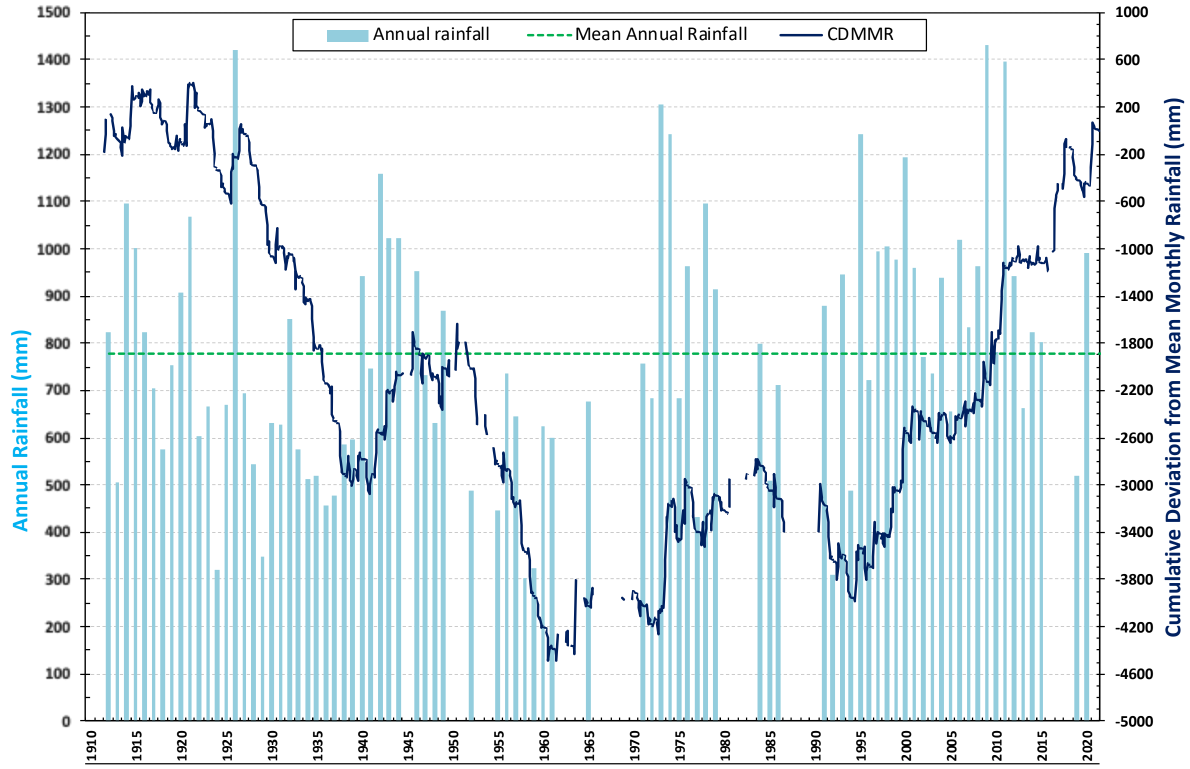
7. ACE then consulted with Warrwa and Wilinggin traditional owners to request cultural heritage clearance to drill and construct monitoring bores at Scrubby and Hawkstone sites; approvals were granted in August 2020. Drilling occurred in September 2020 with both sites confirming low-salinity Grant Group aquifer, however the Scrubby site produced far more favourable results in terms of airlift yield (>20 L/s cf. 5.5 L/s) and final depth to water (30.6 m below top of casing (TOC) cf. 61 m below TOC) compared to the Hawkstone site.

Hence, the Scrubby site was finally chosen as the preferred site for irrigation development in October 2020. Phoenix Environmental Sciences Pty Ltd. then expanded the search area of their original environmental desktop review (Phoenix, 2019) to include the Scrubby site and found no major constraints to development (Phoenix, 2020; further details provided in Chapter 6).

2. Climate

The climate and hydrology of the area is characterised by distinct wet and dry seasons. On average more than 90% of annual rainfall occurs during the wet season months of December through to April, which are followed by a long dry season of inconsequential rainfall events. Inter-annual variability in rainfall and runoff is extremely high. Across the region, mean annual potential evapotranspiration (APET) is more than 3,500 mm/yr. (BOM, 2021) and far exceeds mean annual rainfall of between 600 – 1200 mm/yr.

IGS (2018b) compiled historical records of rainfall for the Napier Downs BoM station (No.003019) and others nearby, as well as streamflow records for the Lennard River at Mount Joseph gauging station (see Appendix B). Updated rainfall data for Napier Downs and Derby Aero (No.003032) stations is provided below in Figure 2. Mean annual rainfall for the two stations (noting very different lengths of records) is 778 mm/yr. and 704 mm/yr., respectively. In both cases, however, the cumulative deviation from mean monthly rainfall trend is revealing generally above average rainfall since 1995.



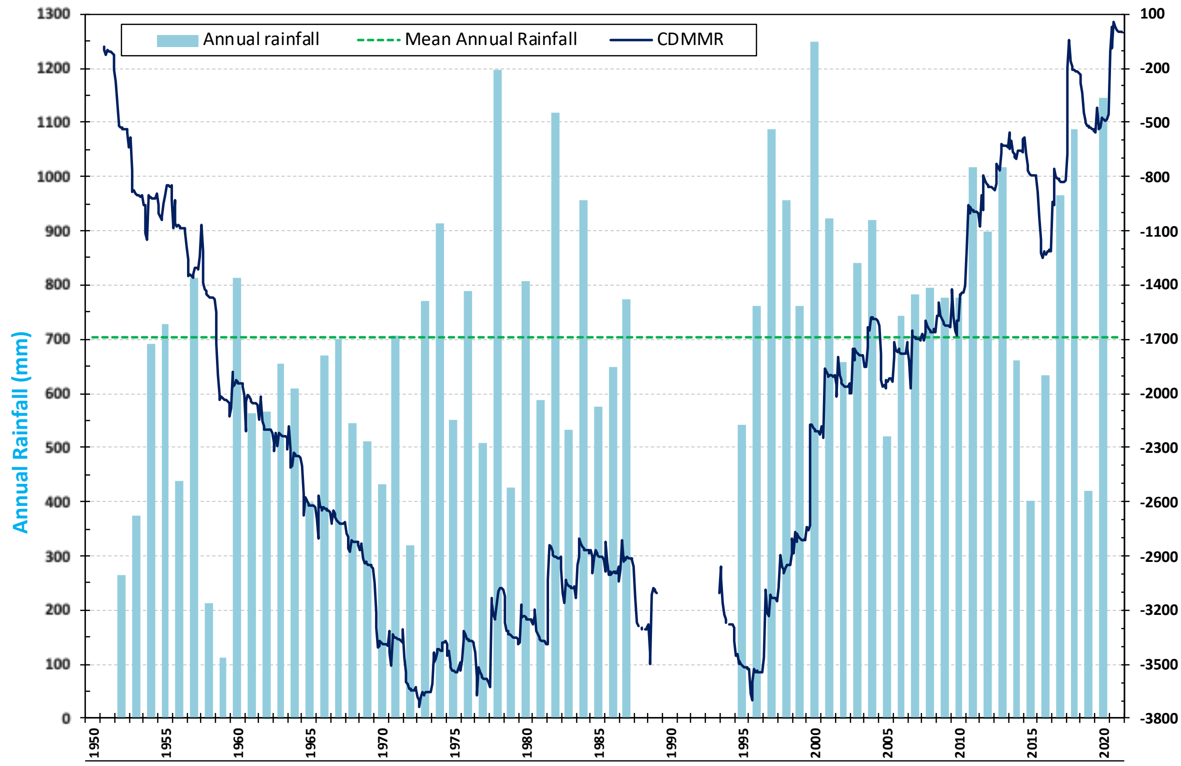


Figure 2. Historical rainfall data for Napier Downs (top) Derby Aero (bottom) BoM stations.

3. Hydrogeology

3.1. Regional Geology

The project site is situated on the Lennard Shelf at the northern margin of the Canning Basin, which forms a Palaeozoic sedimentary border between the Fitzroy Trough graben to the southwest and the Precambrian King Leopold Orogen to the northeast (Figure 3).

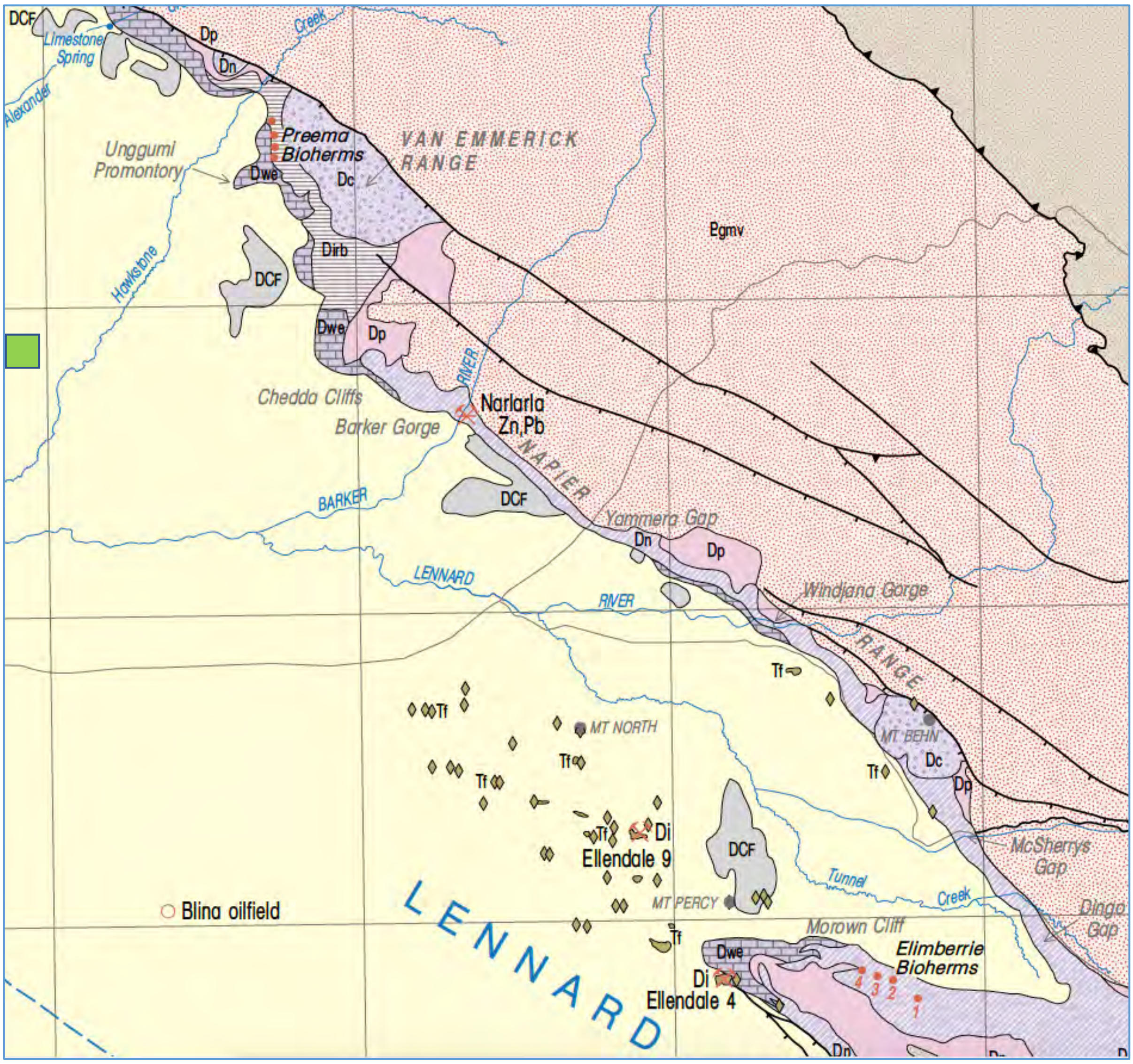


Figure 3. Screenshot taken from simplified geological map of Playford and Hocking (2006) as published in Playford et al. (2009, Plate 8). Key features include the Precambrian King Leopold Orogen to the northeast (Pgmv in speckled red); Devonian conglomerates, limestones, dolomites, siltstones and sandstones (Dc, Dp, Dn, Dwe in purple/pink shades); upper Devonian – lower Carboniferous Fairfield Group (DC_F in grey); and grouped lower Permian to Cenozoic sediments on the Lennard Shelf of the Canning Basin (cream shading). Diamonds represent the Tertiary Fitzroy Volcanics, while the green square signifies the approximate location and maximum extent of project area for reference purposes only. Overlying map grid is 25 km x 25 km.

The geology of the Fitzroy region has been distilled for contextual hydrogeological purposes on numerous occasions over the last ten years (e.g., see Harrington et al., 2011; Harrington and Harrington, 2015; Taylor et al., 2018) and therefore is only briefly summarised below for the stratigraphy most relevant to this H3 hydrogeological assessment. For further detailed descriptions, the reader is referred to the exemplary works of Mory (2010), Mory and Hocking (2011), and Backhouse and Mory (2020) and references therein. Figure 4 depicts the regional bedrock geology according to GSWA (2016) and shows progressively younger Devonian, Carboniferous, Permian and Triassic sediments outcropping towards the southwest.

3.1.1. Proterozoic Basement

The Precambrian basement comprises granitic, metamorphic and volcanic rocks of the King Leopold Orogen, which formed as a result of thrusts that produced west-northwest trending folds approximately 560 million years before present (Ma).

3.1.2. Devonian Reef Complexes

Sandstones and conglomerates of the Van Emerick Formation unconformably overlie the Precambrian basement rocks, which in turn are overlain by Devonian coral reefs, platforms and marginal slope deposits. The karstic Nullara Formation is exposed in the Napier Range 25 km north and east of the project site (Figure 3).

3.1.3. Upper Devonian – Lower Carboniferous Fairfield Group and Carboniferous Anderson Formation

The Fairfield Group comprises mixed carbonate and clastic sediments including the uppermost Laurel Formation, which is primarily mudstone with thin carbonate and sandstone beds. The overlying Anderson Formation comprises mostly sandstone with minor mudstone and limestone. These units directly underlie the aquifers of interest to this H3 hydrogeological assessment and are found in outcrop less than 15 km to the northeast of the project site (Figure 4).

3.1.4. Lower Permian Grant Group

Glaciation in the late Carboniferous to early Permian resulted in karstification and erosion of the Devonian limestone, followed by sedimentary deposition with maximum accumulation occurring in the Fitzroy Trough. The siliciclastic lower Permian Grant Group comprises the Betty, Winifred and Carolyn formations in ascending order. The Carolyn Formation primarily contains massive and cross-bedded sandstone, the Winifred Formation is mainly mudstone with minor fine-grained sandstone, and the Betty Formation is mostly sandstone with minor conglomerate and shale (Mory, 2010). Backhouse and Mory (2020) have recently argued for recognising the three formations based on their palynology as the Hoya, Calytrix and Clianthus floral units, rather than the ‘three ladies’. The underlying Carboniferous Reeves Formation and Anderson Formation, both of which are not always present, are often difficult to distinguish from the Grant Group without palynozonation.

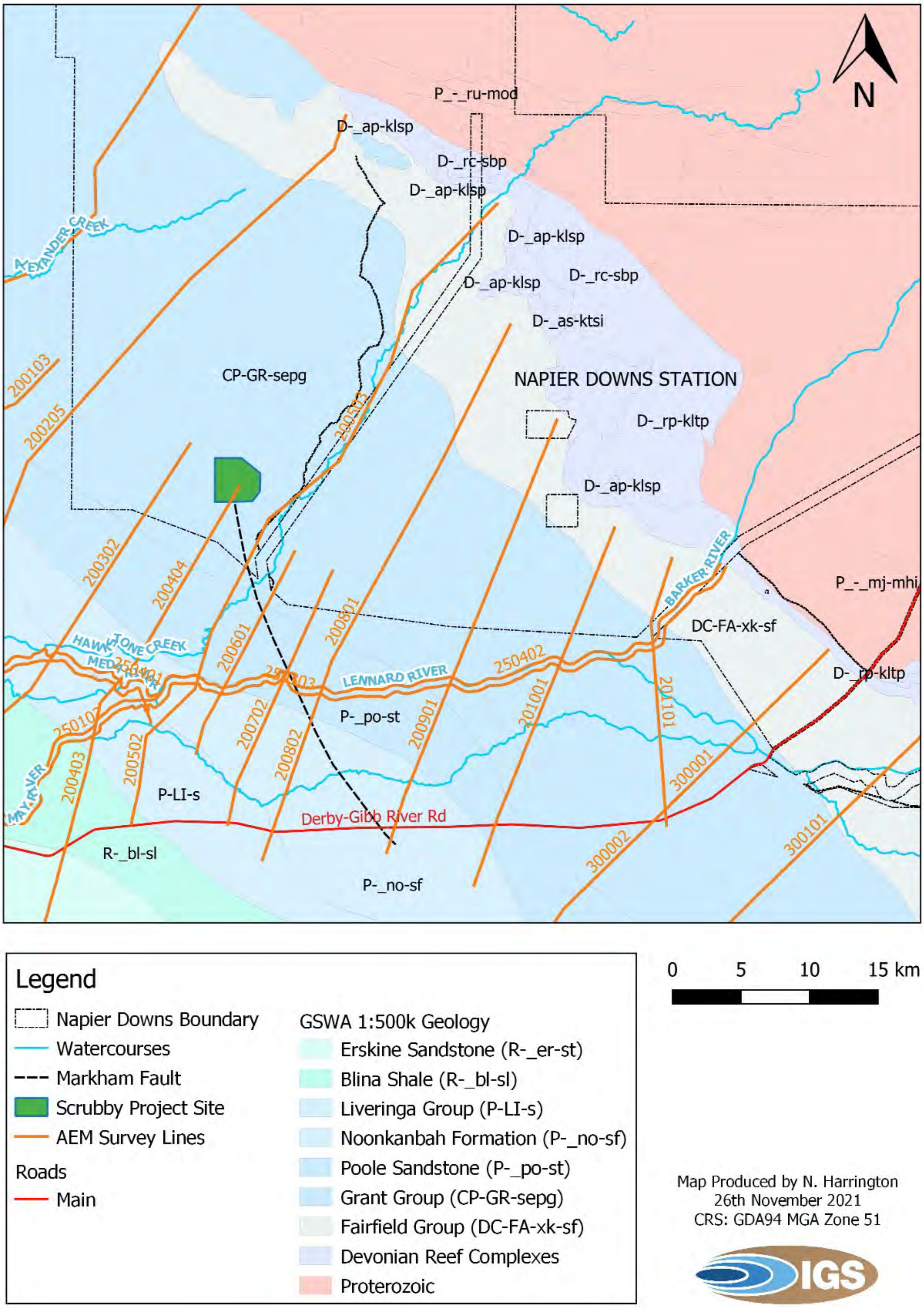


Figure 4. Regional bedrock geology map showing the main structural feature and AEM flight lines.

3.1.5. Lower Permian Poole Sandstone

The Poole Sandstone conformably overlies the Grant Group and is lithologically very similar. The basal Nura Nura Member forms a sandy carbonate unit, whilst the upper Tuckfield Member is mostly comprised of thinly bedded fine sandstone (Mory, 2010).

3.1.6. Middle Permian Noonkanbah Formation

The Noonkanbah Formation comprises predominantly siltstone and shale with minor sandy interbeds. Accordingly, it is important to the current study because it acts as a regional aquitard overlying the connected Grant Group/Poole Sandstone aquifer where the latter becomes confined south of the project site.

3.2. Local Geology

Exploration for minerals and petroleum in this region has been very active since the middle of last century, although records of such activity date back to the early 1900s. Accordingly, there is a wealth of data available in the form of seismic surveys, stratigraphic descriptions from drilling, downhole geophysical logs and palynological testing. It is beyond the scope of this report to provide a comprehensive review of all such data; instead, only the most local and relevant data for this H3 hydrogeological assessment is synthesised. Primary sources of information include geological mapping products from WA Department of Mines, Industry Regulation and Safety (https://www.dmirs.wa.gov.au/), the WAMEX (Western Australian Mineral EXploration) and WAPIMS (Western Australian Petroleum & Geothermal Information Management System) databases, and numerous references as cited herein.

The project site sits on a thin veneer of Quaternary sediments that is draped over Lower Permian Grant Group sandstone, the latter of which outcrops at nearby Hawkstone Peak (Figure 5) and becomes deeper and thicker towards the west and southwest as it enters the Fitzroy Trough. Downhole geophysical logs and palynology for petroleum exploration well Meda 1 (Figure 6), which was drilled approximately 28 km southwest of the project site (Figure 5) provides one of the best local depictions of stratigraphic relations to the Grant Group (Backhouse and Mory, 2020). Recall that moving southwards from the project site, the Poole Sandstone, then Noonkanbah Formation, then Liveringa Group form the shallow sub-cropping geology (Figure 4). The Grant Group was encountered at Meda 1 between 726 – 1281.4 m depth (i.e., a thickness of 555 m) and Figure 6 reveals the three distinct formations within the Grant Group.

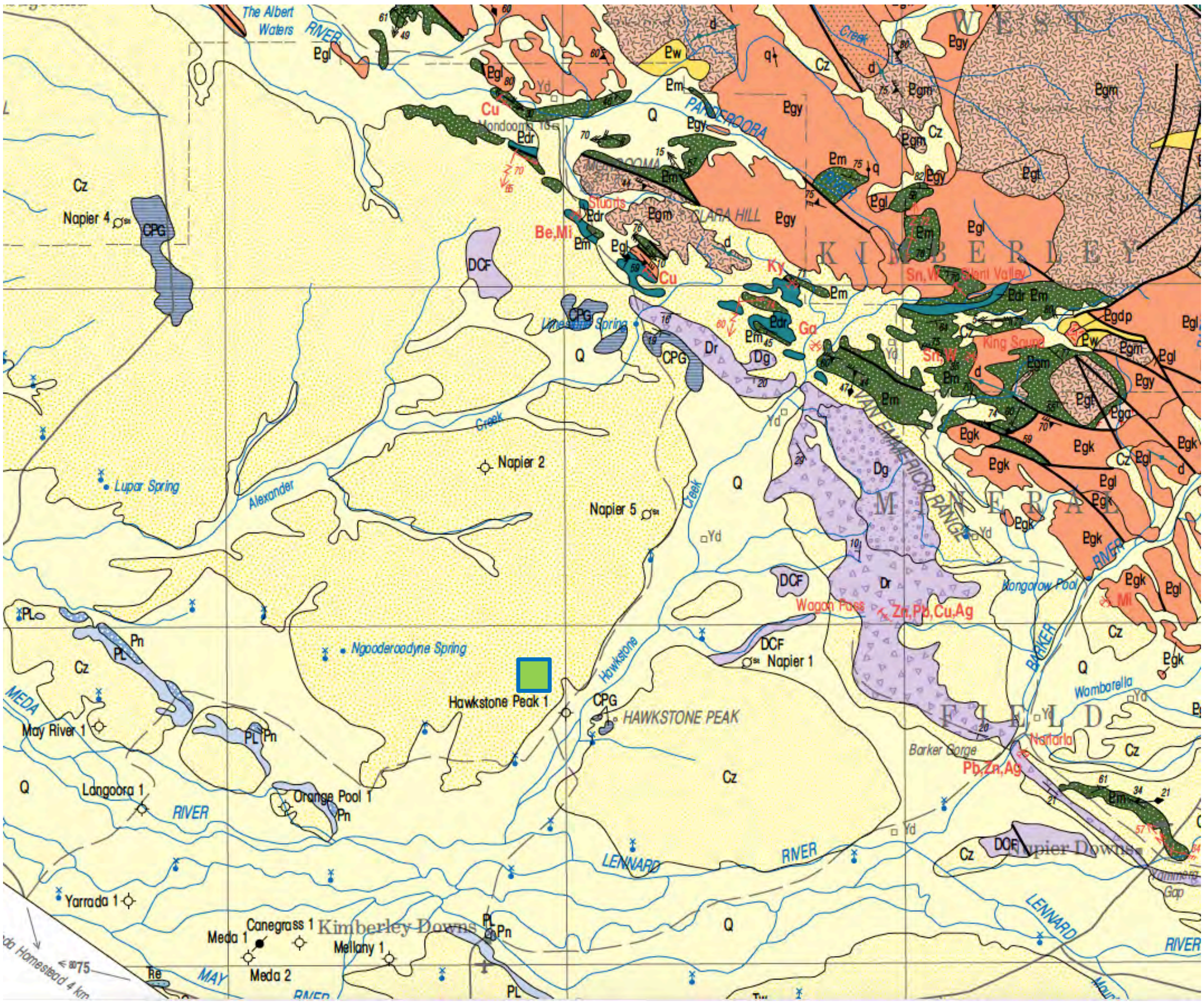


Figure 5. Screenshot taken from surface geology map by Griffin and Tyler (1995, Plate 1). Units labelled CP_G, P_n and P_L represent Grant Group, Noonkanbah Formation and Liveringa Group, respectively. Note different colours, symbology and labels for other geological units compared to Figure 3 and Figure 4. The green square signifies the approximate location and maximum extent of the project area for reference purposes only. Overlying map grid is 25 km x 25 km.

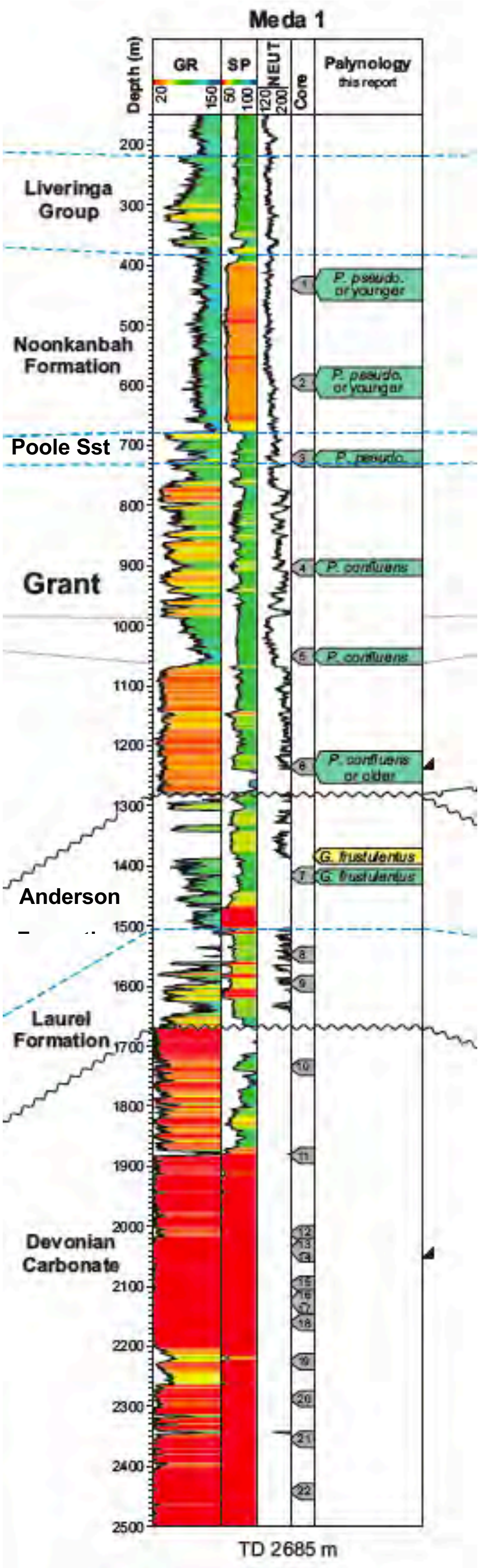


Figure 6. Geophysical and palynological logs for Meda-1 petroleum exploration well with stratigraphic interpretation (source: Backhouse and Mory, 2020).

Other petroleum wells located nearer the project site include Hawkstone Peak No.1 (Gardner, 1963) to the immediate southeast, Napier No.1 (Newstead, 1969) to the east, and Napier No.2 (Watt and Newstead, 1970) and Napier No.5 (Watt and Temple, 1971) to the north (Figure 5). A summary of their stratigraphic intersections has been compiled in Table 1 and clearly demonstrates the absence of Grant Group at a distance of approximately 14 km to the east (Napier No.1) and northeast (Napier No.5) of the project site; instead Anderson Formation or Fairfield Group is present at ground surface in these locations, despite the Grant Group being mapped as occurring here (Figure 4).

Table 1. Depths to formation tops and bottoms in petroleum wells, which have been converted from feet below Derrick Floor / Kelly Bushing in original well completion reports to metres below ground surface. Formation thicknesses in parentheses.

<table>
<tr><th></th><th>Hawkstone No.1</th><th>Napier No. 1</th><th>Napier No. 2</th><th>Napier No. 4</th><th>Napier No. 5</th></tr>
<tr><td>Quaternary Alluvium</td><td>0 – 12.5 m
(12.5 m)</td><td></td><td></td><td>0 – 11 m
(11 m)</td><td></td></tr>
<tr><td>Permian Grant Group</td><td>12.5 –
241.5 m
(229 m)</td><td></td><td>0 – 143 m
(143 m)</td><td>11 – 64.5 m
(53.5 m)</td><td>“Eroded Off”</td></tr>
<tr><td>Upper Carboniferous Anderson Formation</td><td></td><td>0 – 198.5 m
(198.5 m)</td><td></td><td></td><td rowspan="2">0 – 79 m
(79 m)</td></tr>
<tr><td>Lower Carboniferous Laurel Formation (upper Fairfield Group)</td><td>241.5 –
357 m
(115.5 m)</td><td></td><td rowspan="2">143 – 845 m
(702 m)</td><td>64.5 – 166 m
(101.5 m)</td></tr>
<tr><td>Upper Devonian Fairfield Group</td><td>357 – 588 m
(231 m)</td><td>198.5 –
829 m
(630.5 m)</td><td>166 –
295.5 m
(129.5 m)</td><td>79 – 458 m
(379 m)</td></tr>
<tr><td>Devonian Napier Formation and other reef / inter-reef / fore-reef deposits</td><td>588 –
1172.5 m
(584.5 m)</td><td>829 –
1769 m
(940 m)</td><td>845 –
1583.5 m
(738.5 m)</td><td>295.5 –
940.5 m
(645 m)</td><td>458 –
914.5 m
(456.5 m)</td></tr>
<tr><td>Middle Devonian Van Emerick Formation</td><td></td><td></td><td></td><td></td><td>914.5 –
1646 m
(731.5 m)</td></tr>
<tr><td>Precambrian basement</td><td>1172.5 –
1185 m</td><td>1769 –
1797 m</td><td>1583.5 –
1603 m</td><td>940.5 –
961.5 m</td><td>1646 –
1653.5 m</td></tr>
</table>

The cross-section displayed in Figure 7 shows this outcropping area of Fairfield Group to the east and progressive thickening of the overlying Grant Group towards the project site. Whilst not shown in the cross-section, exploration well Hawkstone Peak No.1 found Grant Group extending to 241.5 m below ground (Table 1), which is very similar to the depth indicated at point ‘C’ on the western end of the cross-section (Figure 7). This depth is approximately 50 m greater than the 189 m recorded by BHP (Dendle, 1985) for mineral exploration well TBD-1, which was drilled approximately 3 km directly east on the opposite side of Hawkstone Creek, again demonstrating a trend of Grant Group thickening westward. Similar trends are observed in AEM conductivity depth sections, including those presented in Appendix A (see Figure 3 and Appendix B therein). For reference, well TBD-1 also encountered calcareous siltstones, mudstones, minor limestone and sandstone of the Fairfield Formation to 359.5 m depth below the Grant Group.

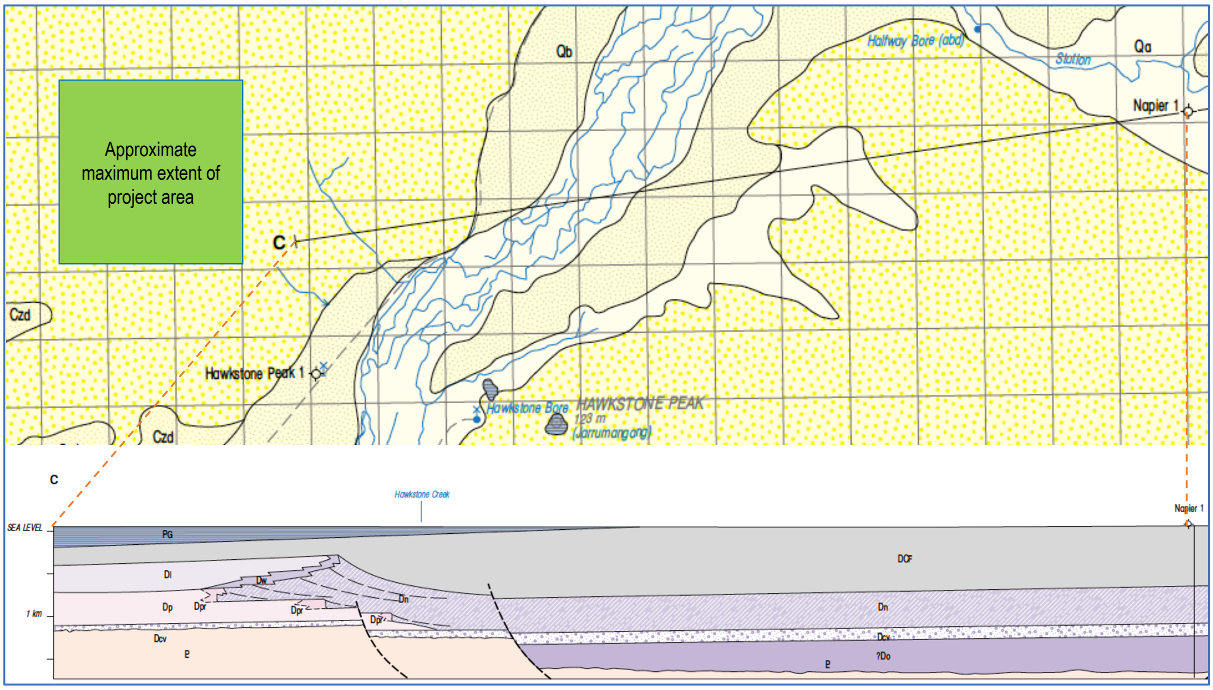


Figure 7. Compilation of two screenshots taken from the Napier Range Area map of Hocking & Playford (1998) as published in Playford et al. (2009, Plate 1). Key features include the laterally extensive upper Devonian – lower Carboniferous Fairfield Group (DC_F in grey) that outcrops to the east; and the overlying and thickening westward Grant Group (P_G in blue). The green square signifies the approximate location and maximum extent of the project area for reference purposes only. Overlying map grid is 1 km x 1 km.

Despite the limited extent of the Grant Group to the northeast and east of the project site, petroleum exploration well Napier No.2 drilled approximately 15 km to the north-northwest (Figure 5) encountered a friable to unconsolidated, very massive sand unit correlated to the Grant Formation immediately below a thin laterite crust (Watt and Newstead, 1970). Likewise, exploration well Napier No.4 (Temple, 1970) drilled approximately 44 km to the northwest (Figure 5) encountered Grant Group at shallow depth (Table 1). That particular observation is consistent with the results of nearby exploration drilling for Devonian carbonate-hosted Pb-Zn-Ag deposits in the early 1980s. Western Mining Company found what they interpreted to be Permian sandstone sequences in the north around Limestone Spring (WMC, 1983), and later in the west and northwest at Lupar Spring and Albert Waters, respectively (WMC, 1985) – refer to Figure 5 for locations of these three hydrological features.

The only structural feature of note in the immediate vicinity of the project area is the Markham Fault, the location of which has been digitalised from the original source map (Towner, 1980) and reproduced in Figure 4. IGS was unaware of its existence until a detailed review of the local geology was undertaken for the numerical model presented in Chapter 10. Hence, it was completely accidental that the Scrubby site is located precisely at the northern tip of the fault.

It is currently unknown whether the Markham Fault was active since the early Permian, and thus has potential to impact groundwater flow in the Grant Group, or instead if its vertical extent is limited to older strata. Regardless, it is a large dilatational fault that interrupts a major magnetic anomaly, which is very similar to the structural setting of the Ellendale diamond field (Haren, 2007). The magnetic structure is clearly visible (pink shading) at depth on the right hand (i.e. northern) side of AEM conductivity-depth sections 200502 and 200601 (Figure 8). However, the fault is perhaps only visible in the latter as a thin, sub-vertical, more conductive (green coloured) trace through the surrounding low conductivity (blue coloured) Grant Group.

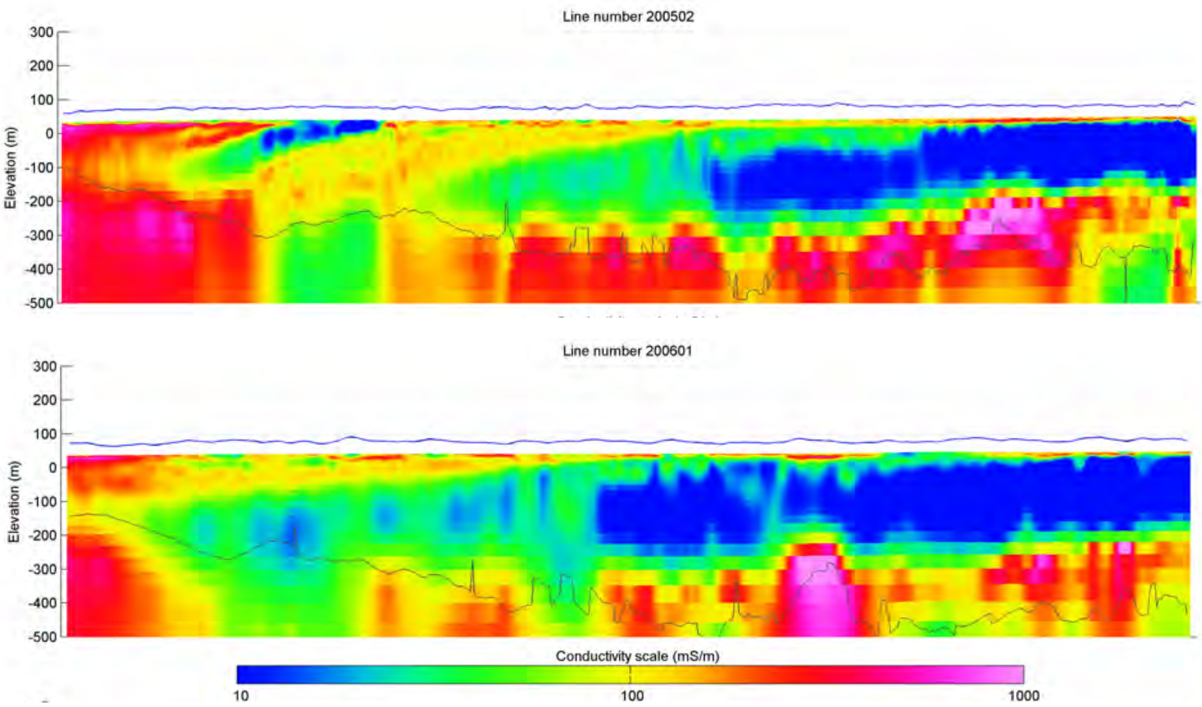


Figure 8. Selected AEM conductivity-depth sections (source: Brodie, 2016). Refer to Figure 4 for locations of survey lines and position of Markham Fault.

3.3. Hydrogeology of the Grant Group/Poole Sandstone Aquifer

3.3.1. Aquifer Extent

The lithological similarities of the uppermost Grant Group and overlying Poole Sandstone (e.g., see Figure 6), combined with the variable extent of the basal sandy carbonate unit in the latter, means the two formations are regularly considered as one connected aquifer system (Taylor et al. 2018). Both units extend in outcrop (or shallow sub-crop) many tens of kilometres to the northwest and southeast of the project area (Figure 4). Their greatest extent, however, is south-westward into the Fitzroy Trough and beyond, ultimately outcropping offshore in the Indian Ocean.

The focus area for this H3 hydrogeological assessment, and therefore the groundwater model domain presented in Chapter 10, was a very small part the regional aquifer system that has been defined as follows (Figure 9):

- the north-eastern limit of the mapped extent of Grant Group (Figure 4) with a slight modification to reflect the absence of this formation in petroleum exploration wells Napier No.1 and Napier No.5. The revised extent was delineated using aerial imagery and the Hydrologically Enforced 1" SRTM Digital Elevation Model of Wilson et al. (2011);
- sufficiently far enough to the northwest and northeast of the project area to ensure no significant drawdown impacts caused by long-term pumping at Scrubby site are observed beyond these boundaries; and
- the boundary of Noonkanbah Formation outcrop to southwest, acknowledging the aquifer system becomes confined beyond this boundary.

Note that further details surrounding how these four boundaries were implemented in the numerical groundwater flow model are provided in Chapter 10.

The bottom elevation of the aquifer system has been contoured using stratigraphic picks from nearby petroleum exploration wells (Table 1). However, in order to constrain this contouring south of the project area it was necessary to interrogate stratigraphic logs for petroleum wells Orange Pool No.1 (Townsend, 1981), May River No.1 (Johnson and Brownhill, 1967) and Langoora No.1 (Gardner, 1963), where both the Liveringa Group and Noonkanbah Formation overlie the confined portion of the aquifer.

3.3.2. Aquifer Hydraulic Properties

Following a literature review for the Lower Fitzroy region, Harrington and Harrington (2015) reported historical estimates of aquifer hydraulic conductivity (K) for the Grant Group that range from 1.2 – 20 m/day at Ellendale Mine, 0.08 – 4 m/day at various locations explored by Buru Energy, and less than 25 m/day at Fitzroy Crossing. Likewise, previous K estimates for the Poole Sandstone range from 0.14 – 3 m/day. No literature values were available for aquifer storage coefficient.

The Kimberley Downs trial production bore KD16PB001 installed as part of the Water for Food initiative (Figure 1) was subject to test pumping by Resources Water Group with the aid of adjacent monitoring bore KD16MB002 (DWER, 2017). Step drawdown tests were conducted

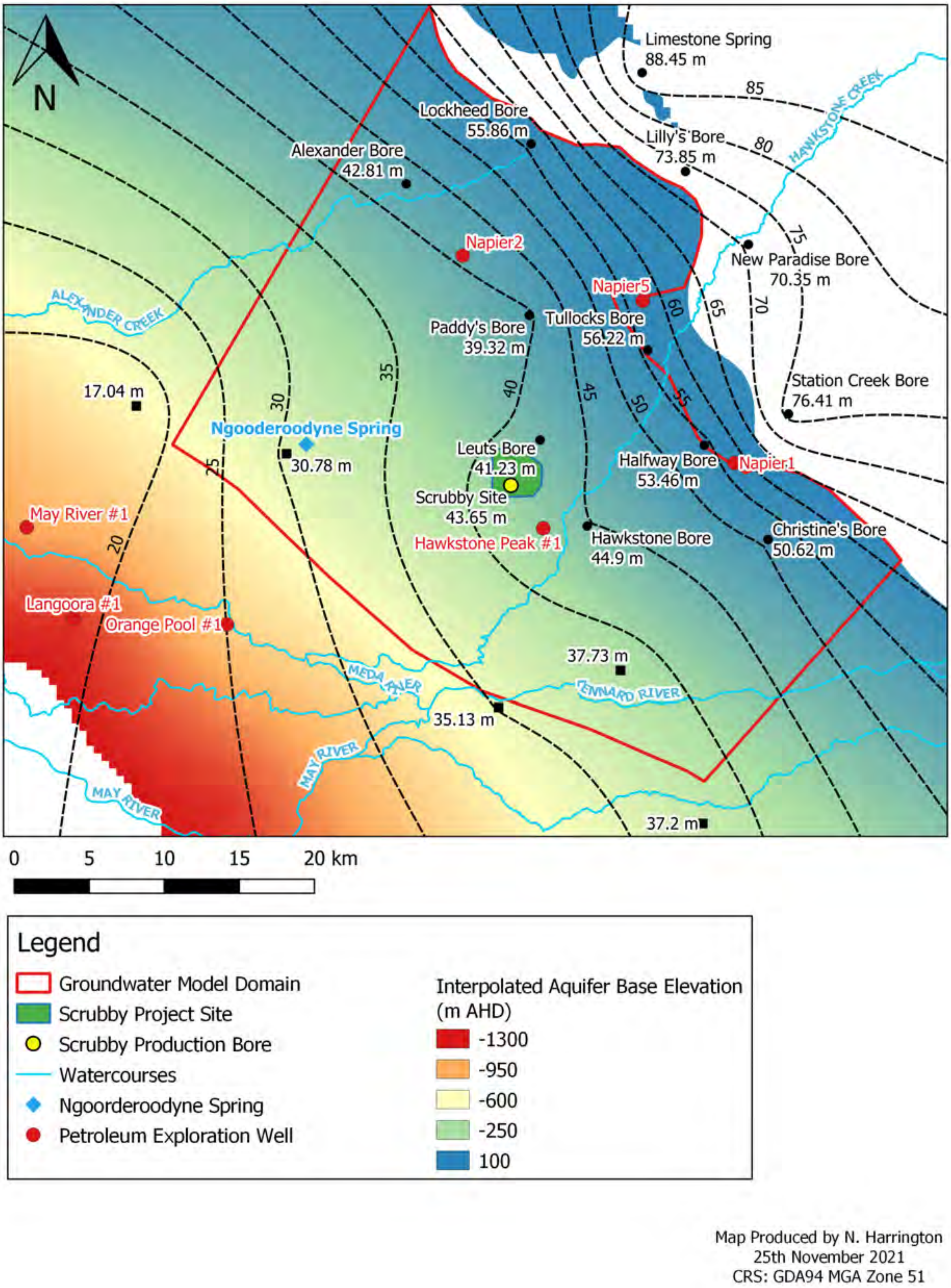


Figure 9. Hydrogeology map showing combined Grant Group/Poole Sandstone aquifer extent, interpolated aquifer base elevations and potentiometric groundwater levels.

at between 5 – 25 L/s for a maximum drawdown of 47.55 m. A 48-hour constant rate test was performed at 20 L/s, resulting in a maximum drawdown of 38.82 m. Note that this magnitude of drawdown is considerable given the relatively low pumping rates, suggesting this part of the aquifer is very poor from the perspective of irrigation development potential. The Grant Group aquifer is confined in this location and, as a result, aquifer parameters were estimated as K between 0.78 and 1.37 m/day, and S between 0.00001 and 0.0002.

3.3.3. Recharge and Discharge

The most comprehensive investigation into groundwater recharge for the Grant Group and Poole Sandstone was the CSIRO Northern Australia Water Resource Assessment (Taylor et al., 2018). Recharge to both systems occurs via diffuse rainfall infiltration and localised infiltration from losing rivers and creeks where the aquifers exist in outcrop and shallow sub-crop. Regional estimates of mean annual recharge rate for the Grant Group ranged from approximately 40 – 100 mm/yr. based on a water balance and upscaled steady-state chloride mass balance (CMB) method. Likewise, regional estimates for the Poole Sandstone range from 20 – 35 mm/yr. Point estimates of recharge rate for Kimberley Downs Water for Food bores (Figure 1) range from 14.5 – 19.5 mm/yr. using the CMB method.

The actual rate of diffuse rainfall recharge within the project area is expected to be controlled primarily by soil type. Two broad soil types have been mapped in the area (Figure 10): sandy pindan soils of the Wanganut, Camelgooda, Yeeda and Sisters systems; and cracking clays of the Duffer, Gogo, Fossil2, Djada and Alexander systems (DPIRD, 2018). As shown in Figure 10, the study area for this H3 hydrogeological assessment is dominated by sandy pindan soils, with relatively small areas of cracking clays occurring on floodplains. Recharge is known to be limited in areas of northern Australia where cracking clay ‘vertosol’ soils exist (Crosbie et al., 2019) and therefore rainfall recharge is expected to occur predominantly in the areas covered with sandy pindan soils.

The primary groundwater discharge mechanisms for the Grant Group and Poole Sandstone aquifers within the study area / model domain (Figure 9) are evapotranspiration and baseflow to ephemeral rivers, both of which are restricted to areas of shallow water table. As discussed in Section 1.1, a run-of-river survey of the Lennard River found that two pools sampled more than 10 km south of the Scrubby site revealed a low level of groundwater dependence (IGS, 2019e; Appendix D). Importantly, these sites overlie Noonkanbah Formation (Figure 4) and thus are completely disconnected from the Grant Group/Poole Sandstone aquifer.

At the regional scale, discharge from confined portions of this aquifer system occurs via upward leakage to overlying strata, as well as via distinct preferential pathways (i.e., geologic faults) to the Fitzroy River (Harrington et al., 2011).

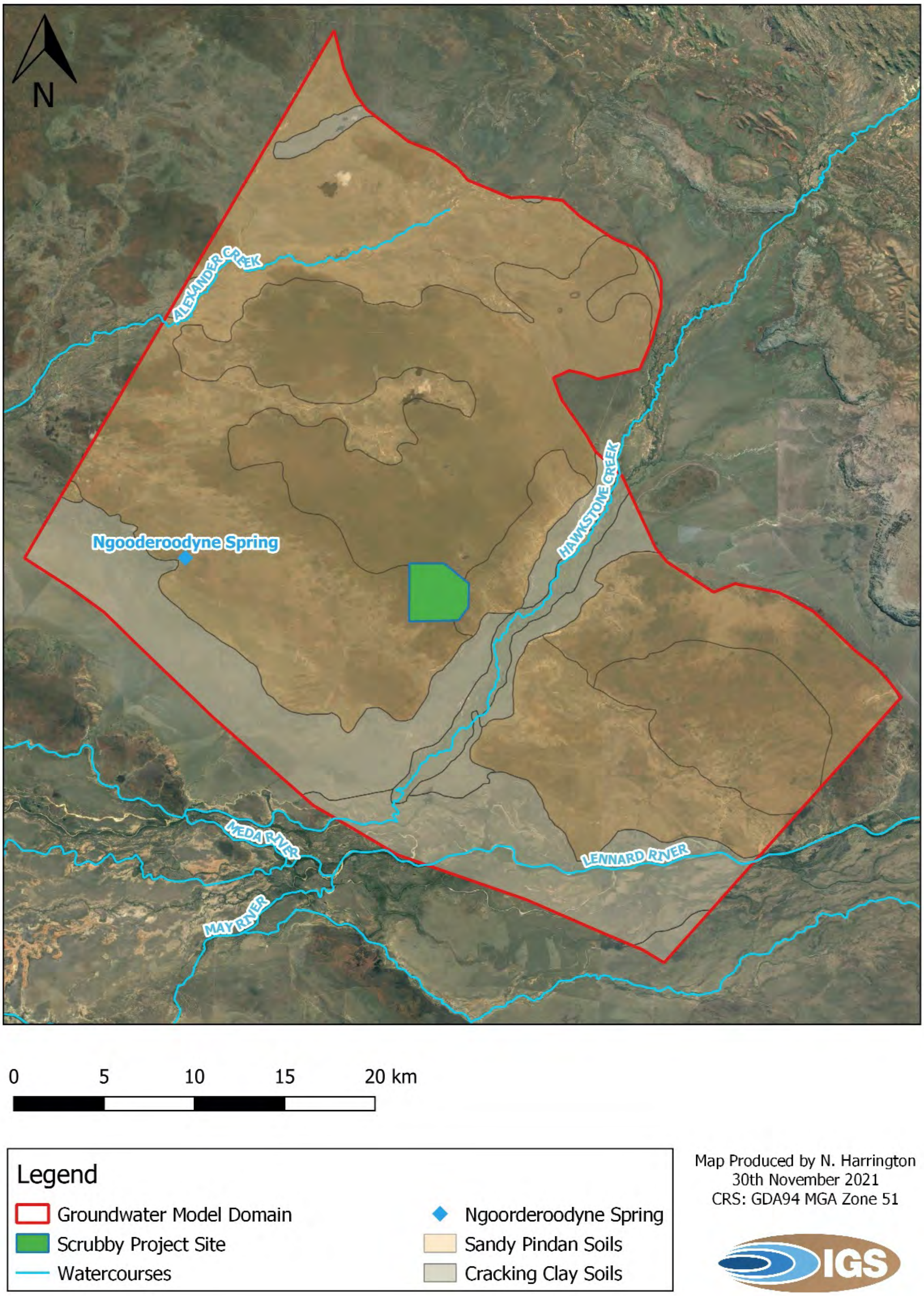


Figure 10. Map showing distributions of sandy pindan and cracking clay soils across the project area based on the dataset provided by DPIRD (2018).

3.3.4. Groundwater Levels and Flow

Given the nearby outcrop and otherwise shallow sub-crop of the Grant Group around the project site, unconfined aquifer conditions generally prevail. However, Sheffield Resources Limited (2016) reports that two bores drilled near the contact between the Grant Group and Poole Sandstone, approximately 2.5 km south and 7.5 km west-northwest of Ngooderoodyne Spring, were artesian. Three other bores in the Grant Group further to the northwest exhibited confined, sub-artesian conditions with water levels rising after drilling.

IGS undertook a regional bore audit on 17-18 September 2021 to collect as many groundwater levels around the project site as possible (Table 2). Field water quality parameters were also measured where existing infrastructure permitted (Table 3). At the time of conducting the audit, drilling of the test production bore at the Scrubby site was still ongoing (Section 9.1) and thus values reported for this bore in Table 2 were provided at a later date on 21 October 2021 by the pumping test contractor (Section 9.2).

All measured depths to standing water level have been converted to elevations relative to Australian Height Datum to create the potentiometric surface shown in Figure 9. Historical water levels from several bores in the DWER WIN database were also included to enable extrapolation of the potentiometric surface beyond the immediate project area and the boundary of Napier Downs Station where it was not possible to obtain permission for bore access (Table 4). The conversion of measured and historical depths to water level into relative elevations was achieved using ground elevations from the Hydrologically Enforced 1” SRTM Digital Elevation Model of Wilson et al. (2011), recognising this introduces a source of potential error in the mapped contours. Regardless, the resulting potentiometric surface indicates a general groundwater flow direction from east-northeast to west-northwest (Figure 9). At the time of preparing this map it was unclear what was the significance and cause of the apparent deviation of flow direction north of the Scrubby project site, however these became more obvious during the groundwater modelling (see Chapter 10).

The only time series groundwater level monitoring data for the Grant Group anywhere near the project site is from the bores drilled at Kimberley Downs (Figure 1) as part of the WA Government’s Water for Food initiative (DWER, 2017). Monitoring bores KD16MB001 and KD16MB002 were drilled through both Poole Sandstone and Grant Group, although only screened in the latter, while monitoring bore KD16MB003 was drilled and constructed just in the Grant Group. All available data for KD16MB002 and KD16MB003 are plotted below in Figure 11 and show a steady rise in water levels over the two years of record, most likely reflecting above average wet seasons of 2016/17 and 2017/18 (Figure 2).

Table 2. Groundwater levels recorded during the regional bore audit, 17-18 September 2021.

Site	Easting	Northing	Ground Elevation derived from 1" SRTM DEM (m AHD)	SWL (m below TOC)	TOC (m above ground level)	RSWL (mAHD)	Likely Pumping Influence	Comments
Leut's Bore	649388	8098591	75.5	34.77	0.50	41.23	Y	Tank overflowing
Paddy's Bore	648663	8106896	92.92	54*	0.4	39.32	?	Bore not accessible so SWL from station records
Tullocks Bore	656563	8104583	65.24	9.24	0.22	56.22	Y	Solar bore not accessible so SWL from old mill, tank overflowing, large pond to east
Christine's Bore	664569	8091957	111.92	61.83	0.53	50.62	N	2020 monitoring bore, 'Hawkstone' site
Halfway Bore	660324	8098245	67.35	14.05	0.16	53.46	N	Three bores within 8m of each other, SWL from central 4" PVC, two others blocked
Hawkstone Bore	652523	8092861	53.7	9.95	1.15	44.90	N	Mill bore '10-8-65' blocked at 8 m, SWL from 8" steel cased bore approx. 1m away
New Paradise Bore	663260	8111617	77.7	7.70	0.35	70.35	N	Likely to have been pumped recently
Lilly's Bore	659070	8116482	86.7	13.08	0.23	73.85	Y	Tank overflowing, large pond to north
Lockheed Bore	648793	8118325	61.26	5.77	0.37	55.86	N	Two PVC bores, no pump installed
Alexander Bore	640476	8115657	49.81	7.45	0.45	42.81	N	Tank full so WQ from open tank
Station Creek Bore	665936	8100330	80.67	4.66	0.4	76.41	N	Not equipped
Limestone Spring	656182	8123068	88.45	0	NA	88.45	NA	Long pool approx. 1.5m deep, white surface scum
Scrubby site	647446	8095575	72.8	29.9*	0.75	43.65	N	Recorded by pumping test crew 21/10/2021

Table 3. Field water quality measurements made during the regional bore audit, 17-18 September 2021.

Site	SPC * (µS/cm)	T (°C)	pH	Comments
Leut's Bore	59.3	31.2	7.80	Water quality from tank overflow pipe
Paddy's Bore	266.7	30.1	-	Water quality from open tank
Tullocks Bore	560	33.0	7.67	Water quality from tank overflow pipe, note large pond to east
New Paradise Bore	654	32.0	8.21	Water quality from covered tank
Lilly's Bore	1060	32.4	8.24	Water quality from covered tank, note large pond to north
Lockheed Bore	135	32.2	8.98	Two PVC bores, no pump installed but tank 3/4 full so water quality from open tank, supplied by bore further away
Alexander Bore	538	33.0	8.5	Tank full so WQ from open tank
Limestone Spring	441	24.7	8.98	Long pool approx. 1.5 m deep, white surface scum

*SPC is Specific Electrical Conductance, which is EC corrected to 25°C

Table 4. WIN bores used in development of the regional potentiometric surface. Water level measurement dates are unknown.

Site	Easting	Northing	Ground Elevation derived from 1" SRTM DEM (m AHD)	SWL (m below ground elevation)	RSWL (m AHD)
Brandy's Bore (sub artesian)	622495	8100859	21.00	3.96	17.04
Macs Corner Bore or Arthurs's Camp	660226	8073078	53.00	15.8	37.2
The Dip	646624	8080801	44.23	9.10	35.13
Charles Bore	632501	8097682	40.54	9.76	30.78
Travellers Bore	654742	8083243	49.92	12.19	37.73

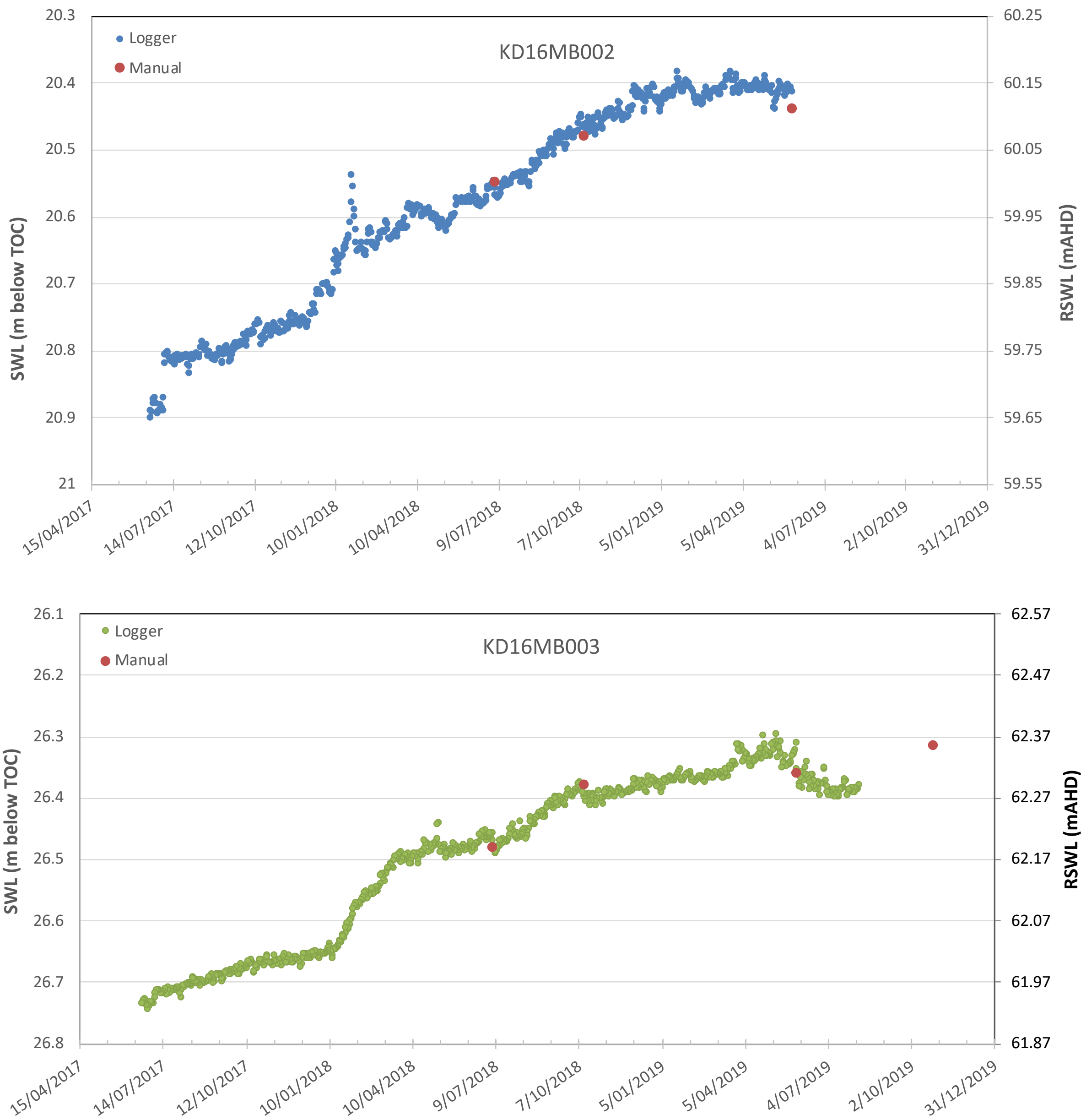


Figure 11. Time series groundwater level data for the Grant Group from Kimberley Downs bores.

4. Existing and Future Groundwater Use

At the time of preparing this H3 hydrogeological assessment report the total volume of groundwater allocated from the Grant Group aquifer in the Canning-Kimberley Groundwater Area was 1,175,875 kL/yr. (i.e., approximately 1.2 GL/yr.) (DWER, 2021). This volume is spread across 23 licences with the largest allocations held by Gibb River Diamonds Limited (0.36 GL/yr. issued across two licences on 19 May 2019) and Water Corporation (0.3 GL/yr. on one licence for Fitzroy Crossing town water supply). In other words, more than 50% of the total allocated volume is associated with two licensees. The nearest licenced allocations to the Scrubby site are held by Buru Energy Limited (0.010 GL/yr.) and West Kimberley Diamonds Pty Ltd. (0.015 GL/yr.), both of which are more than 20 km south of the site.

Unlicensed use from the Grant Group aquifer in the local area is solely for the purpose of stock water supply, including the bores captured in the regional bore audit (Section 3.3.4) and those on neighbouring stations. The nearest Aboriginal community of Windjingare is located more than 23 km east of Scrubby site and has been completely uninhabited for many years (pers. comm. Manager, Napier Downs Station, September 2021). In any case, the community overlies Devonian reef and thus any local groundwater supply – if one ever existed – is almost certainly disconnected from the Grant Group aquifer to the south.

The current allocation limit for the Grant Group is 100 GL/yr. (DOW, 2014) which means the resource is significantly under-allocated and there is potential for future increases in allocation and use.

5. Cultural values

ACE has routinely queried the Aboriginal Heritage Inquiry System and found no registered sites at any of the potential irrigation areas. The nearest registered site is Hawkstone Peak, which is approximately six kilometres southeast of Scrubby.

More importantly, ACE has embraced the opportunity for meaningful engagement with both Warrwa (Lennard site and Scrubby site) and Wilinggin (Hawkstone site) traditional owners throughout the course of exploratory studies to identify the most suitable site for this irrigation development. The methods of engagement have included written correspondence, telephone conversations, coordinated site visits on country, and helicopter reconnaissance flights over prospective areas. Written permission has been sought for all drilling programs including the latest test production bore at Scrubby site.

ACE understands from recent correspondence with Warrwa that a full heritage survey of the Scrubby site will be required once the H3 hydrogeological assessment has demonstrated sufficient groundwater availability for the project and that groundwater drawdown impacts, particularly to the Lennard River pools, can be managed sustainably.

6. Environmental and Social Values

6.1. First Pass Environmental Scan Identifying the Values

Phoenix Environmental Sciences Pty Ltd. undertook detailed environmental desktop assessments on the three proposed irrigation locations: 'Lennard', 'Hawkstone' and 'Scrubby' (Phoenix 2019, Phoenix 2020). The assessments included identification of potential environmental values with reference to current Environmental Protection Authority (EPA) guidance, an assessment of potential constraints based on the outcomes of the above, mapping of key assets, and recommendations for further field survey requirements.

Within the footprint for the proposed Scrubby project area the key findings were:

- the project area does not intersect any of the specific features described in the West Kimberly National Heritage Place;
- the project area is not located in a Wild River catchment;
- the project area is not situated within any conservation reserves or Environmentally Sensitive Areas (ESAs);
- there are no Ramsar or other significant or perennial wetlands within the project area;
- there are no public drinking water source areas near the project area;
- the project area does not contain mapped rivers or drainage lines;
- the Fitzroy Sandplain vegetation association covers the extent of the project area;
- there are no groundwater dependent Priority Ecological Communities (TEC / PEC) within the project area;
- there is the possibility of several significant flora species being located in the project area; and
- there is the potential for stygofauna to be present in the project area.

Regionally, the following findings were of note:

- the Indigenous Protected Area, Wilinggin is located 3 km to the east of the project area;
- several groundwater springs are located outside the project area, the closest being Ngooderoodyne Spring located approximately 13 km to the west;
- the nearest surface water drainage lines are located east of the project area and drain into Hawkstone Creek, located approximately 5 km to the east, and the Lennard River, located approximately 13 km to the south of the project area;
- the closest potentially groundwater dependent PEC is the Kimberley Vegetation Association 759 (Priority 3), which is associated with the riparian zones of Hawkstone Creek and Lennard River, with the buffer zone approximately 1 km to the east of the project area;
- additional potentially groundwater dependent PECs include the Napier Range Cave invertebrate communities (Priority 1) located 51.6 km east and the Napier Range monsoon vine thickets (Priority 1) located 21.7 km east; and
- several terrestrial fauna and flora species of conservation significance may be associated with the riparian and floodplain ecosystems of Hawkstone Creek to the east of the project area.

Field investigations were undertaken by IGS in 2019 to assess the potential for groundwater connectivity to the Lennard River (IGS 2019; Appendix D). A run-of-river survey of every remaining pool along the Lennard River was conducted on 13 November 2019, focusing on the reach between the Lennard site adjacent the Gibb River Road and the downstream Hawkstone and Scrubby sites. Sampled pools adjacent the Lennard site revealed a strong contribution of groundwater input, which was later corroborated through surveying and water level monitoring. The two sampled pools nearest the Scrubby site were found to have a low likelihood of groundwater dependence. Given these two pools overlie Noonkanbah Formation and the significant distance of the Scrubby site from the river, it was concluded that any groundwater pumping from the regional aquifer at Scrubby would not detrimentally impact the river and its permanent pools.

Visual analysis of timeseries imagery (Sentinel and Google Earth satellite imagery) was also undertaken to detect any additional surface water assets near the proposed Scrubby project area that may be groundwater dependent. Several sites of interest were identified as containing surface water during the wet season but were observed to dry out during every dry season suggesting they are not groundwater fed.

6.2. Environmental Impact Assessment

Mapping of assets and a review of the findings from the Phoenix Environmental Sciences desktop biological assessment identified the riparian flora and fauna of Hawkstone Creek to the east of the project area as potential groundwater dependent values that may be impacted by the proposed abstraction of groundwater. Additionally, Ngooderoodyne Spring to the west, and Limestone Spring to the north, were also identified as nearby groundwater dependent values (Figure 12).

6.2.1. Hawkstone Creek

Hawkstone Creek is an ephemeral (i.e., non-perennial) watercourse that drains the Van Emerick Range and Napier Range to the northeast and flows southwest towards the Meda River (Figure 12). It has a braided channel and a floodplain that ranges in width from three to four kilometres near the proposed project site. The taller riparian vegetation generally follows the braided channels whereas the floodplain is dominated by seasonal grasses over cracking clay soils. The depth to groundwater just to the east of the creek was observed to be less than 15 mbgl (Hawkstone Bore, Table 2) however there were no permanent pools identified along the creek line in the vicinity of the project area during recent ground-based and helicopter reconnaissance surveys.

Given the potential for riparian and floodplain habitat to host significant flora or fauna species, identified under both Commonwealth and Western Australian legislation, a value ranking of ‘1’ may be assigned. However, Hawkstone Creek and its associated flora and fauna are unlikely to be highly groundwater dependent – this will need to be confirmed by Phoenix Environmental Sciences following completion of their seasonal flora and significant fauna surveys.

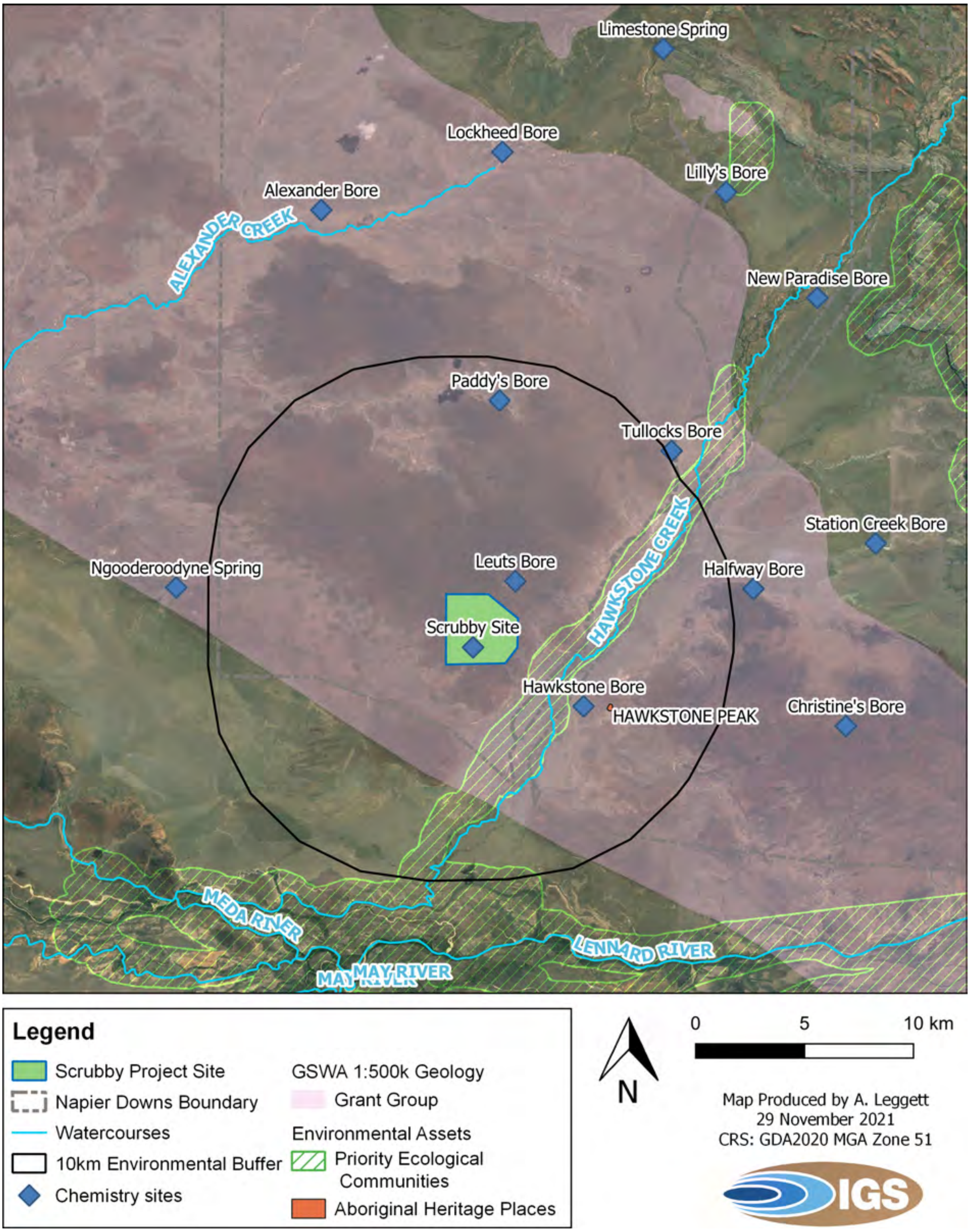
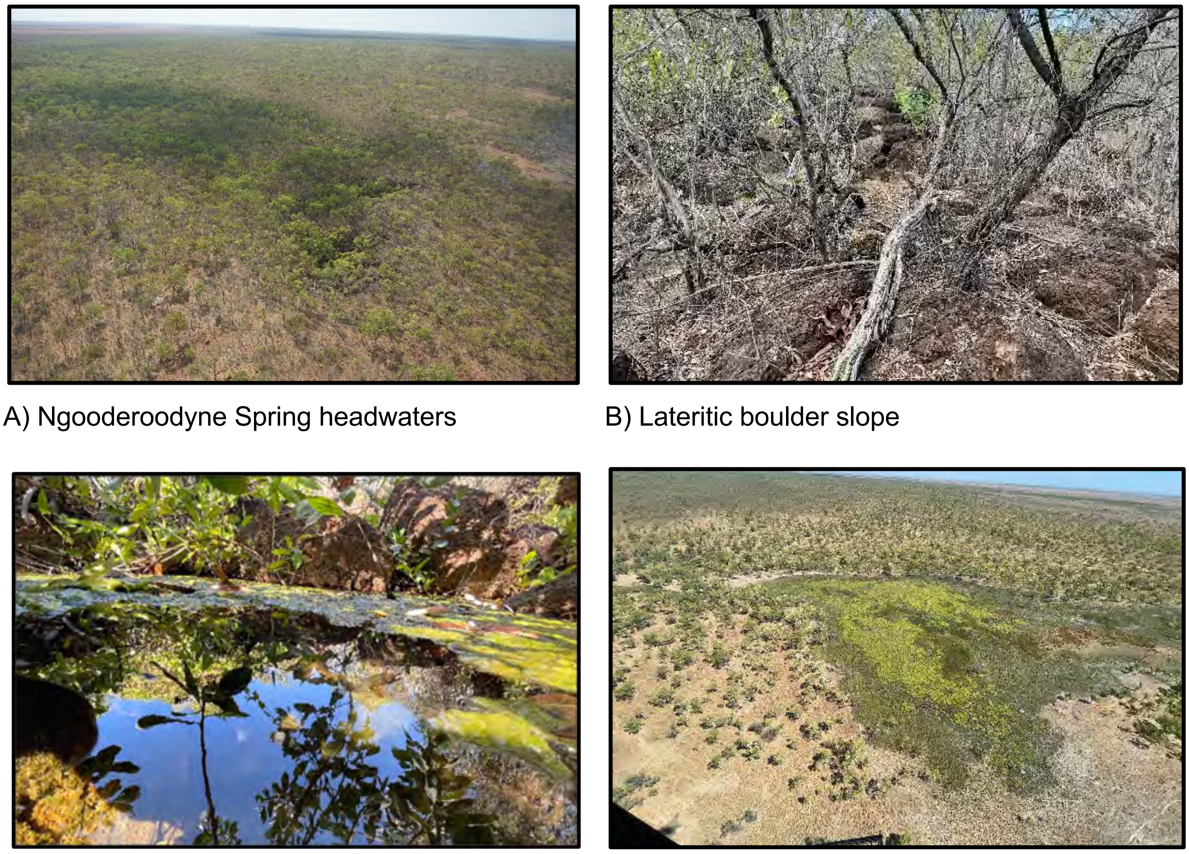


Figure 12. Potentially groundwater dependent environmental and cultural assets near the Scrubby site.

6.2.2. Ngooderoodyne Spring

Ngooderoodyne Spring is a permanent groundwater spring located approximately 13 km west of the project area. The bedrock geology is mapped as Grant Group (Figure 12), suggesting this to be the primary source aquifer. A literature review revealed no publicly available information for the spring, so a site visit was conducted on 1 November 2021 to collect additional data. The headwaters of the spring rise at the base of a lateritic boulder slope, which is incised approximately 10 m below the upgradient topography. The headwaters support a localised area of diverse and dense vegetation, before the water follows a narrow creek line for approximately one kilometre before dispersing into a shallow terminal wetland (Figure 13).



A) Ngooderoodyne Spring headwaters

B) Lateritic boulder slope

C) Clear headwater pool approx. 2m x 2m in area covered by algae

D) Terminal wetland located approx. 1 km southwest of headwaters

Figure 13. Selected photographs from Ngooderoodyne Spring, 1 November 2021.

Chemistry analysis of surface water collected from the headwater pool of Ngooderoodyne Spring indicated fresh waters (EC of 79 µS/cm) with a sodium-chloride dominated composition (NB. all chemistry results are tabulated in Section 9.3). Nutrient and metals concentrations were low. The major ion composition of Ngooderoodyne Spring was similar to that of groundwater collected from the Scrubby test production bore (Figure 14) although the latter had almost double the conductivity (EC of 140 µS/cm) and a sodium-chloride-bicarbonate signature.

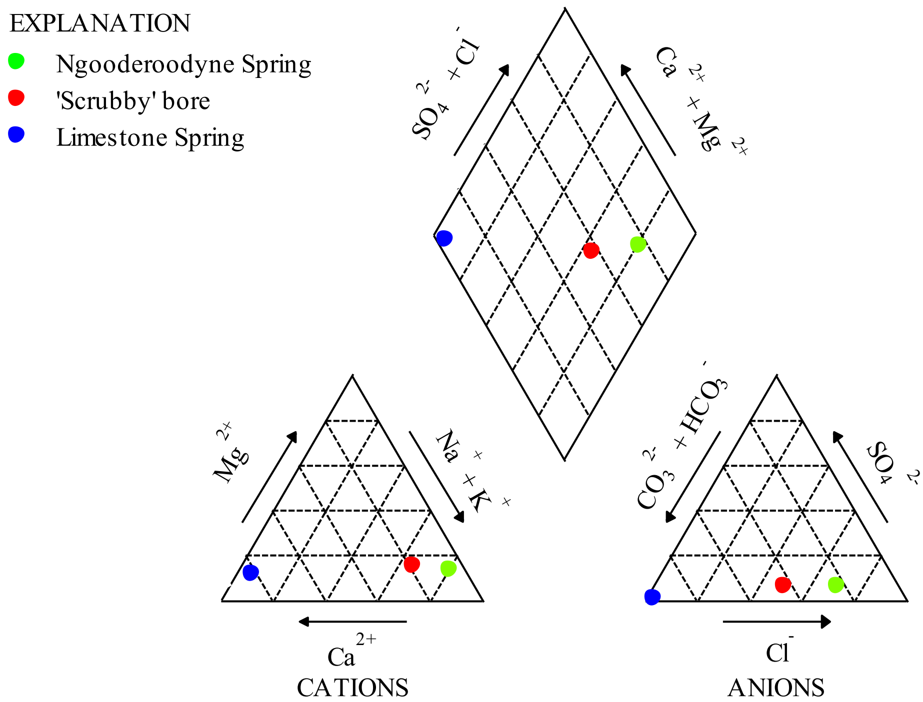


Figure 14. Major ion compositions of water samples collected from Ngooderoodyne Spring, Limestone Spring and ‘Scrubby’ production bore.

6.2.3. Limestone Spring

Limestone Spring is the other permanent groundwater spring in the area; however, it is much further away from the Scrubby project site, approximately 29 km to the north (Figure 3 and Figure 9). The spring is located in the headwaters of Alexander Creek on the southern flank of the outcropping ridge of Devonian limestone, hence its name. It was visited by IGS in September 2021 at which time two pools of stagnant but fresh water were observed, both sustaining local oases of diverse tree species (Figure 15). Chemical analysis of a water sample collected from the site shown in Figure 15A revealed a calcium-bicarbonate dominated composition (Figure 14), which is distinct from Ngooderoodyne Spring but entirely consistent with the source aquifer.

A) Limestone Spring headwater pool where water sample was taken

B) Isolated stagnant pool approx. 1km downstream of headwater pool

Figure 15. Selected photographs from Limestone Spring, 17-18 September 2021.

7. Risk Assessment

Previous sections of this report, most notably section 1.1 and chapter 6, have already detailed the significant body of background research and supporting field studies that have gone into selecting the Scrubby site from the perspective of minimising potential risks to environmental and cultural values. This required deliberate attention to known high value assets and the consideration of all potential causal pathways for impact. A Preliminary Risk Assessment (PRA) report was prepared and submitted to DWER for the Lennard site (IGS, 2019d, Appendix C), which led to further investigations before that site was eventually abandoned.

Since the focus changed to Hawkstone and ultimately Scrubby sites, ACE and IGS have regularly updated DWER on each phase of work being undertaken to properly assess risks and thereby limit the chances of any "showstoppers" emerging through the relevant licensing and approvals processes. Accordingly, IGS believes the proposed irrigation development at Scrubby site is consistent with DWER's risk 'Category 3', which is defined as *"High value cultural and environmental assets - value ranking 1 and 2 - that are unlikely to be impacted by water abstraction*".

8. Referral to Other Agencies

At the time of submitting this report, Phoenix Environmental Sciences had just completed the first of at least two seasonal botany surveys, representing the end of the 2021 dry season. Based on preliminary results of that first survey, there is no significant flora that would require referral to either WA Environmental Protection Authority (EPA) or the Commonwealth Government under the *EP Act 1986* or *EPBC Act 1999*, respectively. However, it must be stressed that this first survey did not include seasonal flora such as species that may emerge through the wet season; nor did it include surveys for significant fauna. Therefore, the decision on whether or not the project is likely to have significant environmental effects requiring referral to other agencies will have to await the outcomes of future surveys. Likewise, the application for a Clearing of Native Vegetation permit will be conditional on the outcomes of a baseline environmental survey in 2022.

ACE have already engaged with WA Department of Planning, Lands and Heritage (DPLH) to start the process of obtaining a Diversification Permit to carry out irrigated agriculture in addition the primary pastoral use of grazing native vegetation with authorised stock.

9. Groundwater Investigations

As highlighted in Section 1.1, several desktop and field-based groundwater investigations were undertaken between October 2018 and October 2020 before final selection of the Scrubby project site. The purpose of these studies was to de-risk the irrigation project by acquiring new information to characterise the hydrogeology and to provide early insights into the likelihood of the proposed development having adverse impacts to environmental and cultural values. Accordingly, the Scrubby site was deemed the most suitable area for sustainable development.

9.1. Drilling & Geophysical Logging

Drilling at the Scrubby site commenced in September 2020 using air-rotary methods, resulting in the construction of a monitoring bore (hereafter named NDSMB01) with 150 mm ID PVC casing to 102 m depth (Figure 16). Fine grained sandstone of the Grant Group was encountered from 11 m below ground level to total depth. The driller noted numerous water cuts at 30-32 m, 51-54 m, 60-62 m, 82-86 m and 93-102 m. Slotted PVC casing was used for the last 30 m from 72-102 m depth. Bore hole development by airlifting yielded greater than 20 L/s and the final depth to water upon recovery was 30.6 m below TOC (Table 5).

Table 5. Details of bores drilled at Scrubby project site

Bore	Easting	Northing	Date Completed	Casing Dia. (mm)	Slot/Screen Interval (m)	SWL (mTOC)
	GDA94 MGA Zone 51					
Monitoring Bore (NDSMB01)	647417	8095610	24/09/20	150	72-102	30.60
Bent Bore	647458	8095579	28/07/21	254	84-114	29.72
Production Bore (NDPB01)	647452	8095563	21/09/21	254	84-114	29.90

The first attempt to drill a test production bore was undertaken in July 2021. It was drilled to 115 m depth and constructed with 254 mm ID PVC casing and a 30 m section of 217 mm ID stainless-steel screen positioned just off the bottom of the hole (Table 5). The bore was located only 51.5 m away from the monitoring bore, however significant blowout of surficial sediments immediately below the steel surface collar resulted in extensive contamination of all lithological samples. A greater consequence, however, was that the bore casing bent significantly due to concrete slumping after installation – to the extent that the final resting water level at about 30 m depth could not be viewed from surface. Accordingly, the ‘bent bore’ as it is now affectionately known, was deemed unsuitable for either test pumping or ultimate production. It was not backfilled as it provided a perfect additional monitoring bore for the pumping tests (Section 9.2). No bore log is provided herein as it is identical to the following.

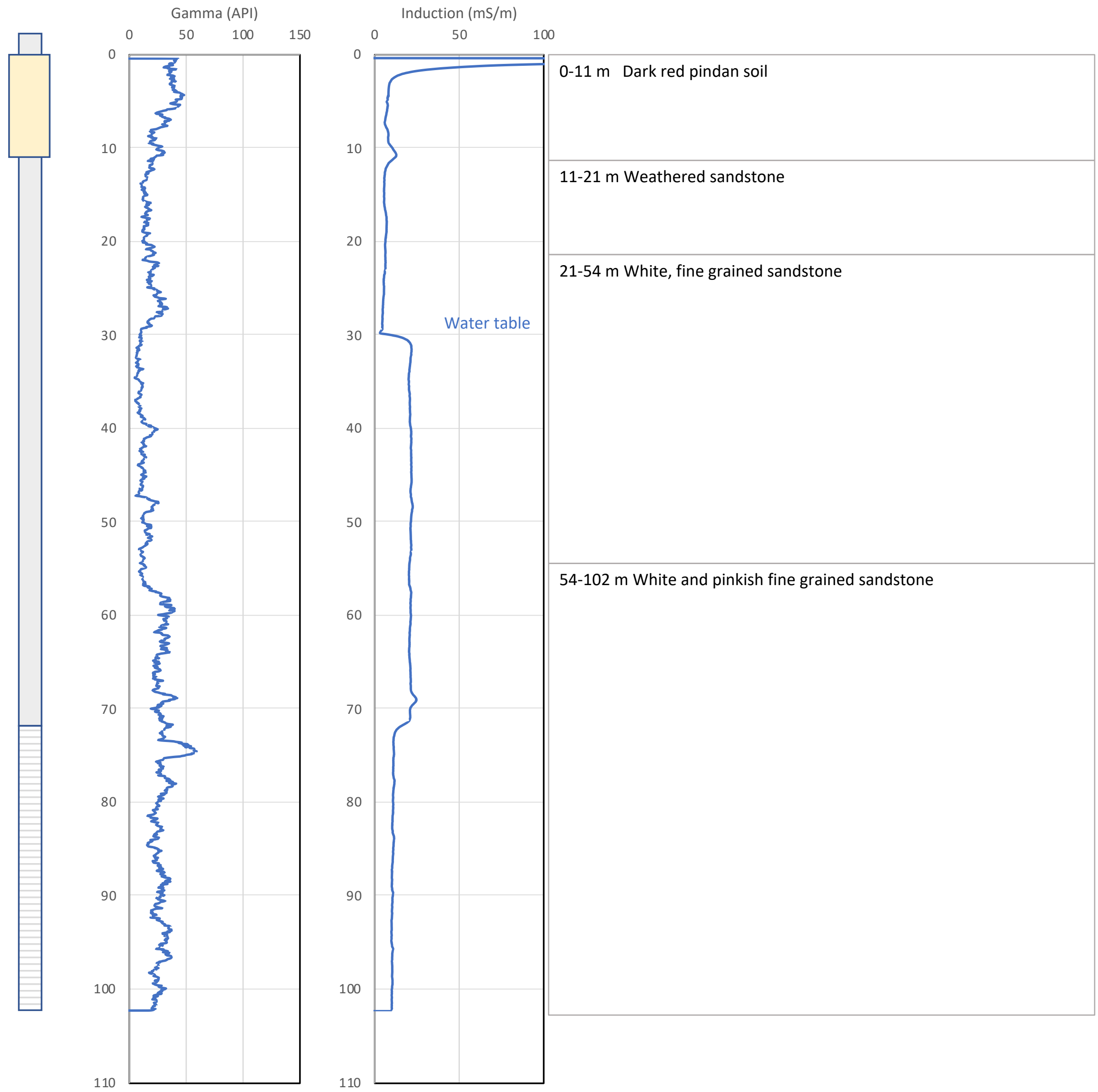


Figure 16. Scrubby monitoring bore NDSMB01 construction, downhole geophysics and lithology log.

A second attempt at drilling the test production bore (hereafter named NDSPB01) in September 2021 was successful. The bore was located only 16.5 m away from the bent bore and 58 m away from the monitoring bore, and thus provided a very similar lithological log to the latter (Figure 17). Construction details were identical to the bent bore (Table 5) and airlift yield was estimated to be in excess of 50 L/s but could not be reliably measured.

All drilling services for the project were provided by Sing Drilling Pty Ltd (Derby) and selected photographs from site are shown in Figure 18. The monitoring bore and production bore were geophysically logged by Westlog Wireline Services (Perth) for gamma and induction in late November 2021.

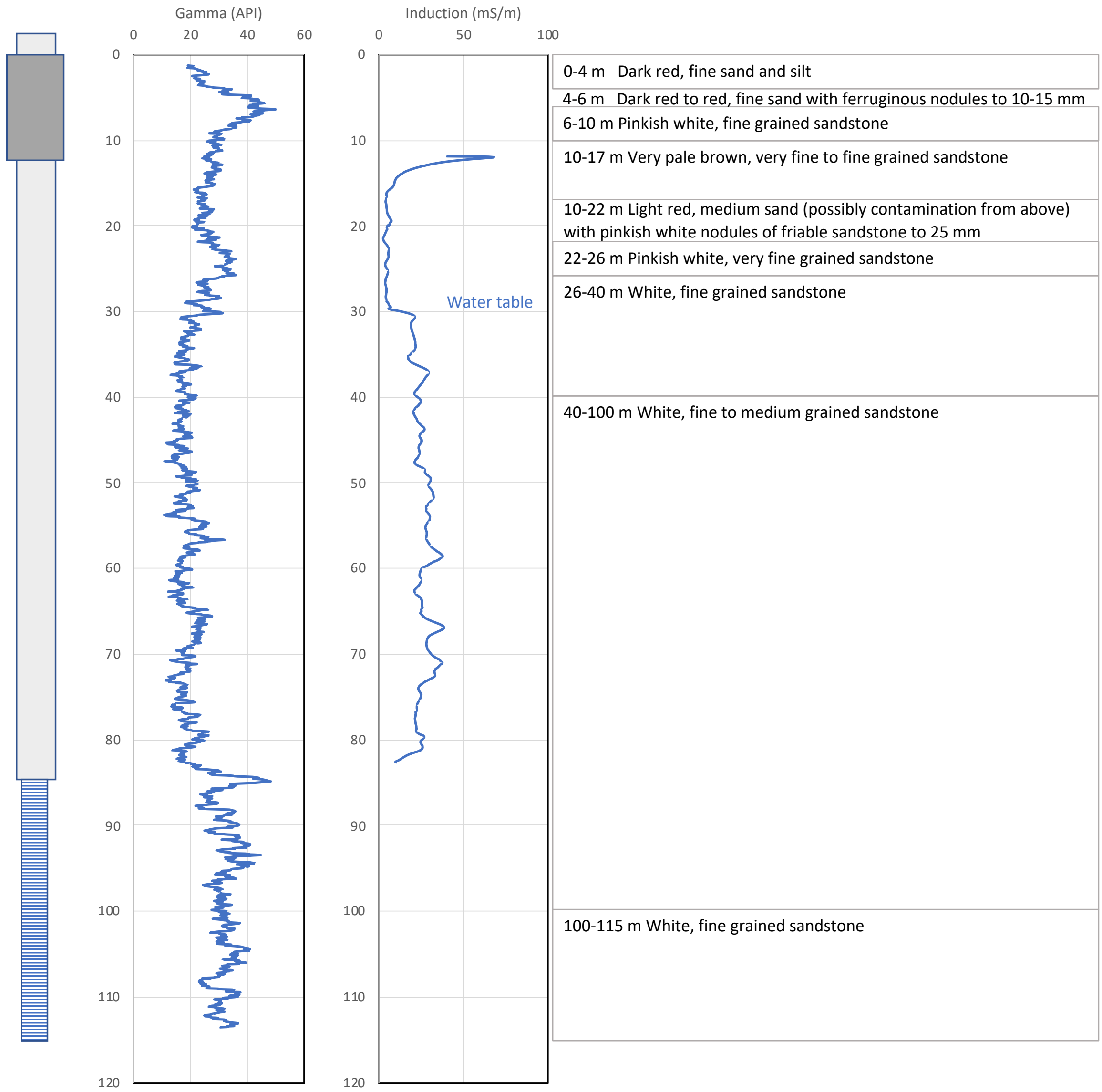


Figure 17. Scrubby production bore NDSPB01 construction, downhole geophysics and lithology log.

Figure 18. Drilling the test production bore at Scrubby site; note fine white sandstone in drill cuttings.

9.2. Test Pumping

Both the monitoring bore and bent bore have slots/screens across a similar depth interval to the production bore, thereby enabling a meaningful long-term aquifer pumping test with drawdown observations possible at distances of 16.5 m and 58 m from the pumping bore, as well as observations in the pumping bore itself.

Detailed design specifications for a step-drawdown test (SDT) and constant-rate test (CRT) were developed by IGS and accepted by DWER with minor refinements on 2 August 2021. The objectives of the tests were to adequately stress the aquifer to provide an understanding of drawdown responses, to determine a sustainable pumping rate, and to enable the estimation of aquifer hydraulic properties (i.e., transmissivity, hydraulic conductivity and storage coefficient).

Watertorque Pty Ltd. (Broome) was engaged by ACE to conduct the testing, which occurred from 21-24 October 2021 with remote supervision by IGS. In addition to taking manual water level measurements, Watertorque were required to supply and install loggers in the pumping bore and at least one of the two observation bores. However, one of the loggers could not be activated prior to the test, leaving only one available for installation in the pumping bore.

Following initial testing to establish suitable pumping rates, the SDT was conducted with three 100-minute steps at 35 L/s, 45 L/s and 55 L/s, followed by recovery to initial pre-test conditions. Results are shown graphically in Figure 19 and electronic data can be made available to DWER upon request. It is notable that the logger data displays noisy behaviour, whereas the high-resolution manual measurements reveal a stable water table response, suggesting the logger was faulty. Salinity as EC was measured frequently and did not change throughout the test from what is presumably the hand-held device’s lower limit of detection of 0.1 mS/m.

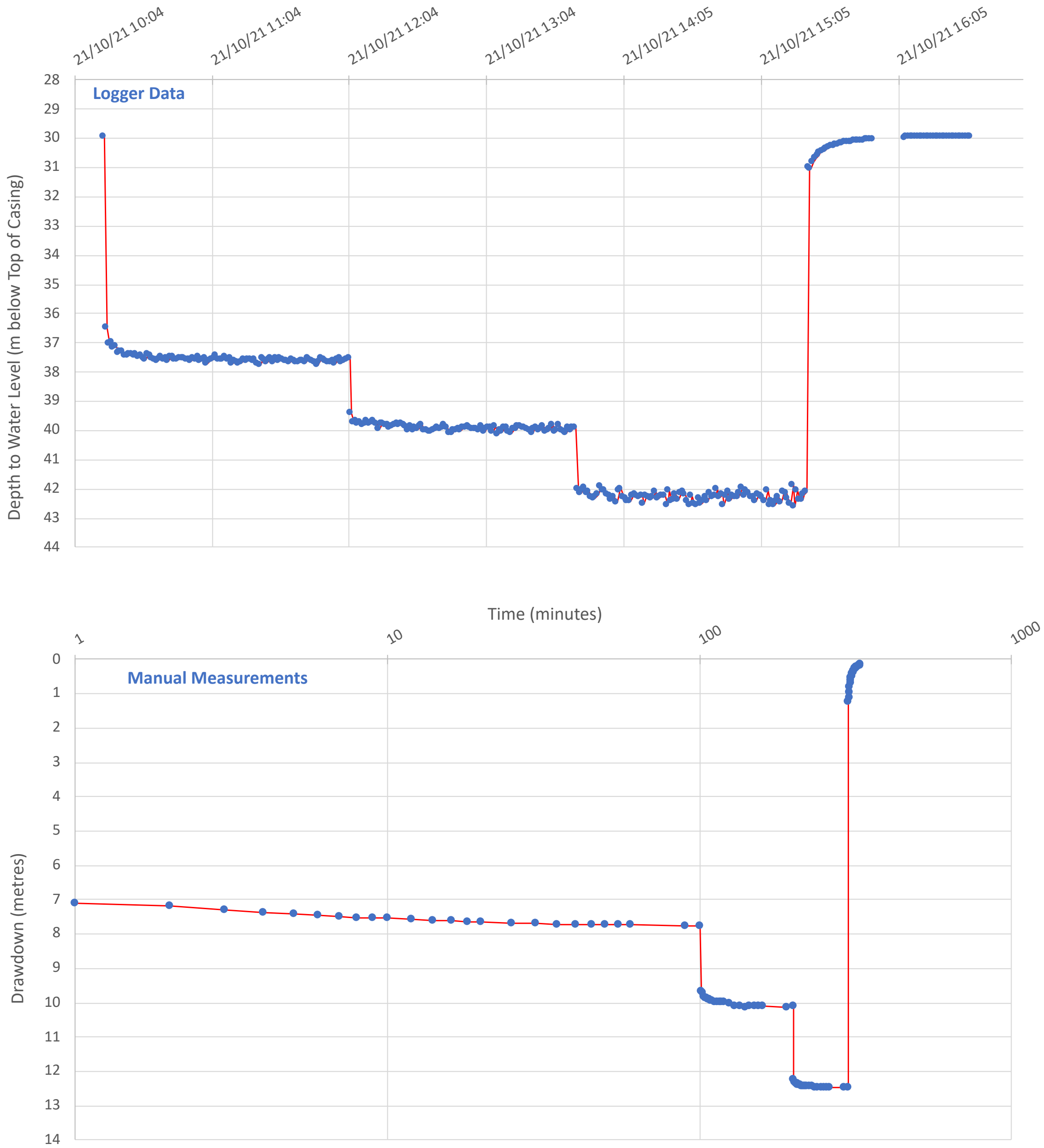


Figure 19. Results of step-drawdown test on Scrubby production bore at 35 L/s, 45 L/s and 55 L/s. Upper panel shows noisy logger data on linear time scale, while bottom panel shows smooth manual data on log time scale.

A 50-hour CRT was then conducted at 55 L/s, followed by a minimum 95% recovery period. Results are shown graphically in Figure 20 and electronic data can be made available to DWER upon request. Again, the logger data displays noisy behaviour even though the manual measurements are stable. And again, salinity as EC did not change from a value of 0.1 mS/m throughout the test.

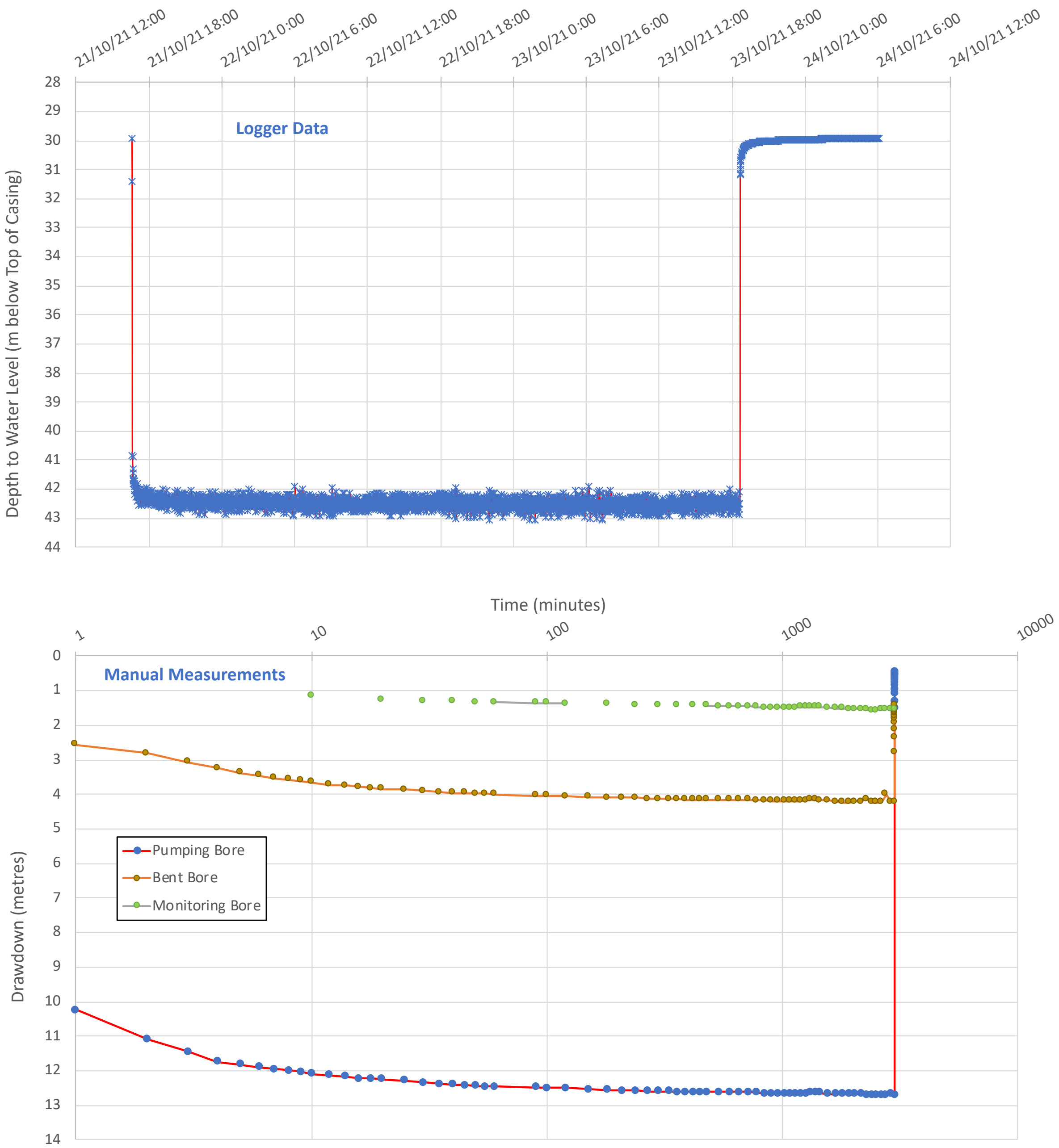


Figure 20. Results of 50-hour constant-rate test on Scrubby production bore at 55 L/s. Upper panel shows noisy logger data on linear time scale, while bottom panel shows smooth manual data on log time scale.

While the pump had a non-return valve installed to prevent backflow of water from the rising main into the bore once the pump was switched off, the rapid rate of recovery seen in both the step-drawdown and constant-rate tests suggest this was not working properly. Therefore, analysis of the CRT data only focused on the pumping period and excluded the recovery period. Analysis was performed using AQTESOLV (Duffield, 2007) with the Neuman solution for an unconfined aquifer with delayed water table response. A saturated aquifer thickness of 220 m was assumed based on a standing water level of 30 m and nearby evidence of Grant Group extending to 250 m depth (Section 3.2). In addition to specifying bore dimensions and screen lengths, the effective screen length in the monitoring bore was extended up to 66 m depth to account for a longer gravel pack. The resultant automated least-squares fit to the observed data (Figure 21) provides confidence in the test design, data collection methods and conceptual hydrogeological model for the site. Aquifer transmissivity was estimated at 2970 m^2/day, which equates to a K of 13.5 m/day, and specific yield was a low value of 1.7%. The K value compares favorably with the range of previous estimates for the Grant Group aquifer (i.e., 1-20 m/day, Section 3.3.2), however there are no previous estimates of specific yield for comparison. The anisotropy ratio of 0.02 is also consistent with notes from the driller that several ‘hard bands’ were encountered in each drillhole at the Scrubby site.

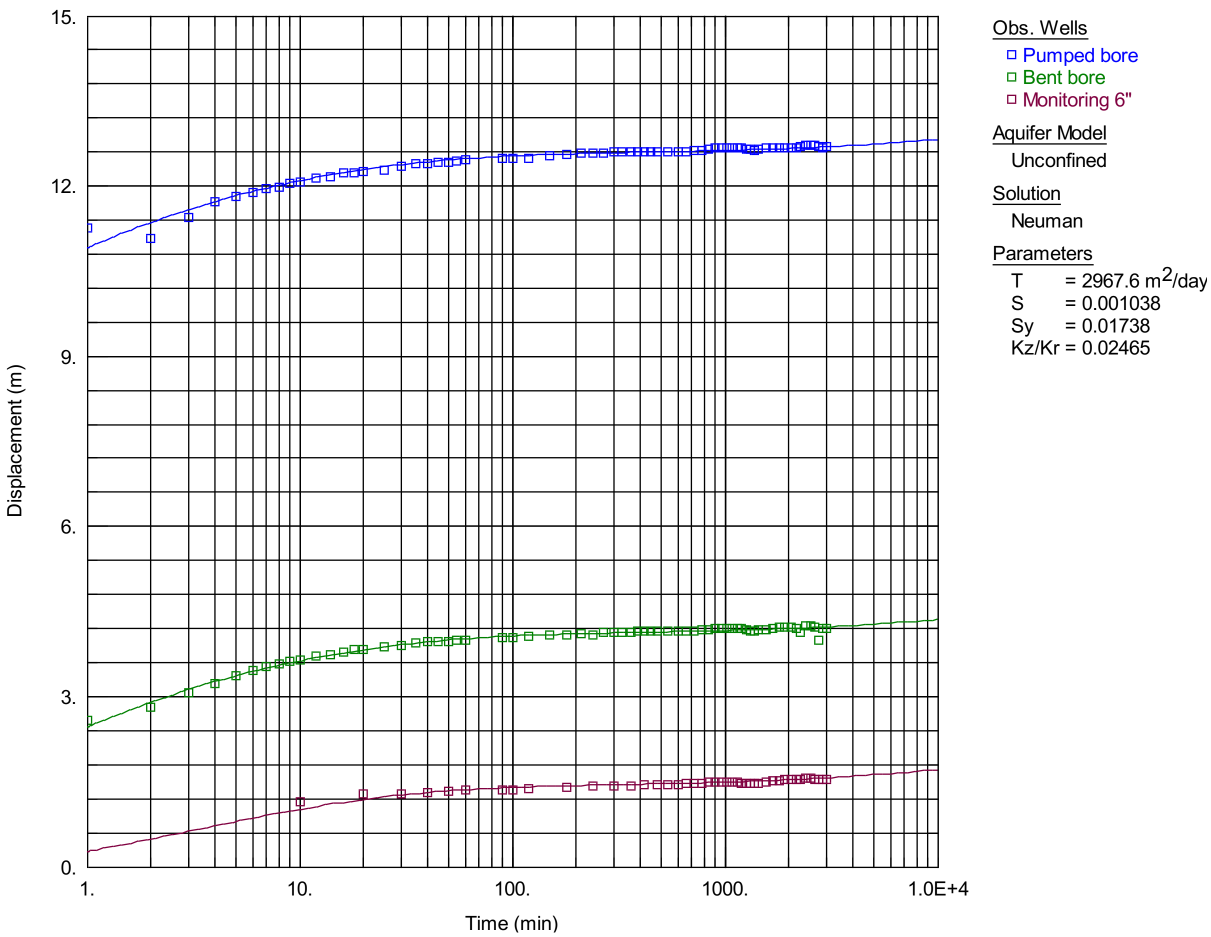


Figure 21. Simulated fit to observation data from the pumping period of the CRT at Scrubby site.

9.3. Groundwater Chemistry

Chemistry data is available for regional groundwater sampled from the Scrubby site and Kimberley Downs bores KD16MB002 and KD16MB003, located approximately 35 km to the south-east of the Scrubby site (Figure 1; DWER, 2017), along with Ngooderoodyne Spring and Limestone Spring (Table 6). The major ion chemistry compositions for these sites are plotted on Figure 22, where a clear linear trend between the Ca-CO_3-type groundwater at Limestone Spring and Na-Cl-type groundwater at Ngooderoodyne Spring can be observed. Whilst the Ca-CO_3 type waters reflect interaction with limestone and would be expected of groundwater inflows to the Grant Group aquifer from the limestones of the Devonian Reef, progression towards a more Na-Cl dominated groundwater is indicative of mixing with rainfall recharge. Likewise, a concurrent reduction in total dissolved solids (TDS) with increased Na-Cl dominance is also consistent with an increased input of relatively fresh rainfall recharge. The chemistry results for the Scrubby site and Ngooderoodyne Spring therefore suggest the occurrence of significant rainfall recharge within the study area.

All groundwaters sampled from the Grant Group had low concentrations of dissolved metals and nutrients (Table 6).

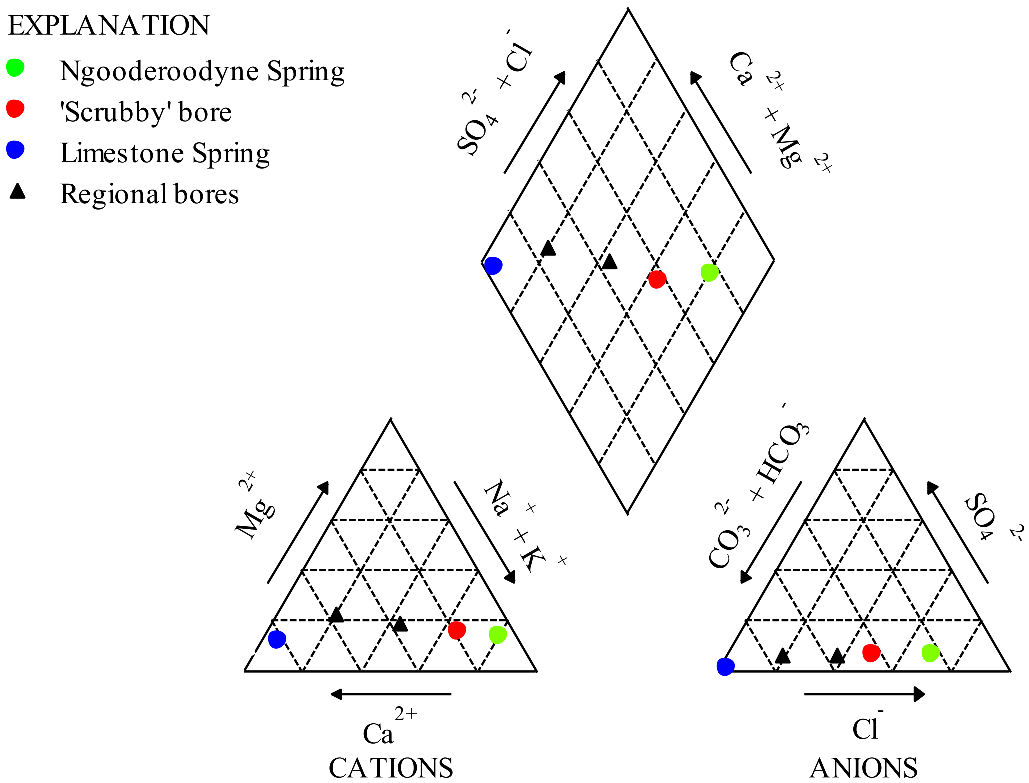


Figure 22. Major ion compositions of Ngooderoodyne Spring and Limestone Spring shown with available regional groundwater chemistry data from the Scrubby site and Kimberley Downs regional bores.

Table 6. Field and laboratory chemistry data for regional groundwater samples collected from Kimberley Downs (DWER, 2017), the Scrubby site and Limestone and Ngooderoodyne Spring.

Bore / Site ID		**KD16 MB002**	**KD16 MB003**	**Limestone Spring**	**Scrubby NDSPB01**	**Ngooderoodyne Spring**
Date Sampled		**5/07/2017**	**5/07/2017**	**18/09/2021**	**22/10/2021**	**01/11/2021**
pH		6.5	6.4	9.0		
Specific Conductivity	μS/cm	424	277	441	100	79
Temperature	deg. C	34.6	33.4	24.7		32.2
Dissolved Oxygen	mg/L	1.34	3.68			
Alkalinity	mg/L	151	73			
Calcium - Dissolved	mg/L	48	18	93	4.6	0.7
Magnesium - Dissolved	mg/L	11	5.3	7.7	2.2	1
Sodium - Dissolved	mg/L	14	23	6.6	17	9
Potassium - Dissolved	mg/L	8.2	2.2	2.4	1.1	4.4
Carbonate as $CaCO_3$	mg/L			<5	<5	<5
Bicarbonate as $CaCO_3$	mg/L			290	33	10
Chloride	mg/L	23	29	5	22	17
Sulphate	mg/L	9.2	6	2	4	2
Bromide	mg/L	0.06	0.09			<0.5
Fluoride	mg/L	<0.05	<0.05			<0.1
Sulfur	mg/L	3.7	2.4			
Total Dissolved Solids	mg/L	269	176	290	74	49
Hydroxide as $CaCO_3$	mg/L			<5	<5	<5
Total Alk. as $CaCO_3$	mg/L	163.4	83.5	290	33	10
Ionic Balance	%			-2.7	-6.9	-6.5
Hardness as $CaCO_3$	mg/L			260	21	6
Total Nitrogen	mg/L	0.3	0.6			0.4
NPOC	mg/L	0.5	0.3			

Table 6 (continued). Field and laboratory chemistry data for regional groundwater samples collected from Kimberley Downs (DWER, 2017), the Scrubby site and Limestone and Ngooderoodyne Spring.

Bore / Site ID		**KD16 MB002**	**KD16 MB003**	**Limestone Spring**	**Scrubby NDSPB01**	**Ngooderoodyne Spring**
Total Kjeldahl Nitrogen	mg/L					0.2
Nitrate as N	mg/L	0.2	0.4			0.18
Nitrite as N	mg/L					<0.005
NOx as N	mg/L					0.18
Ammonia as N	mg/L					<0.005
Total Phosphorus	mg/L					<0.05
Phosphate as P	mg/L					<0.005
Organic N	mg/L					0.2
Aluminium-Dissolved	mg/L	<0.05	<0.05			<0.01
Arsenic-Dissolved	mg/L	<0.05	<0.05			
Boron-Dissolved	mg/L	<0.05	0.07			0.06
Cadmium-Dissolved	mg/L	<0.05	<0.05			<0.0001
Cobalt-Dissolved	mg/L	<0.05	<0.05			
Chromium-Dissolved	mg/L	<0.05	<0.05			<0.001
Copper-Dissolved	mg/L	<0.05	<0.05			<0.001
Iron-Dissolved	mg/L	<0.1	<0.1			0.05
Manganese-Dissolved	mg/L	<0.05	<0.05			
Molybdenum-Dissolved	mg/L	<0.05	<0.05			<0.001
Nickel-Dissolved	mg/L	<0.05	<0.05			0.003
Lead-Dissolved	mg/L	<0.05	<0.05			<0.001
Selenium-Dissolved	mg/L	<0.05	<0.05			
Silicon - Dissolved	mg/L	5.7	7.2			15
Strontium-Dissolved	mg/L	0.25	0.27			0.024
Zinc-Dissolved	mg/L	<0.05	<0.05			0.003

10. Groundwater Modelling

10.1. Objectives

A numerical groundwater flow model was constructed with the following objectives, as per email communication from DWER on 5th February 2021:

1. Quantify the potential drawdown impacts of the proposed development on local receptors, which have been identified as:
    a. Ngooderoodyne Spring
    b. The closest point(s) of the Fitzroy River and its tributaries, which are assessed as being groundwater dependent, i.e. the Lennard River, Robinson River, May-Meda river system, Barker River and Hawkstone Creek.
2. Quantify the uncertainty in model predictions of drawdown caused by uncertainty in aquifer properties, recharge, evapotranspiration and regional water balance, to enable a transparent assessment of risks.

10.2. Methodology

10.2.1. Modelling Approach

Based on the information provided in Section 3 of this report, there is sufficient data available for the project area to enable construction and steady-state calibration of a low complexity numerical groundwater flow model to assess potential impacts from the project. That is, information is available on:

- Aquifer geometry. Aquifer base elevations were obtained from eight petroleum exploration wells located at distances of approximately 2 km to 30 km from the project site (Section 3.3.1) and ground surface elevation was obtained from the 1 second DEM (Wilson et al., 2011).
- Recent groundwater levels, from measurements at 12 bores/springs obtained during the regional bore audit, plus a measurement obtained for the Scrubby site during test pumping (Table 2).
- Aquifer properties for the Grant Group / Poole Sandstone from previous studies (Section 3.3.2) and for the project site (Section 9.2).

However, the above data is sparse for the study area and there is negligible site-specific information available to constrain other model parameters such as rainfall recharge and evapotranspiration, and regional water balance components such as lateral groundwater inflow and outflow to/from the study area. Therefore, it was expected that there would be large uncertainty in model predictions of drawdown.

The modelling approach selected for this project incorporated a formal uncertainty analysis, whereby an ensemble of calibrated models was developed using plausible ranges for uncertain model parameters and was used to make the required predictions. Predictions made using each model from the ensemble are therefore equally plausible. Rather than providing outputs from a single model, graphs of drawdown from the entire ensemble of models are presented, along with the 10th, 50th and 90th percentile, enabling a risk-based assessment of the predicted outcomes.

10.2.2. Model Platform and Grid

The groundwater flow model was constructed in MODFLOW 6 version 6.2.2 (Langevin et al., 2018) with FloPy version 3.3.5 (Bakker et al. 2016).

The model domain was implemented as described in Section 3.3.1. A single model layer was used to represent the combined Grant Group and Poole Sandstone aquifer system. Top elevations of the model layer were defined by the 1 second Digital Elevation Model (DEM) (Wilson et al., 2011) and layer bottom elevations were based upon the aquifer base layer presented in Section 3.3.1 (Figure 9). As described in Section 3.3.1, the latter was interpolated from a coarsely spaced dataset extracted from logs of petroleum exploration wells. As such, it was necessary to make a minor modification to the interpolated surface by setting a minimum layer thickness of 20 m at the north-eastern model boundary. Doing so ensured that there were no areas of the model domain with zero or negative thickness, or that would be simulated as completely unsaturated. Comparison of the interpolated aquifer base with the potentiometric surface indicated that the Grant Group may be unsaturated in some parts of the north-eastern portion of the model domain. In these areas, the water table may occur within the Fairfield Group. However, there is insufficient data on aquifer base and water levels in these areas to confirm this hypothesis. Implementing additional aquifer thickness, along with a reduced lower bound for aquifer hydraulic conductivity, acknowledges this possibility and captures the uncertainty in the location of the boundary between saturated and unsaturated conditions in the Grant Group. This approach additionally avoids potential model instability caused by cells going dry in parts of the model domain, a phenomenon that could differ spatially between model realizations.

The model grid was developed with the quadtree mesh creator Gridgen (Lien et al., 2015) from within FloPy and features refinements at the model boundaries and in the center of the model domain around the proposed irrigation development (Figure 23). The largest cells in the model are 1,000 m x 1,000 m and the smallest are 125 m x 125 m. External boundary cells are all 250 m x 250 m.

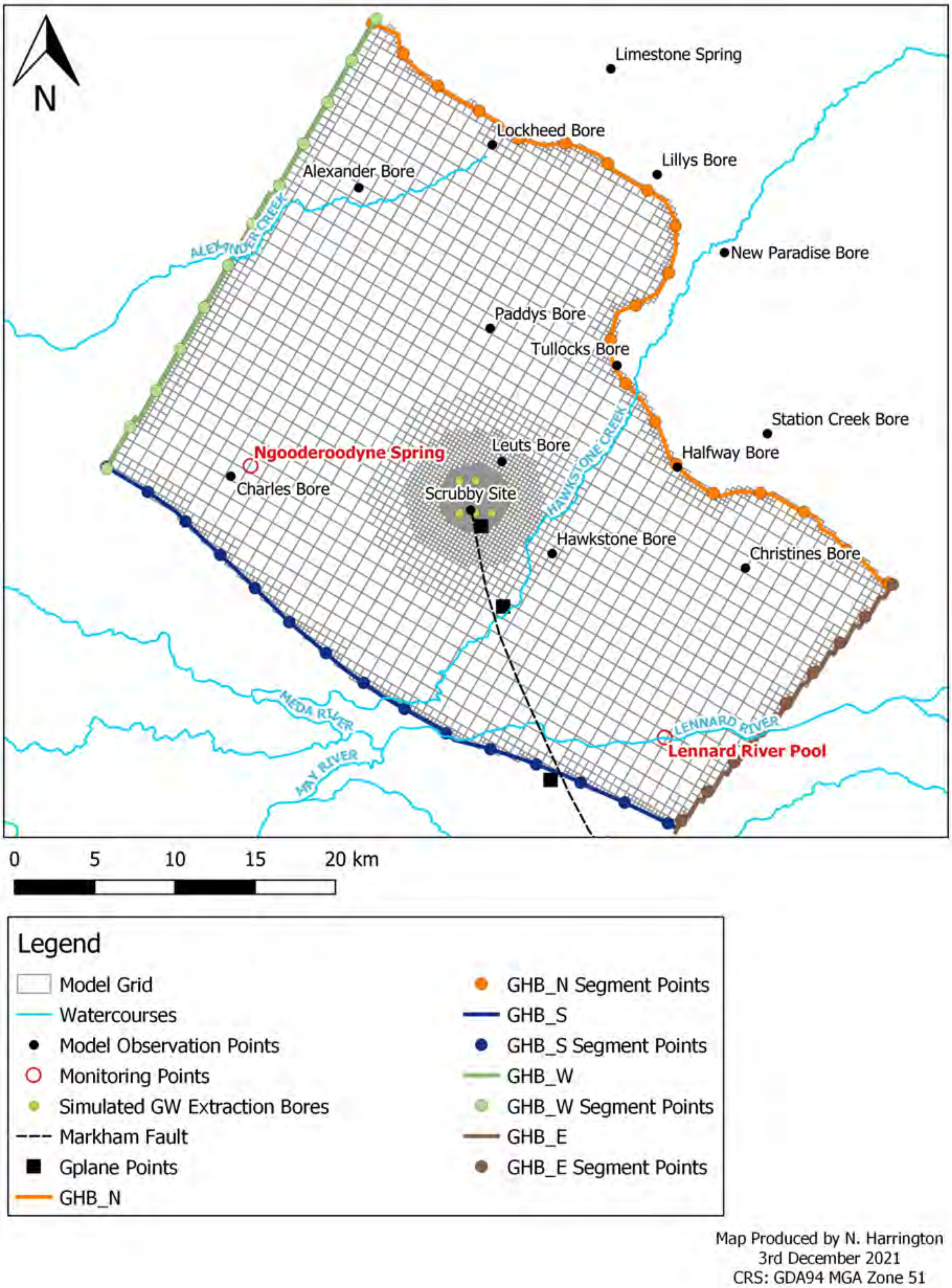


Figure 23. Model domain, grid, boundary conditions, steady state calibration points (Model Observation Points), monitoring locations (Ngooderoodyne Spring, Lennard River Pool), and simulated production bores at the Scrubby site.

10.2.3. Boundary Conditions

The base of the model was set as a no-flow boundary, assuming that lateral groundwater flow dominates in the aquifer and that there is little vertical exchange of groundwater between the Grant Group and the underlying Fairfield Group. Vertical exchange is expected to be limited by the uppermost mudstone unit of the Fairfield Group, the Laurel Formation (Section 3.1.3). As described in Section 3.3.1, the north-eastern extent of the model domain was set at the mapped boundary between the Grant Group and the Fairfield Group (Figure 9, Figure 23). The hydrogeological conceptual model suggests some lateral groundwater flow across this boundary, probably via the more permeable units of the Fairfield Group (see Section 3.1.3). Figure 9 shows a hydraulic gradient across this boundary. Therefore, the north-eastern model boundary was set as a General Head Boundary (Figure 23) described by 19 segments using the SEGLIST feature of PLPROC (Doherty, 2020a). General Head Boundaries were preferred instead of Fixed (Constant) Head Boundaries as this allows the flux of water across the boundary to be controlled by a boundary conductance value. The boundary distance was set at 0 m and elevations for each segment vertex were based upon the interpolated potentiometric surface with a range of up to ±10.0 m depending on how well the boundary elevations were constrained by head measurements. The large range for the hydraulic heads assigned was due to the relatively steep hydraulic gradients north of the model domain (0.004) compared to within the domain (0.0005). Conductance values for each vertex were allowed to vary between 0.1 m^2/day and 1,000 m^2/day during conditioning of the ensemble (see Section 10.2.6 below).

As described in Section 3.2, the Grant Group / Poole Sandstone aquifer thickens throughout the study area towards the south-west and is approximately 600 m thick at the south-western model boundary. Significant groundwater outflow from this boundary is expected based upon the conceptual model. The south-western model boundary was consequently set as a General Head Boundary, comprising 14 segments, with elevations of each segment given a 5 m range based upon the inferred equipotential surface (Figure 9). Conductance was allowed to vary for each segment vertex between 0.1 m^2/day and 100,000 m^2/day for ensemble development.

The north-western and south-eastern model boundaries were also designated as General Head Boundaries, with 11 and 8 segments respectively. The hydraulic heads assigned to each segment were given ranges of ±2 m on the values of the interpolated potentiometric surface. The large change in aquifer thickness along this boundary required staggered ranges for the conductance used in ensemble development with segment vertices in the north assigned a range between 0.1 m^2/day and 100 m^2/day while vertices in the south were between 10 m^2/day and 100,000 m^2/day.

10.2.4. Recharge and Evapotranspiration

Rainfall recharge across the model domain was described by 54 pilot points divided into two zones: (1) sandy pindan soils and (2) cracking clay soils (Figure 10, Figure 24). Pilot point recharge values were allowed to vary during conditioning of the ensemble (Section 10.2.6) between 10 mm/yr. and 100 mm/yr. for the sandy pindan soil zone and between 0.5 mm/yr. and 5.0 mm/yr. for the cracking clay soil zone based on values presented in Section 3.3.3.

Hawkstone Creek has a very coarse sandy bed and is conceptualised as a losing system, thereby presenting a potential zone of localised enhanced recharge. This is one possible reason for the observed elevated hydraulic head at the Scrubby site compared with the regional hydraulic gradient (Figure 9). A separate recharge zone was therefore designated in the model along Hawkstone Creek (Figure 24), allowing recharge in this zone to increase by 200 mm/yr. (i.e., double the maximum allowable value for diffuse recharge to sandy soils). Importantly, model cells with dimensions that exceed the local width of the creek bed had the enhanced recharge rate scaled back proportionately. This approach was found to improve model calibration to the observed water levels at the Scrubby site and Leuts Bore. The sensitivity of model predictions to the recharge rate applied in the Hawkstone Creek zone was explored in the Sensitivity Analysis presented in Section 11.3.

The maximum evapotranspiration rate across the project area was allowed to vary between 350 mm/yr. and 1,700 mm/yr., with an extinction depth between 1.0 m and 2.5 m.

10.2.5. Aquifer Properties

Horizontal hydraulic conductivity (Kx) across the model domain was described by the same distribution of 54 pilot points as for recharge (Figure 24), with pilot point values allowed to vary between 1 m/day and 20 m/day during the conditioning of the ensemble (see Section 10.2.6) based on the information presented in Section 3.3.2 and Section 9.2.

The influence of the Markham Fault as a potential barrier to groundwater flow was explored by implementing it as a GPLANE using PLPROC (Doherty, 2020a). The GPLANE was assigned a hydraulic conductivity of 0.1 m/day, a constant influence width of 500 m, and a decay length of 500 m. The sensitivity of model predictions to the hydraulic conductivity assigned to the GPLANE was assessed in the Sensitivity Analysis presented in Section 11.3. It was found that, based on the current hydrogeological conceptualisation, acceptable calibration to the observed head distribution required implementation of both the Markham Fault as a flow barrier and enhanced recharge along Hawkstone Creek.

Specific yield was set at 0.017 (1.7%) based on the high level of confidence in the results of the long-term pumping test at the Scrubby site (Section 9.2).

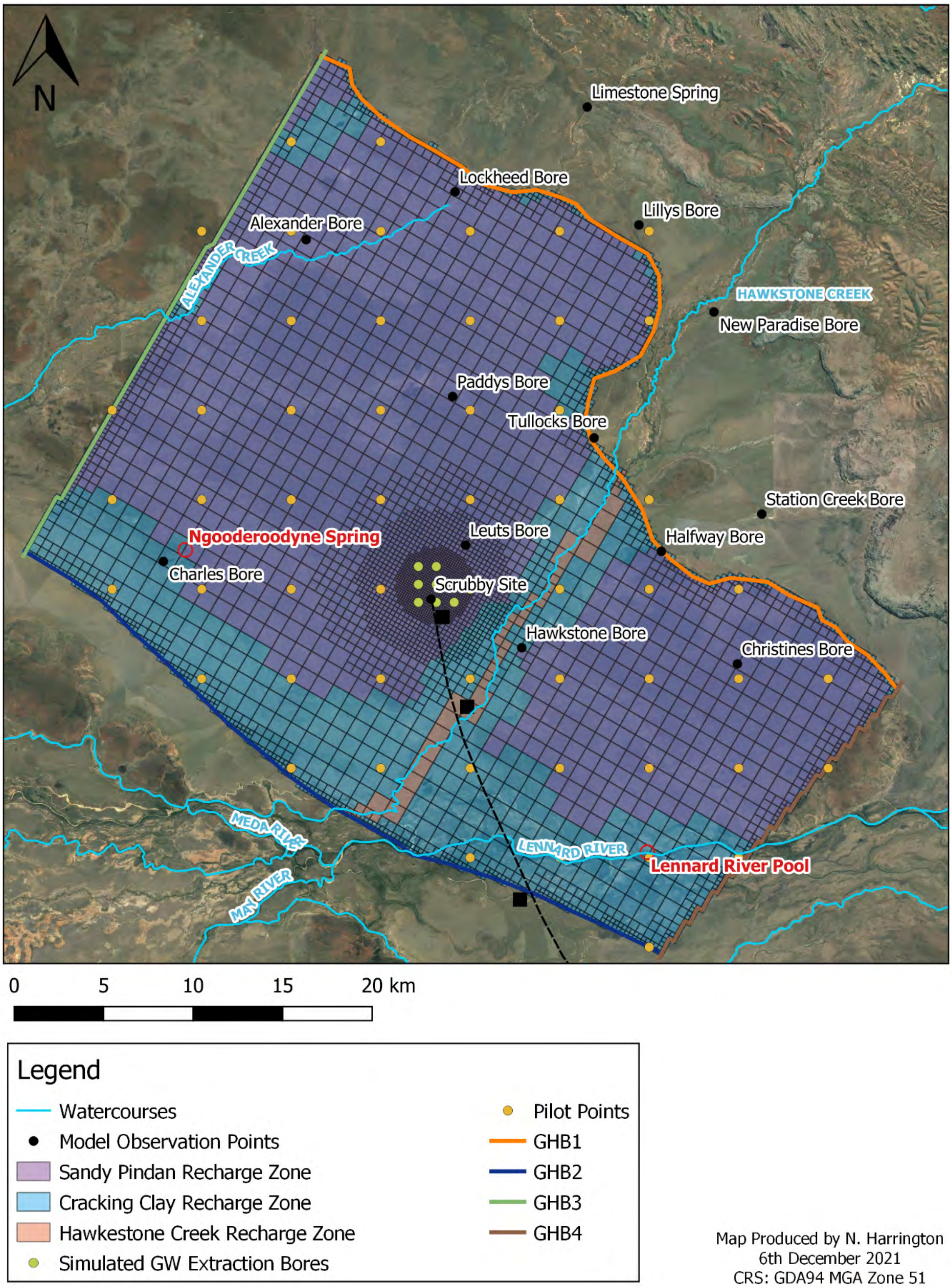


Figure 24. Distribution of model recharge zones and pilot points.

10.2.6. Steady-State Conditioning and Ensemble Development

PESTPP-IES (White, 2018) was used to condition an ensemble of 480 steady-state models. Correlation between pilot points for hydraulic conductivity or recharge were accounted for via an uncertainty file featuring covariance matrices developed with members of the PEST Groundwater Utilities Suite (Doherty, 2020b). General head boundary conductance and hydraulic head values estimated at SEGLIST vertices were assumed to be uncorrelated to facilitate greater exploration of the potential flux ranges across external boundaries. These, along with the evapotranspiration parameters, were included in the uncertainty file as standard deviations of their prior uncertainties.

The groundwater level measurements obtained during the regional bore audit (Table 2) were used as targets for the conditioning process. Those bores that were pumping at the time of the survey were given a lower weighting of 2.0 compared with the bores that were not pumping, which were given a weighting of 4.0. As the regional bore audit dataset provided no data in the south-western portion of the model domain for use in conditioning of the models, the historical water level from Charles Bore, located adjacent Ngooderoodyne Spring and available via the WIN database, was implemented as a calibration target (Table 4, Figure 23). Charles Bore is located on Meda Station and was not accessible during the regional bore audit. Water levels from the WIN database are considered to have low reliability, as the measurement date and the measurement conditions and protocols used are unknown. The measurement for this bore was given a weighting of 1.0 in the calibration scheme.

In addition to hydraulic head observations, secondary observations of net boundary fluxes were also used to discourage the conditioning process from producing flow fields that were inconsistent with the conceptual model. This was accomplished via a combination of MODFLOW 6's boundary name observation feature and the observation list processor OLPROC (Doherty, 2020c). These were configured to penalise the conditioning objective function if net flux through the northern boundary was negative and if net flux through the southern boundary was positive, where positive and negative are flows in and out of the model respectively.

PESTPP-IES was configured to condition the ensemble of models for six iterations. Completion of the conditioning process yielded 320 model parameter sets, which were then further culled based on a Scaled Root Mean Squared (SRMS) error threshold of 10%. The final ensemble comprises 218 models for the predictive simulation.

10.2.7. Predictive Simulation

The conditioned ensemble was used to simulate groundwater extraction from eight production bores, each pumping at 750 ML/yr. for 30 years, with production bore locations shown on Figure 24. The prediction models included a steady-state stress period prior to the commencement of extraction from production wells in the second stress period. A total of 31 stress periods were used, one for each of the thirty years plus the initial steady-state simulation. There were twelve time steps per stress period.

10.3. Steady-State Conditioning Results

Figure 25 shows the steady-state residuals (observed head minus simulated head) for the final ensemble of 218 models. The medians and interquartile ranges of the residuals for all bores used in the conditioning are between approximately -1 m and +1 m, with the exception of Scrubby, Leut's and Paddy's bores. As described above, only models with SRMS error less than 10% were accepted as part of the ensemble (Figure 26). The median SRMS error for the final ensemble was 8.2%, with the 75th percentile being 9.1%. Leut's bore was pumping at the time of the head observation and the water level for Paddy's bore was taken from station records (Table 2), with the date of the water level measurement and pumping status of the latter bore unknown. Therefore, median residuals of between -1.9 m to -3.4 m (i.e. model simulating higher than observed water levels) is considered to be an acceptable result for these bores.

Despite the implementation of preferential recharge from Hawkstone Creek (Section 10.2.4) and a flow barrier associated with the mapped extent of the Markham Fault (Section 10.2.5), the ensemble consistently underpredicts the water level at the Scrubby site by between 0.4 m and 3 m (median 1.3 m). Whilst this result is certainly acceptable for a model of this scale, it suggests that some local process or feature maintains higher heads at this location compared with those that can be predicted using the current conceptual model. Examples of such processes or features could include local preferential recharge, occurrence of a barrier to groundwater flow (beyond the low K zone simulated to be associated with the Markham Fault), or upward leakage from lower units (e.g., from more permeable units of the Fairfield Group). The occurrence of any of these could reduce drawdown impacts from pumping at the Scrubby site compared with those simulated.

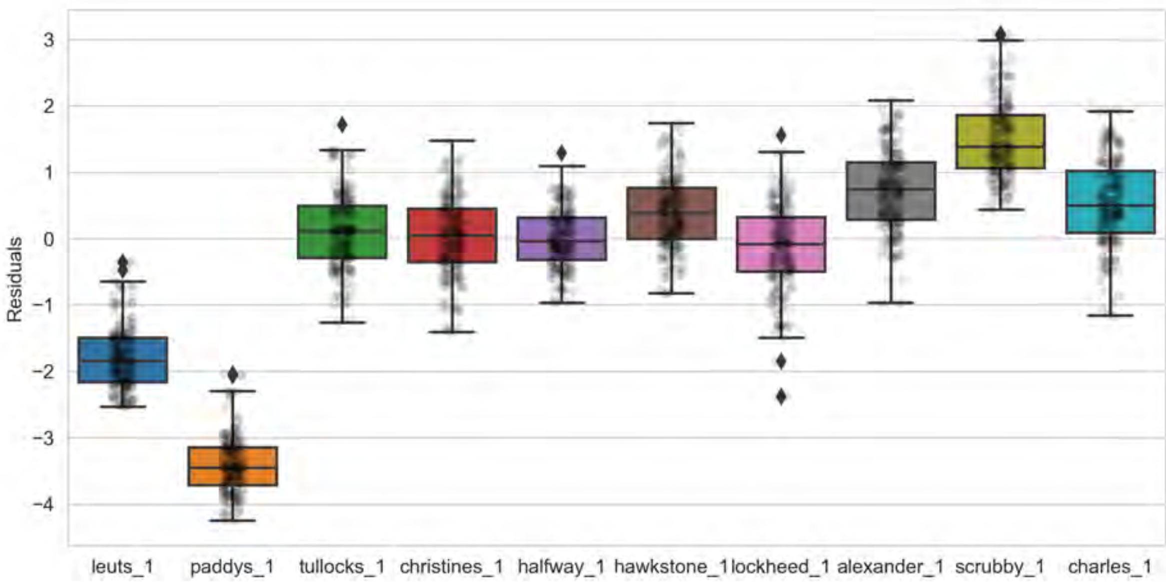


Figure 25. Steady-state residuals calculated as observed head minus simulated head (in metres) for the conditioned ensemble of 218 accepted models.

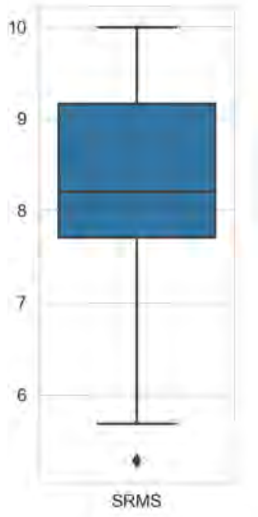


Figure 26. Distribution of SRMS error (%) for the conditioned ensemble of 218 accepted models.

Figure 27a-c provides examples of the conditioned horizontal hydraulic conductivity (Kx) distributions; these correspond to the model realizations that produced the P10, P50 and P90 maximum drawdown values at Ngooderoodyne Spring (Section 11.2). Despite allowing for uncertainty in Kx, whereby the parameter is allowed to vary between 1 m/day and 20 m/day across the model domain, the maps show that conditioning of the models to the observed hydraulic head data results in relatively consistent Kx distributions. A zone of lower hydraulic conductivity is consistently simulated to the south-west of the Scrubby site, and a zone of higher hydraulic conductivity to the north and north-west.

Examples of the conditioned recharge distributions for the model realizations that produced the P10, P50 and P90 maximum drawdown values at Ngooderoodyne Spring are shown in Figure 28a-c. Similar to the Kx distributions, conditioning of the models to the observed hydraulic head data resulted in relatively consistent recharge distributions, even though the model was provided freedom to vary recharge between 10 mm/y and 100 mm/y for the sandy pindan soil zone. A zone of higher recharge occurs between the Scrubby site and Ngooderoodyne Spring. Based on review of aerial photography and the DEM, this area appears to receive runoff or drainage from a zone of higher topographic elevation to the north-east. The higher recharge area stretches towards part of Alexander Creek, with a zone of higher recharge consistently simulated along the part of the creek adjacent Alexander Bore, one of the steady-state head observation points. A zone of higher recharge is also consistently simulated along the stretch of Hawkstone Creek adjacent the Scrubby site as well as in the east of the model domain in the vicinity of Hawkstone and Christine's bores. The latter again approximately coincide with minor drainage features that appear to drain areas of higher topographic elevation.

An example of the simulated steady-state potentiometric contours, using the model realization representing the 50th percentile of the maximum drawdown at Ngooderoodyne Spring, is shown in Figure 29. The simulated contours are consistent with the conceptual understanding of the regional flow system (Figure 9), with groundwater flow from the Napier Range in the north, towards the south-west.

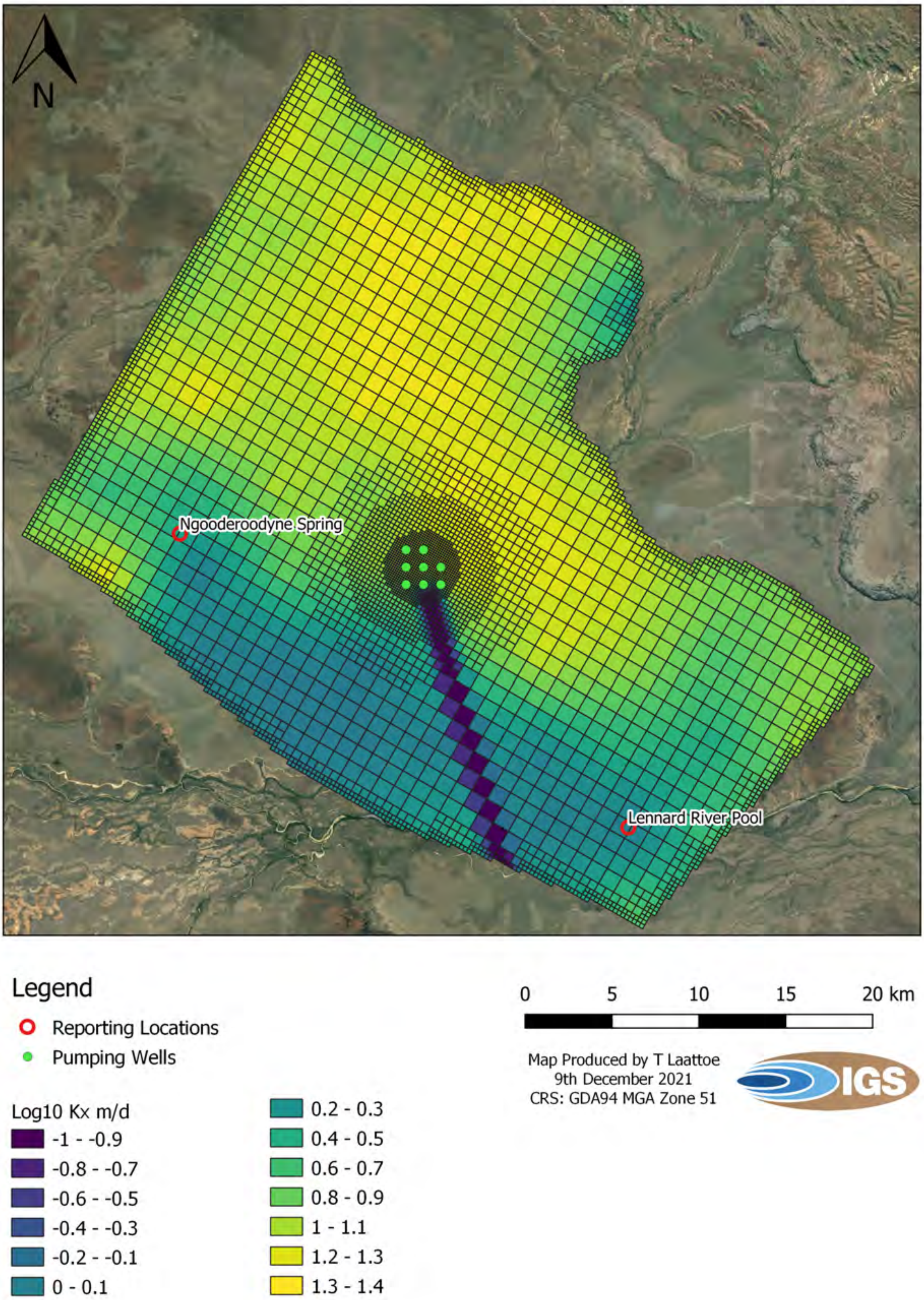


Figure 27a. Example aquifer hydraulic conductivity distribution for the model realization representing the 10th percentile of the maximum drawdown at Ngooderoodyne Spring. Note the log scale.

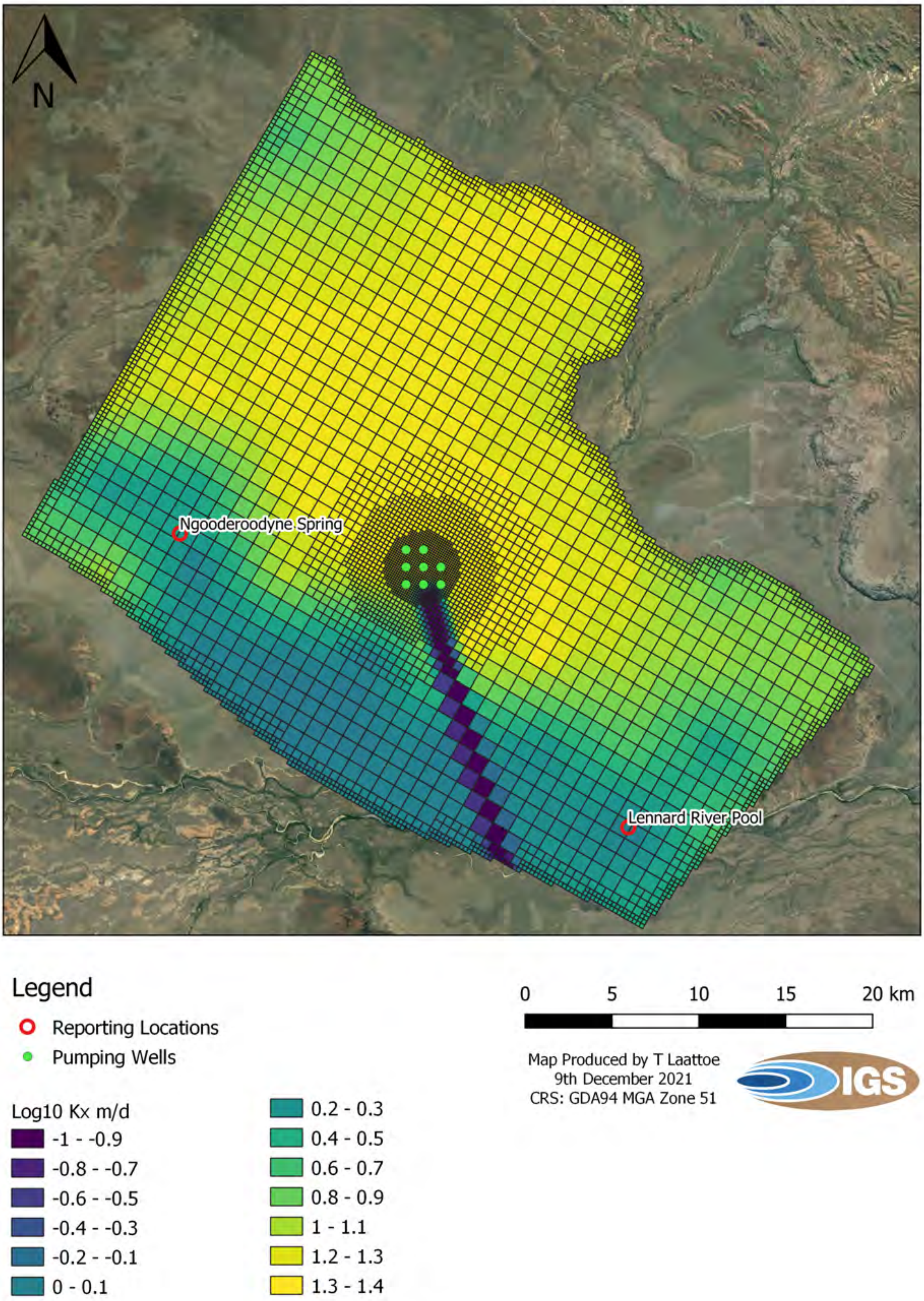


Figure 27b. Example aquifer hydraulic conductivity distribution for the model realization representing the 50th percentile of the maximum drawdown at Ngooderoodyne Spring. Note the log scale.

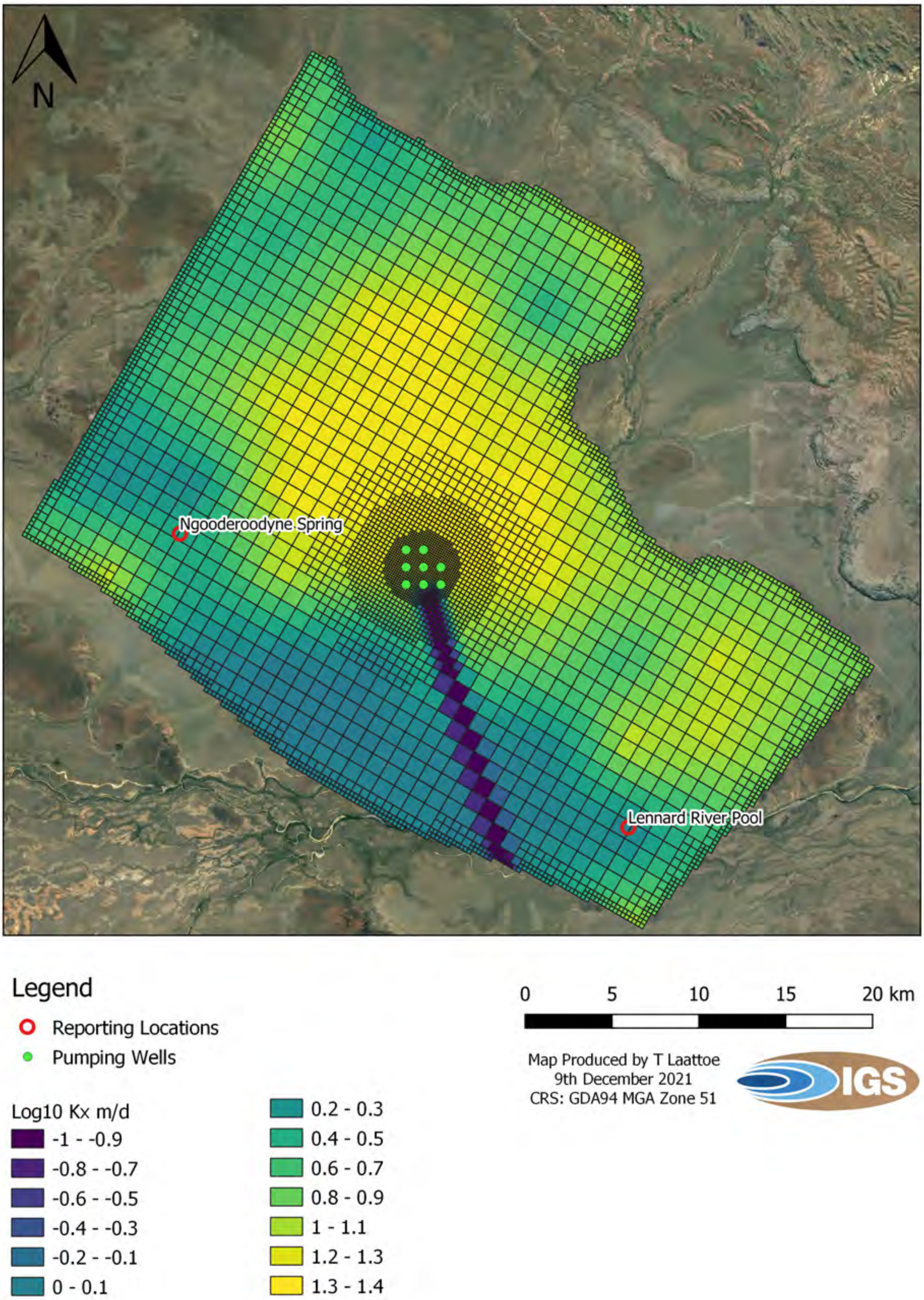


Figure 27c. Example aquifer hydraulic conductivity distribution for the model realization representing the 90th percentile of the maximum drawdown at Ngooderoodyne Spring. Note the log scale.

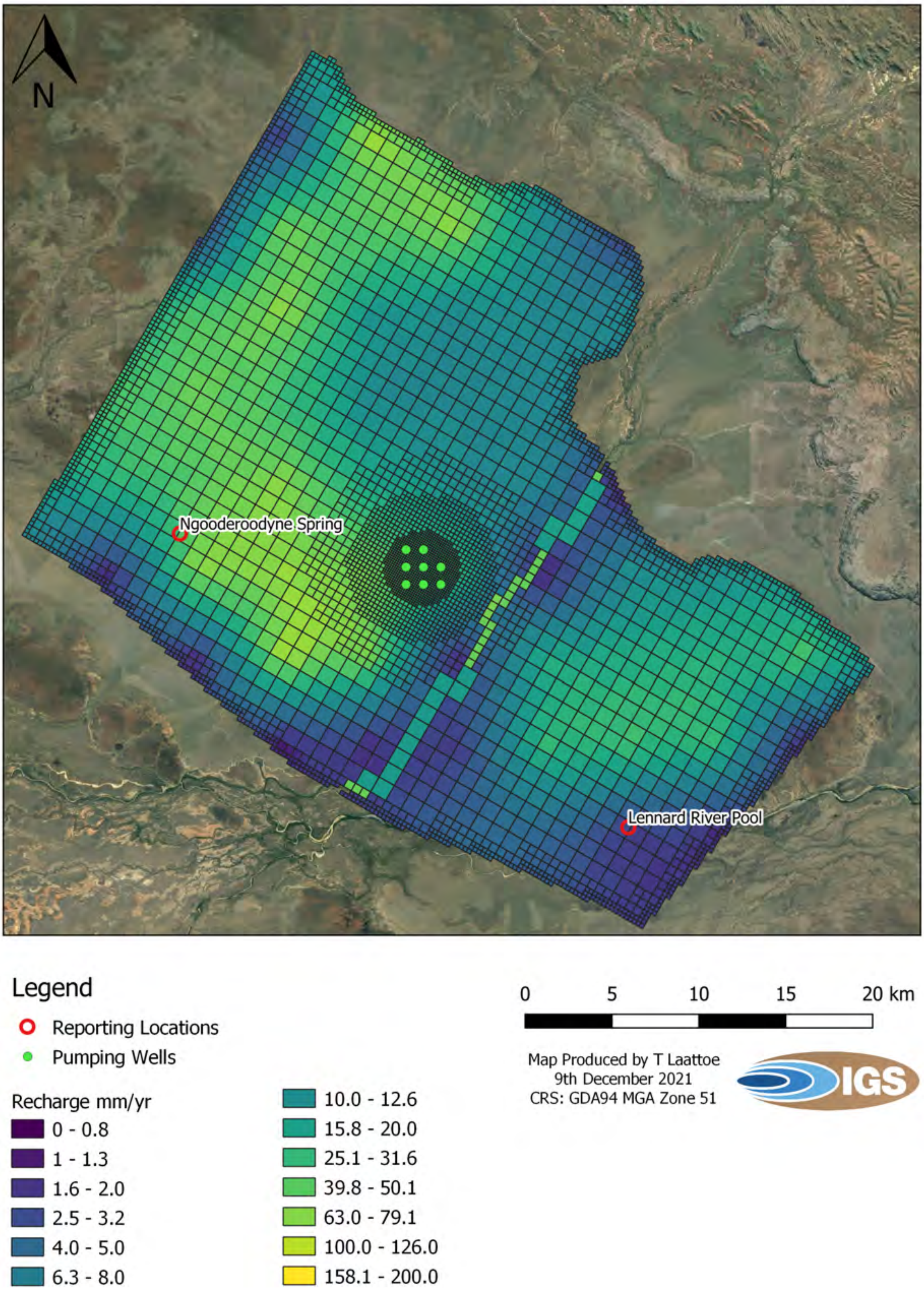


Figure 28a. Example recharge distribution for the model realization representing the 10th percentile of the maximum drawdown at Ngooderoodyne Spring.

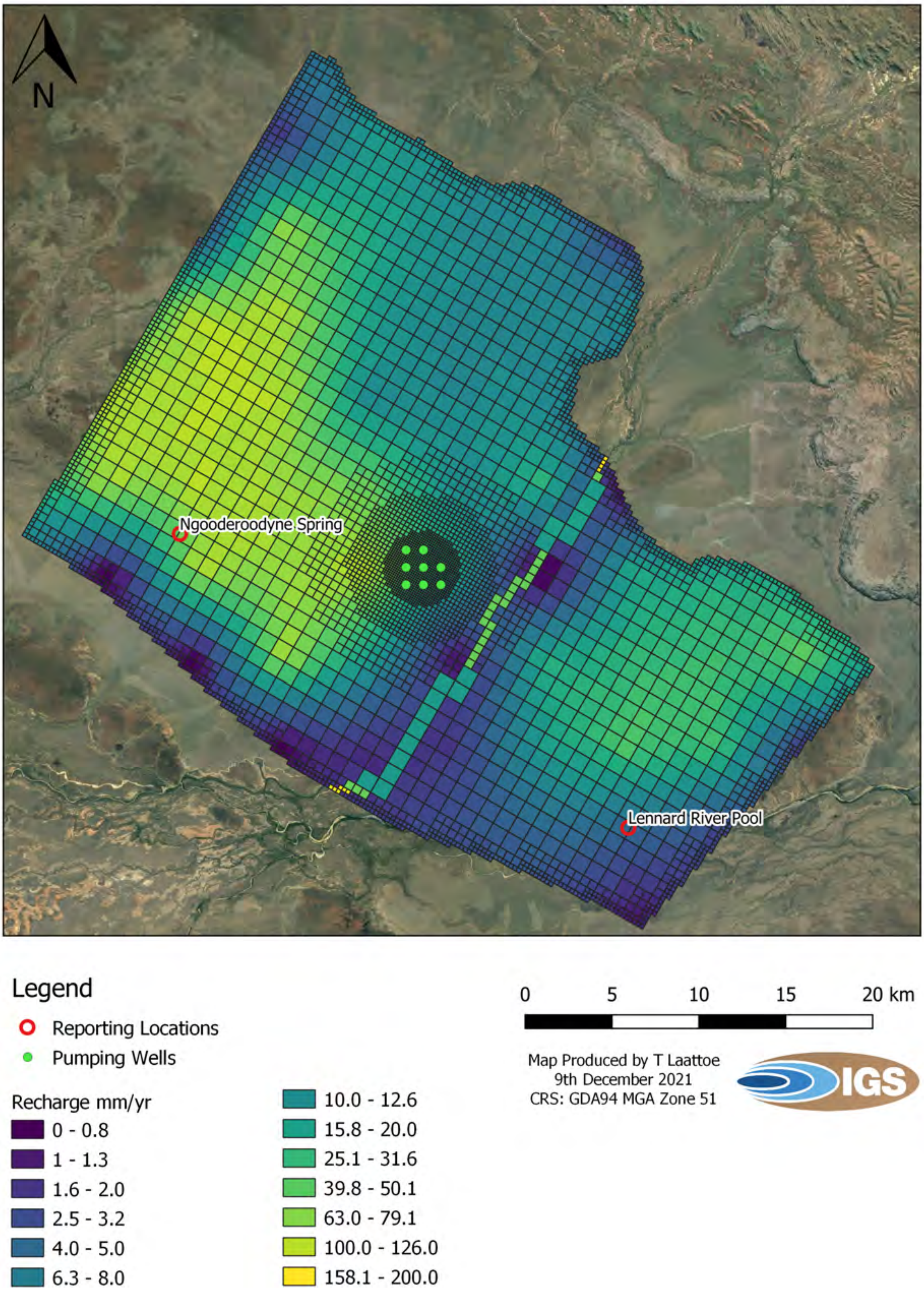


Figure 28b. Example recharge distribution for the model realization representing the 50th percentile of the maximum drawdown at Ngooderoodyne Spring.

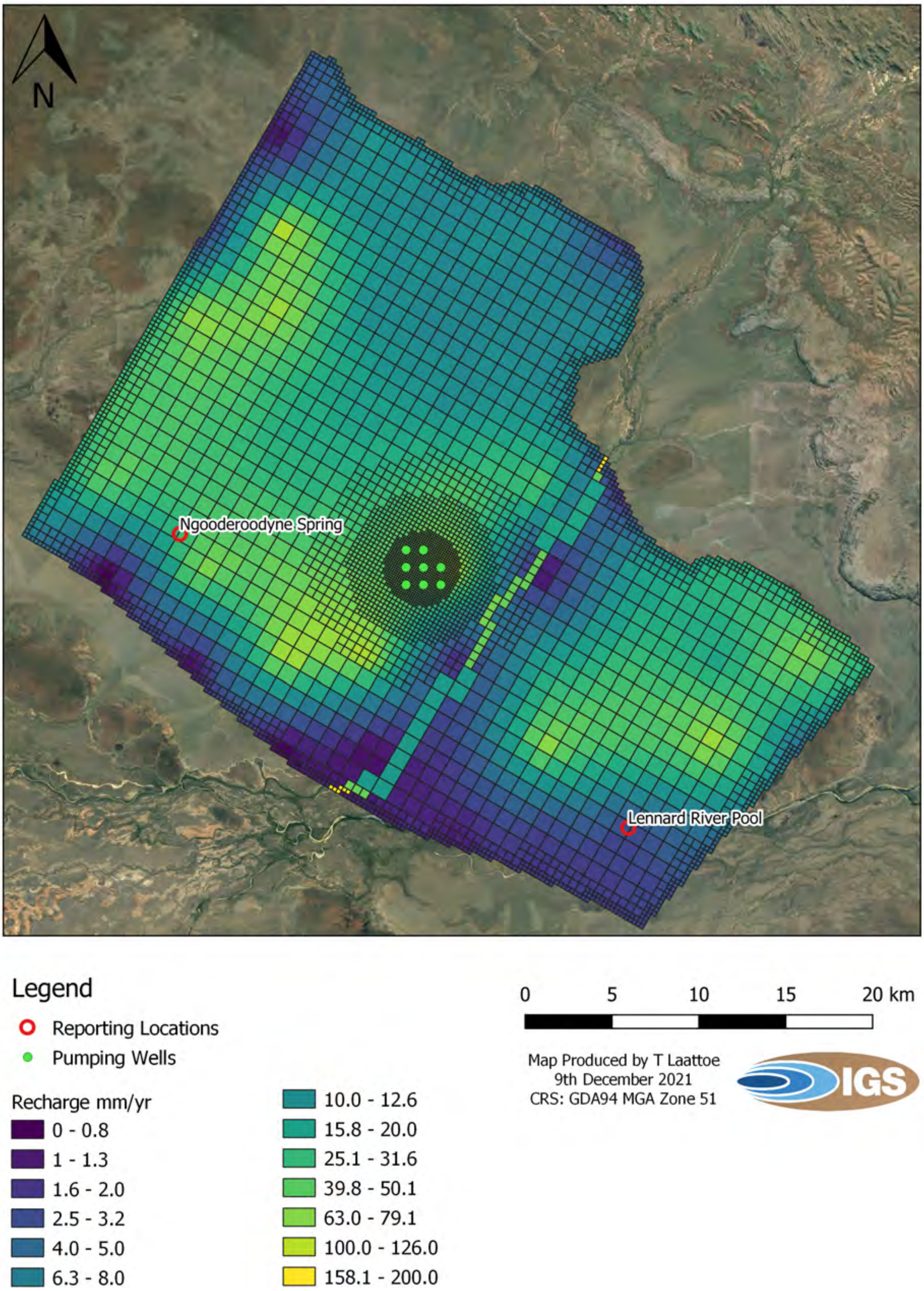


Figure 28c. Example recharge distribution for the model realization representing the 90th percentile of the maximum drawdown at Ngooderoodyne Spring.

The effect of the Markham Fault as a barrier to groundwater flow, observed as closely spaced equipotential contours dividing the flow system into two, is readily apparent from Figure 29. The steep hydraulic gradient near the north-eastern model boundary is caused by relatively steep topographic and aquifer base elevation gradients and a thin aquifer.

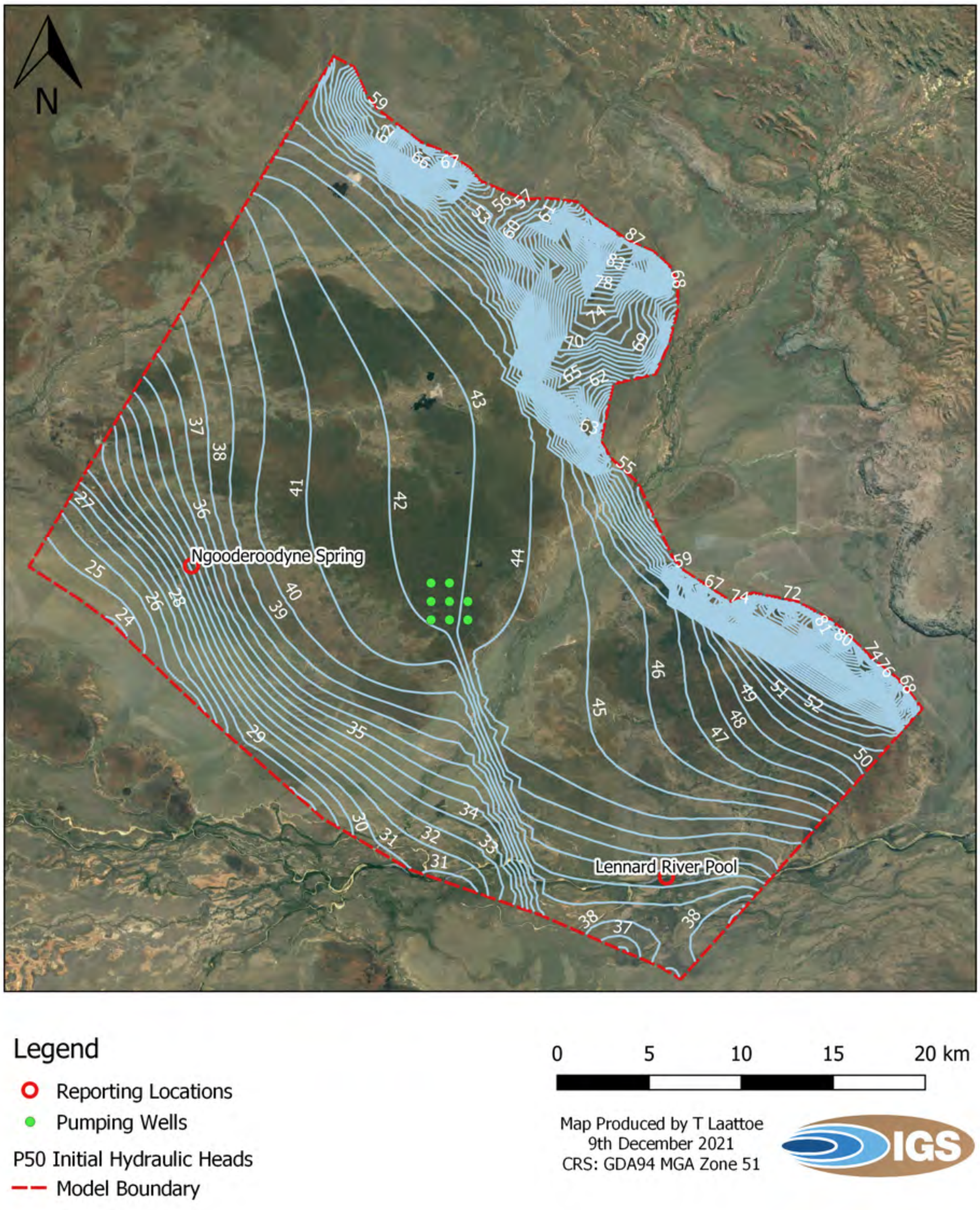


Figure 29. Example simulated steady-state potentiometric surface, for the realization representing the 50th percentile of the maximum drawdown at Ngooderoodyne Spring.

Steady-state water balances for the complete ensemble of conditioned models are presented as a box and whisker plot (Figure 30). The strong disparity between the magnitude of different fluxes is consistent with the conceptual hydrogeological model of recharge (RCH_in) as the primary input and discharge via lateral flow through the southern boundary (GHBS_out) as the primary output for the system. The median recharge rate of approximately 82 ML/day equates to 24 mm/yr. as an areal average for the 1226 km^2 model domain. The full ensemble of models uses an areal average recharge rate of between 14 mm/yr. and 33 mm/yr.

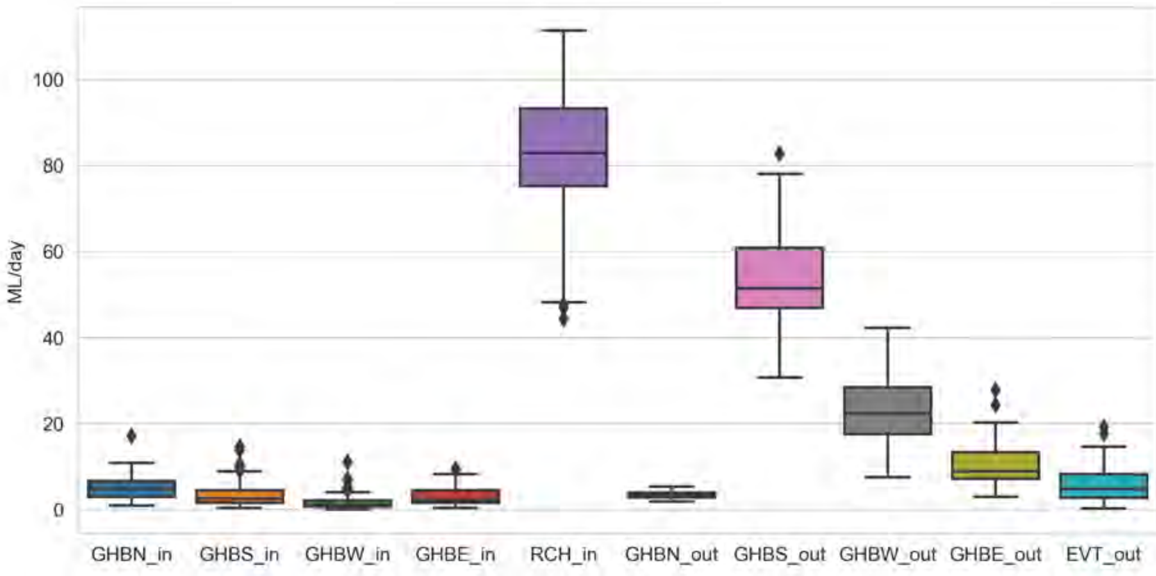


Figure 30. Steady-state water balances for the conditioned ensemble of 218 accepted models.

10.4. Model Limitations

All groundwater models are simplified representations of complex natural systems. As such, they include a range of standard assumptions about the systems they represent, and their outputs are limited by the level of understanding of the system and amount of input data available. Specific limitations of the model described here are:

1. Aquifer geometry and geological structures. Aquifer geometry used in the model is based on limited data obtained from petroleum exploration wells (Figure 9). The influence of faults and other geological structures on groundwater flow is unknown. The Markham Fault has been mapped within the study area (Figure 4) and can possibly be observed in one AEM transect (Figure 8). However, there is no geological log or water level data in the vicinity of (or on either side of) the fault to enable an assessment of its impacts on the groundwater flow system or to confirm its extent. The fault has been implemented as a partial barrier to groundwater flow, which is consistent with the limited observed head data (Section 10.2.5)
2. Local processes. Some hydraulic head observations may be influenced by local processes such as local-scale recharge and discharge or local variations in aquifer conditions that are not captured by the model. This has been highlighted through the

consistent under-prediction by the ensemble of 218 models of groundwater levels at the Scrubby site (Section 10.3).

3. Transient calibration data. There is no transient pumping and head measurement data available for the site to facilitate a transient calibration and constraint of aquifer storage values. A uniform value of aquifer storage has been implemented for the ensemble of predictive simulations, based on the results of the pumping test at Scrubby site. Spatial variations in aquifer storage between the Scrubby site and key receptors will influence drawdown. Review and transient calibration of the model once a time series of metered abstraction and groundwater level monitoring data is available will improve the model's ability to predict drawdown at receptors as a result of pumping at the Scrubby site.
4. Recharge and evapotranspiration. There are no local measurements of recharge rate and evapotranspiration available. Literature values have been used and uncertainty in these parameters has been captured via ranges applied during the conditioning process.

11. Assessment of Potential Impacts

11.1. Key Reporting Sites

The key reporting locations for this assessment are Ngooderoodyne Spring (Section 6.2.2) and the nearest permanent pool on the Lennard River that has been assessed as being groundwater dependent (Figure 23). Ngooderoodyne Spring is located approximately 13 km to the west of the Scrubby site. Hawkstone Creek is the closest surface water feature to the Scrubby site; however, the creek and its associated flora and fauna are currently considered unlikely to be highly groundwater dependent (Section 6.2.1). Sections of the May and Meda rivers also occur approximately 14.5 km to the south of the project site, however, these are separated from the Grant Group / Poole Sandstone aquifer system by the low permeability Liveringa Group and Noonkanbah Formation (Figure 4). Persistent surface water pools on the Lennard River represent the next closest surface water features to the Scrubby site. IGS (2019) conducted a run-of-river survey of these pools (Section 6.1; Appendix D) and found that the closest of these to the Scrubby site, located approximately 13.5 km to the south, had a low level of groundwater dependence based on measured surface water radon-222 activities. However, one pool located approximately 18 km to the south-east (site 10) was found to have a radon concentration of 1.08 Bq/L, suggesting a significant groundwater contribution. This pool therefore forms one of the key reporting sites, along with Ngooderoodyne Spring, for the groundwater impact assessment for this project.

11.2. Predicted Drawdown

Graphs of predicted drawdown at Ngooderoodyne Spring and the Lennard River Pool reporting site are shown for all 218 model realizations in Figure 31 and Figure 32. The 50th percentile model realization (based on maximum predicted drawdown for all times) predicts a drawdown after 10 years continuous abstraction of 1.01 m at Ngooderoodyne Spring and 0.46 m at the Lennard River Pool reporting site. Figure 33 to Figure 35 show the drawdown contours predicted at 1 yr., 10 yr. and 30 yr. by the same P50 model realization, while drawdown contours for the 10th and 90th percentile model realizations are provided for completeness in Appendix E.

Predicted drawdown is shown all the way out to 30 years on Figure 31, Figure 32 and Figure 35 and is summarized in Table 7 for the purpose of transparency. However, model predictions made beyond 10 years are considered to have limited relevance or reliability, firstly because there is currently no transient data available to enable conditioning of aquifer storage, limiting the accuracy of long-term drawdown predictions and prohibiting the quantification of uncertainty associated with this model parameter. A uniform specific yield value of 0.017, obtained from the pumping test at the Scrubby site, is valid as a first pass estimate and has been used for the current simulation. Sensitivity of predicted drawdown to changes in this value has been explored in Section 11.3. Secondly, external factors such as changing climate, irrigation practices and crop water requirements will all influence water use in the future, making predictions beyond 10 years irrelevant. The monitoring program and management framework described in Section 12 have been carefully designed to ensure that sufficient data is collected to enable improved prediction and effective mitigation of any long-term impacts.

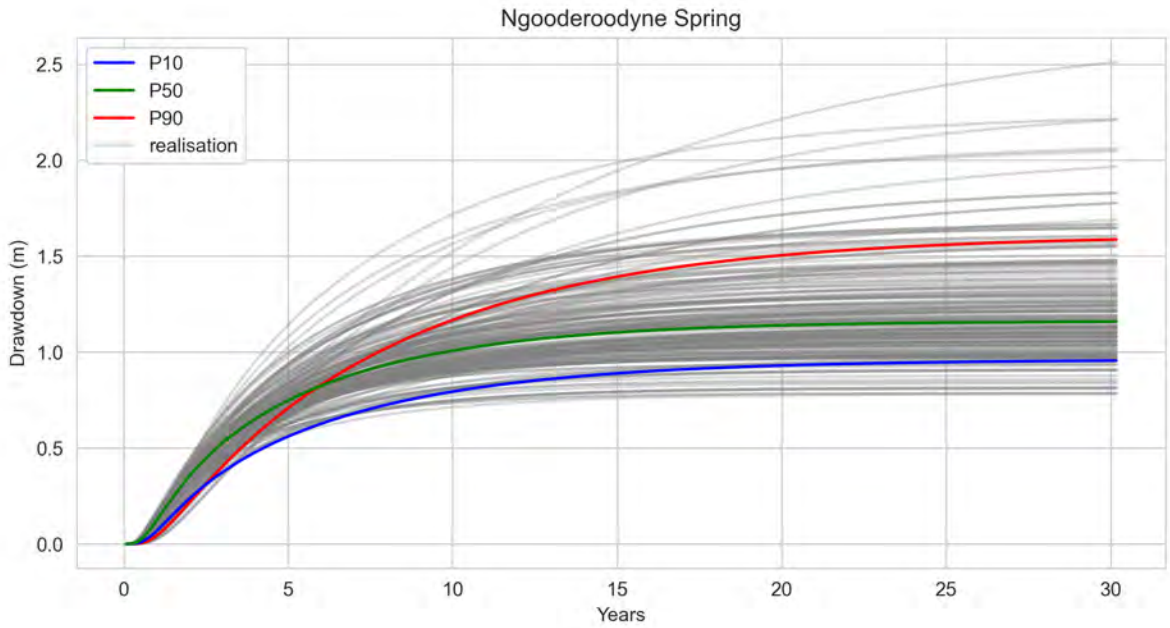


Figure 31. Graphs of predicted drawdown for Ngooderoodyne Spring for the entire ensemble of 218 models, with the P10, P50 and P90 realizations (based on maximum simulated drawdown for all time) indicated.

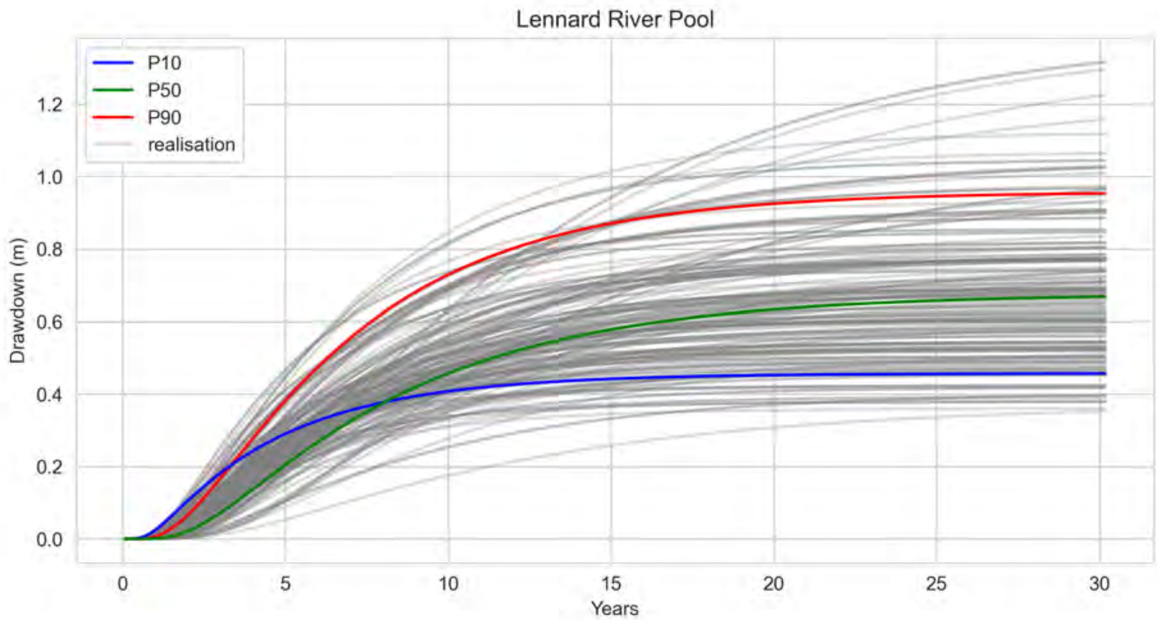


Figure 32. Graphs of predicted drawdown for the Lennard River Pool reporting site for the entire ensemble of 218 models, with the P10, P50 and P90 realizations (based on maximum simulated drawdown for all time) indicated.

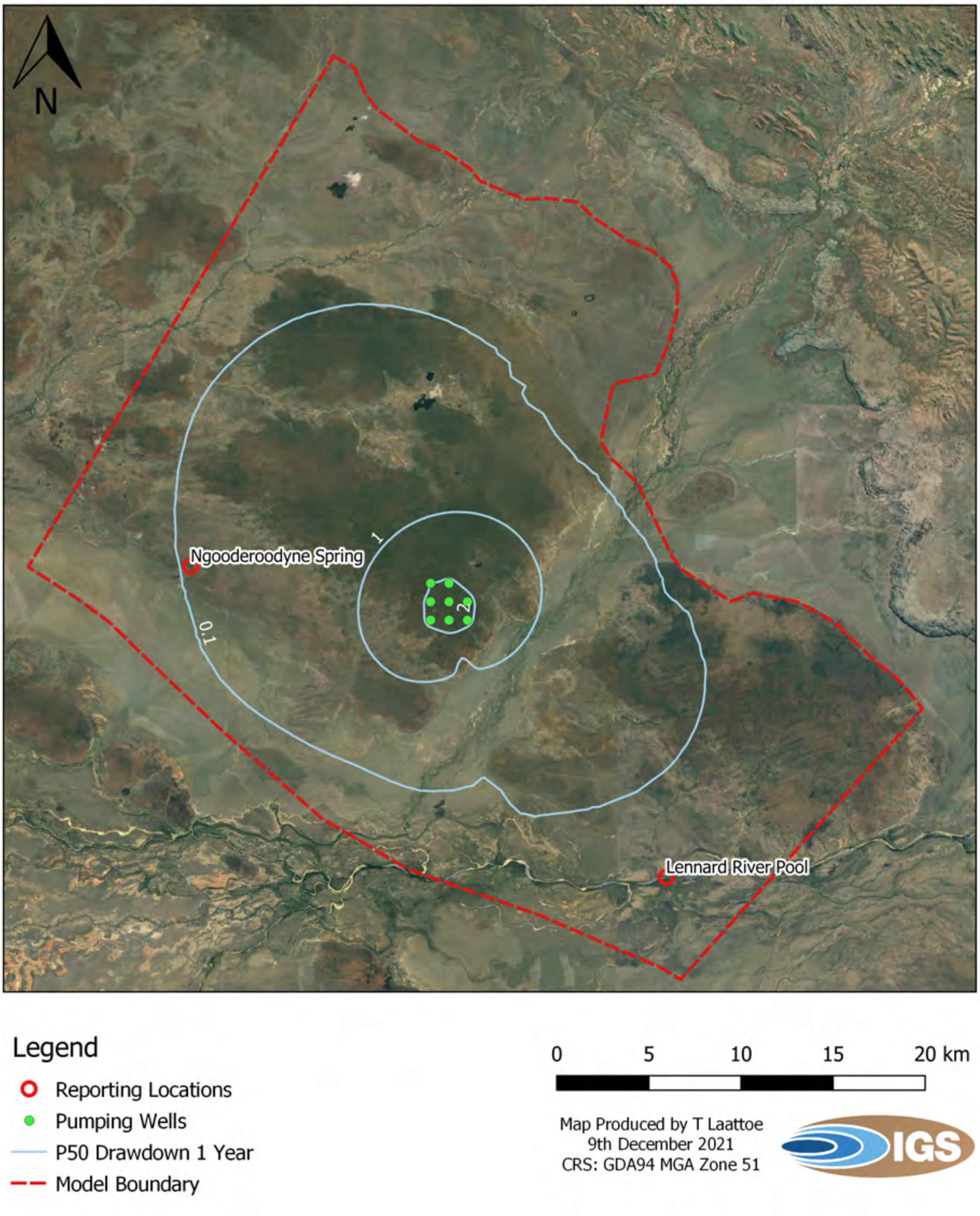


Figure 33. Predicted drawdown contours at 1 year for the model realization representing the 50th percentile of the maximum drawdown at Ngooderoodyne Spring.

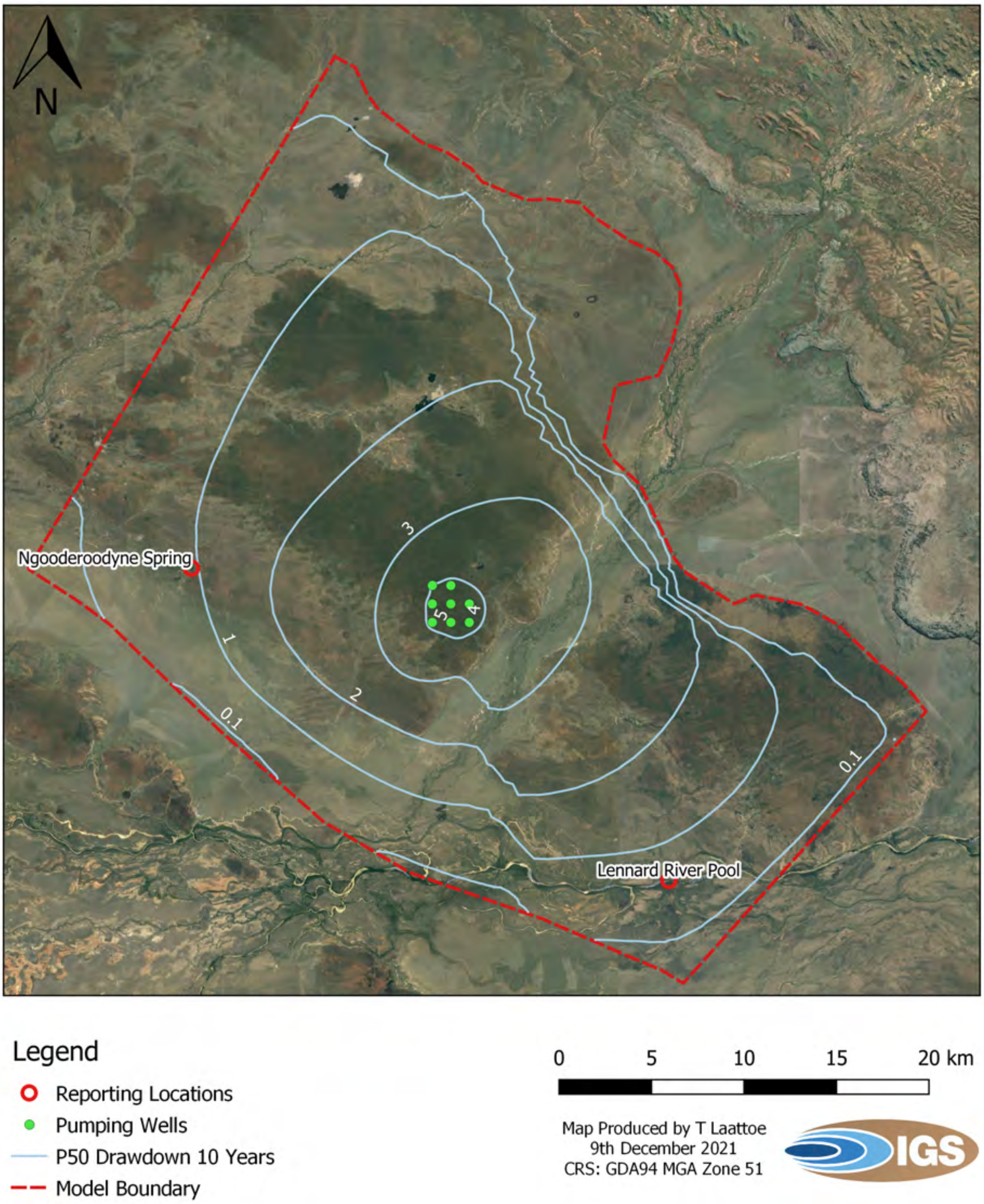


Figure 34. Predicted drawdown contours at 10 years for the model realization representing the 50th percentile of the maximum drawdown at Ngooderoodyne Spring.

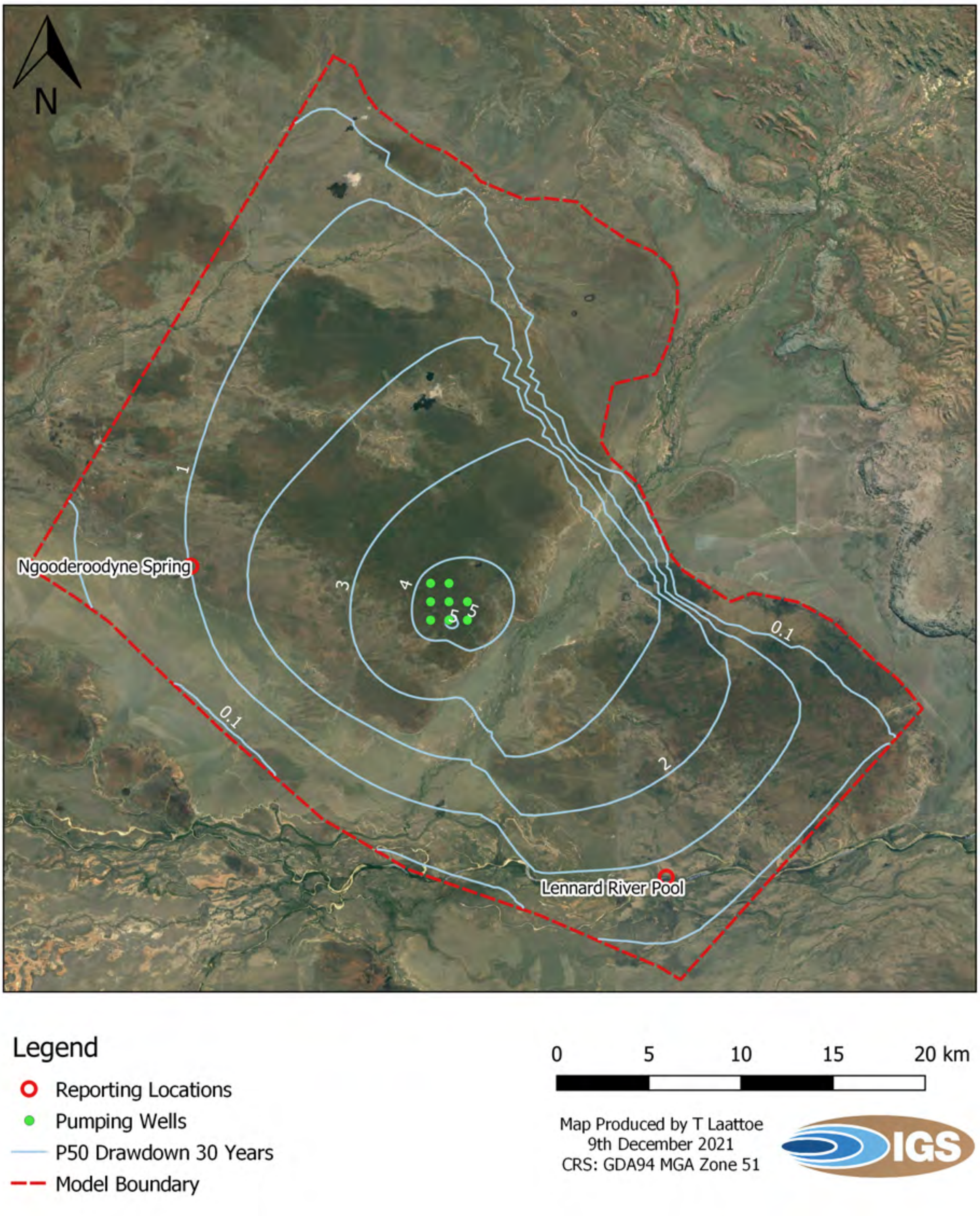


Figure 35. Predicted drawdown contours at 30 years for the model realization representing the 50th percentile of the maximum drawdown at Ngooderoodyne Spring.

Table 7. Summary of predicted drawdown at key receptors.

	Ngooderoodyne Spring	Lennard River Pool
Predicted Drawdown After 1 Year (m)		
P10	0.07	0.24
P50	0.12	0.00
P90	0.08	0.01
Predicted Drawdown After 10 Years (m)		
P10	0.79	0.41
P50	1.01	0.46
P90	1.27	0.68
Predicted Drawdown After 30 Years (m)		
P10	0.96	0.45
P50	1.16	0.67
P90	1.55	0.91

11.3. Sensitivity Analysis

The PESTPP-IES ensemble approach adopted for this investigation did not include any assessment of uncertainty in the amount of enhanced recharge along Hawkstone Creek, the hydraulic conductivity of the Markham Fault (flow barrier) or the aquifer specific yield. This was due to multiple factors including the implementation method in the model as well as limited data available to set prior parameter ranges. Accordingly, the effect of these model parameters on predicted drawdown at key reporting sites was assessed using the parameter changes presented in Table 8. The model realization that produces the P50 maximum drawdown at Ngooderoodyne Spring was used as the base case (Scenario 1).

Larger ranges were initially tested for the Markham Fault Kx and Hawkstone Creek recharge. However, models that used either very low fault Kx at 0.01 m/day, or high Hawkstone Creek recharge at 300 mm/yr., failed to converge in steady state indicating that these extreme parameter values are implausible. Thus, smaller ranges were adopted. Specific yield was varied upwards and downwards by 0.5% for the purpose of the sensitivity analysis, which is considered to be reasonable as all available data for the Grant Group aquifer suggests that it has low storage (Section 3.3.2).

Figure 36, Figure 37 and Table 8 show that, of the parameters tested, the predicted drawdown at key reporting sites is most sensitive to specific yield. For the range of specific yield tested (0.012 to 0.022) there is a difference in predicted drawdown after 10 years at Ngooderoodyne Spring of approximately 20 cm, with the difference becoming negligible after 30 years. Likewise, at the Lennard River Pool reporting site, the range of Sy tested results in a difference in predicted drawdown of approximately 15 cm after 10 years and a negligible difference after 30 years.

Table 8. Parameter combinations included in the sensitivity analysis and resulting drawdown predictions. Numbers in bold represent parameter values that have been changed from the base case scenario. Note that drawdown values for the Lennard River Pool in the base case scenario differ from the P50 results presented in Table 7 because they correspond to a different model realisation.

Scenario	Markham Fault Kx (m/day)	Hawkstone Creek Recharge (mm/yr.) *	Specific Yield	Ngooderoodyne Spring			Lennard River Pool		
				Drawdown at 1 year (m)	Drawdown at 10 years (m)	Drawdown at 30 years (m)	Drawdown at 1 year (m)	Drawdown at 10 years (m)	Drawdown at 30 years (m)
1 (Base Case)	0.1	200	0.017	0.12	1.00	1.16	0.00	0.59	0.77
2	**0.05**	200	0.017	0.12	1.00	1.15	0.00	0.55	0.71
3	**0.5**	200	0.017	0.12	1.00	1.14	0.00	0.54	0.69
4	0.1	**175**	0.017	0.122	1.00	1.16	0.00	0.59	0.77
5	0.1	**225**	0.017	0.122	1.00	1.16	0.00	0.59	0.77
6	0.1	200	**0.022**	0.08	0.92	1.15	0.00	0.49	0.76
7	0.1	200	**0.012**	0.19	1.07	1.16	0.01	0.68	0.77

*Recharge added to interpolated value assigned to model cell from pilot points then scaled according to cell area.

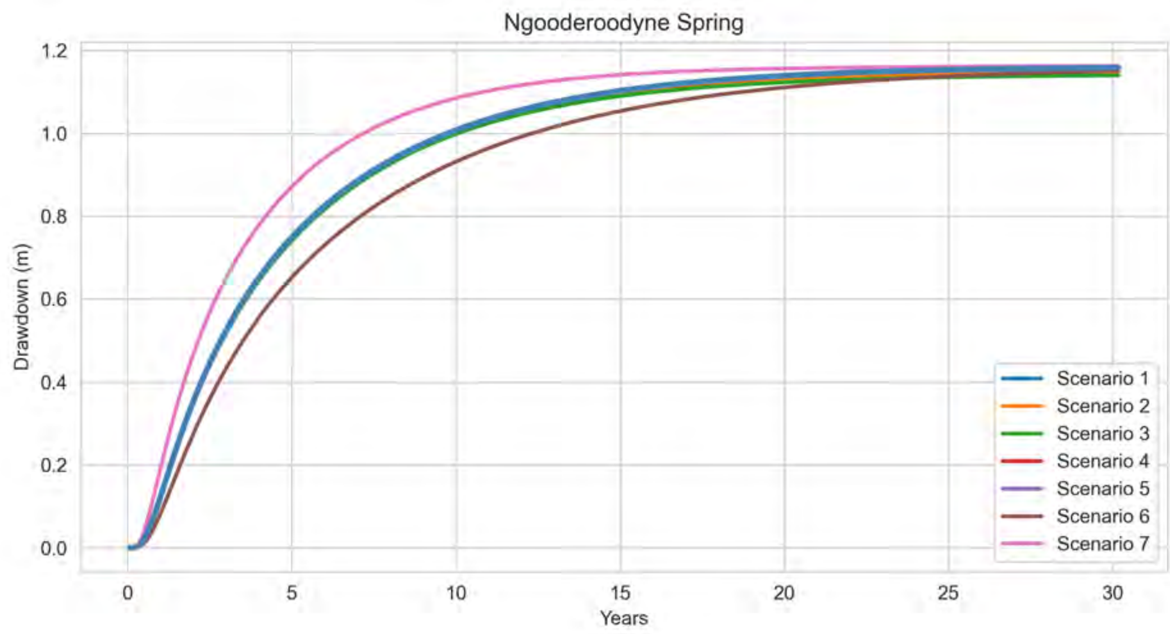


Figure 36. Graph of predicted drawdown vs time at Ngooderoodyne Spring for the sensitivity scenarios listed in Table 8.

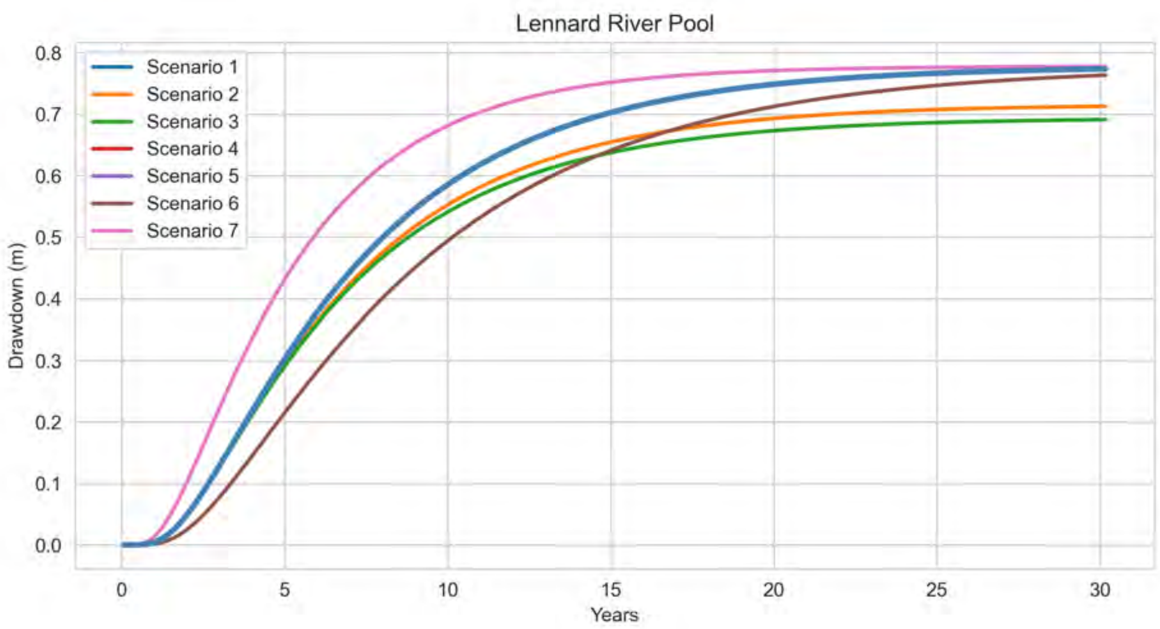


Figure 37. Graph of predicted drawdown vs time at the Lennard River Pool reporting site for the sensitivity scenarios listed in Table 8.

12. Recommendations

This H3 Hydrogeological Assessment has demonstrated that the proposed irrigation development of 6 GL/yr. as per the application by Napier Corporation Pty Ltd. on 4 December 2018 can be sustained at Scrubby site with acceptable levels of drawdown impact to groundwater-dependent environmental values. The inclusion of a formal uncertainty analysis in the modelling has enabled transparent communication of risks in terms of the range in potential long-term drawdown. Whilst any reliance on the 30-year predictions is strongly discouraged for the reasons discussed in the previous chapter, P50 drawdown impacts at Ngooderoodyne Spring and Lennard River Pool provide a defensible management target.

Drawdown at the nearest groundwater-fed pool in the Lennard River after 10 years continuous abstraction is predicted (at P50 probability) to be 0.46 m, which is highly unlikely to have any measurable impact to either the aquatic ecology or the health of adjacent riparian vegetation. However, predicted P50 drawdown at Ngooderoodyne Spring after 10 years is 1.01 m, which is possibly significant in terms of potential impact to supported biological values. However, this amount of predicted drawdown must be considered in the context of very limited knowledge of the conceptual hydrogeological model for the spring. Thus, a conservative approach is recommended for this irrigation development, such that it be permitted over two stages with each comprising 3 GL/yr. Detailed review of monitoring data and remodelling should be undertaken at the end of the first stage before proceeding with the second. This will be necessary to confirm the long-term sustainability of abstracting 6 GL/yr.

The overarching management objectives for this project should therefore be:

1. Do not exceed the licensed groundwater allocation, which is also termed the 'Annual Water Entitlement' (AWE);
2. Maintain drawdowns within acceptable limits so as not to impact ecological function of identified GDEs; and
3. Maintain groundwater quality, including salinity and nutrients, by managing the recycling of irrigation drainage water.

12.1. Monitoring Program

A comprehensive groundwater monitoring network not only provides evidence to DWER that the irrigation development is progressing within the range of predicted levels of impact; it also provides business confidence to ACE that each stage of development is sustainable for the long term.

A first draft of the proposed monitoring program for this irrigation development is outlined below in Table 10, however this should be finessed in consultation with DWER technical specialists once ACE has received notification that the granting of a water extraction licence is imminent. The final adopted management framework will be included as part of the Detailed Water Resource Operating Strategy (DWROS).

Table 9. Draft monitoring program

Category	Parameters	Monitoring Site	Frequency	Time	Comment
Climate	Rainfall	Derby Aero Bureau of Meteorology site no. 003032	daily	9 am	Data downloaded for annual reporting purposes
Water Use	Flowmeter reading	Operating production bores	monthly	As close as practicable to the end of the month	
Barometric pressure	Pressure (pressure transducer logged data)	NDSMB01	hourly	Ongoing	Used to correct pressure readings collected by pressure transducers recording changes in groundwater level
Groundwater pressure	Pressure (pressure transducer logged data)	NDSMB01 plus, two new set of paired monitoring bores: NDSMB02S & NDSMB02I on western boundary of NDS near Ngooderoodyne Spring NDSMB03S & NDSMB03I on southern boundary of NDS near Lennard River Pool	hourly	Ongoing	
Groundwater levels	Depth to water	NDSMB01 Hawkstone Bore Leuts Bore plus, two new set of paired monitoring bores: NDSMB02S & NDSMB02I on western boundary of NDS near Ngooderoodyne Spring NDSMB03S & NDSMB03I on southern boundary of NDS near Lennard River Pool	quarterly	Dec/Jan, Mar/Apr, Jun/Jul, Sep/Oct	
Groundwater quality	Field electrical conductivity and pH	Operating production bores	monthly	As close as practicable to the end of the month. Measurements taken using a	

Category	Parameters	Monitoring Site	Frequency	Time	Comment
				hand-held pH & electrical conductivity meter	
	pH, conductivity (compensated to 25 ^0C), TDS, Alkalinity (as $CaCO_3$), Na, Ca, K, Mg, Carbonate, Bicarbonate, Chloride, Sulphate, Nitrate, Total Nitrogen Oxides (or Nitrite), Ammonia, Total Kjeldahl Nitrogen, Nitrogen, Phosphate, Total Phosphorus, Aluminium, Bromide, Boron, Cadmium, Chromium, Copper, Fluoride, Iron, Lead, Molybdenum, Nickel, Silicon, Strontium, Zinc	Production bores	Annual	Sep/Oct	Comprehensive groundwater chemistry to be collected at new and replacement production bores after bore construction (pumped sample, not airlift sample) then annually. If annual sampling determines that all production bores are of similar chemistry, the number of sampling sites will be reduced to one representative site. Depth of sampling point for monitoring bores must be consistent and stipulated in Detailed Water Resource Operating Strategy
Vegetation monitoring	Vegetation condition	Transect of groundwater dependent vegetation at Ngooderoodyne Spring	Baseline & Annual if water level trigger exceeded	Baseline to be established prior to abstraction commencing. Bi-annual where groundwater level trigger exceeded	Off-lease monitoring at Ngood. Spring will be subject to ACE negotiating an access agreement with the neighbouring Meda Station.

12.2. Management Framework

A first draft of the proposed management framework for this irrigation development is outlined below in Table 10, however this should be finessed in consultation with DWER technical specialists once ACE has received notification that the granting of a water extraction licence is imminent. The final adopted management framework will be included as part of the Detailed Water Resource Operating Strategy (DWROS).

Table 10. Draft management framework

"Level 1 trigger" is to provide early warning that impacts may exceed the predicted conditions, and thus investigation of causal factors is warranted. This in-turn may lead to mitigation measures being implemented.

"Level 2 trigger" is a threshold beyond which the impacts are unacceptable and immediate management intervention is required to mitigate against any adverse impacts occurring to existing users or the environment.

Issue	Management Objectives	Measurement	Trigger Description	Level 1 Trigger value	Level 2 Trigger value	Level 1 response	Level 2 response	Comment
Over abstraction	Do not exceed the licensed groundwater allocation	Monthly flowmeter readings and volume calculations	Change in irrigation operations	Greater than expected cumulative water use in the year	AWE	Manage abstraction so that AWE is not exceeded. Advise DWER of possible breach of licence conditions. Keep record of correspondence	Cease abstraction until new water year	Exceedance of the AWE is noncompliance to licence conditions
Drawdown impacts on GDEs	Drawdowns to be within acceptable limits so as not to impact ecological function of identified GDEs	Groundwater levels at new paired monitoring bores: NDSMB02S & NDSMB02I on western boundary of NDS near Ngooderoodyne Spring NDSMB03S & NDSMB03I on southern boundary of NDS near Lennard River Pool	Water levels lower than acceptable	Adopted trigger level to be established by modelling P50 drawdown at 10 years once bore locations known	Adopted trigger level to be established by modelling P90 drawdown at 10 years once bore locations known	Reassessment of drawdown predictions Review data against climate factors to determine cause of trigger exceedance Commence annual vegetation monitoring at NS and/or pool survey in Lennard River	Conduct bi-annual vegetation monitoring at NS If vegetation is stressed, reduce, move or cease abstraction until water levels recover If vegetation is not stressed, review model and revise triggers if necessary	Off-lease monitoring at Ngood. Spring will be subject to ACE negotiating an access agreement with the neighbouring Meda Station.

Issue	Management Objectives	Measurement	Trigger Description	Level 1 Trigger value	Level 2 Trigger value	Level 1 response	Level 2 response	Comment
Groundwater salinity	Maintain groundwater quality	Electrical conductivity in groundwater from operating production bores	Field electrical conductivity exceeds acceptable value	Values exceed baseline by 25% or 100 μS/cm (whichever is greater). NB. Baseline value to be based on 80th percentile of measured historical data.	Values exceed baseline by 50% or 200 μS/cm (whichever is greater). NB. Baseline value to be based on 80th percentile of measured historical data.	Repeat quarterly measurement. Review EC data to assess seasonal fluctuations and increasing trend. Initiate internal investigation regarding causes for increases in salinity. Report findings in Annual monitoring report.	Repeat quarterly measurement. If the repeat measurement is greater than Level 2 Trigger value, then report exceedance to DWER within 10 working days	Need to account for seasonal and inter-annual wetting and drying cycles and their impact on EC and/or chemistry
Changes to water quality due to abstraction and/or fertiliser application	Maintain groundwater quality	Annual comprehensive water quality analysis of pumped groundwater sampled from operating production bores	TN, TP, pH, EC exceed acceptable values	Adopted trigger levels for nutrients and pH to be set following a minimum one year of continuous baseline monitoring to assess natural variation.	Adopted trigger levels for nutrients and pH to be set following a minimum one year of continuous baseline monitoring to assess natural variation.	Repeat sampling if results deemed spurious. Review data to assess seasonal fluctuations and trends. Initiate internal investigation regarding causes for exceedances. Report findings in Annual report Develop water quality management plan for approval by DWER	Invoke management actions stipulated in water quality management plan	Depth of sampling point in bores must be consistent and stipulated in Operating Strategy Need to establish baseline nutrients and pH before triggers can be set

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Appendix A

IGS (2018a) – Groundwater Opportunities

Groundwater development opportunities for selected pastoral leases in the West Kimberley region

A report prepared for Australian Capital Equity Pty Ltd.

22 October 2018

Final Version 2.0
Commercial in Confidence

Innovative Groundwater Solutions

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Groundwater development opportunities for selected pastoral leases in the West Kimberley region

A report prepared for Australian Capital Equity

by

Innovative Groundwater Solutions

22 October 2018

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The information in this report is considered to be accurate at the time of investigation. IGS has used the methodology and sources of information outlined within this report and has made no independent verification of this information beyond the agreed scope of works. IGS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that the information collated by IGS was false.

Suggested Citation

IGS (2018). Groundwater development opportunities for selected pastoral leases in the West Kimberley region. A report prepared for Australian Capital Equity Pty Ltd. by Innovative Groundwater Solutions Pty Ltd.

EXECUTIVE SUMMARY

Australian Capital Equity Pty Ltd. (ACE) currently owns Napier Downs, Mount House and Glenroy stations in the west Kimberley region, and has expressed interest in subleasing the adjacent Fairfield and Leopold Downs stations from the Bunuba traditional owners. Innovative Groundwater Solutions Pty Ltd. was commissioned by ACE to provide a desktop assessment of the potential groundwater development opportunities for these five stations.

Analysis of regional geology maps and historical bore records, coupled with new hydrostratigraphic interpretation of Airborne Electromagnetic survey data collected by the Water for Food Initiative, has found that the Permian-age Grant Group sandstones and Devonian-age reef limestones offer the greatest prospects for future groundwater development.

Napier Downs Station has a large area of Grant Group aquifer in the southwest corner of the property, which in many places extends 200 – 300 m below ground surface, and a smaller area of Devonian reef in the centre of the property that is mostly unexplored. A future work program that includes a bore audit followed by exploratory drilling and aquifer pumping tests is recommended to provide improved confidence in local bore yields and water quality. Pending success of these investigations, the Grant Group aquifer or Devonian reef aquifer may be capable of sustaining developments of between 2 – 5 GL/yr or 1 – 2 GL/yr, respectively.

> A 2 – 5 GL/yr groundwater development would allow irrigation of fodder crops with a combined area of between 100 – 330 hectares assuming an average crop water requirement of between 15 – 20 ML/ha/yr. By way of example, a carefully managed and routinely harvested crop of Rhodes grass or Forage Sorghum is capable of yielding between 25 – 35 tonnes per hectare per annum in this region. Higher yields are achievable but come at the expense of lower quality product. In any case, these preliminary calculations suggest that fodder production in the order of 2,500 to 11,500 tonnes per annum may be achievable on Napier Downs. This presents a significant commercial opportunity given that ACE purchased approximately 1,300 tonnes of hay last year at a cost of around four hundred and fifty thousand dollars. Such development would also provide opportunities for increasing the volume and/or quality of cattle production that comes with having high-quality feed produced on the property.

Leopold Downs Station has a small area of Devonian reef limestone in the southwest corner of the property. Despite historical drilling records existing for this area, there remains uncertainty around the yields that could be achieved from properly constructed production bores; hence a similar future work program is recommended in this location, which may demonstrate that a development of between 1 – 2 GL/yr (or 50 – 130 hectares) is possible.

The remaining areas of Napier Downs and Leopold Downs stations, and the entirety of Fairfield, Mount House and Glenroy stations, all have very low potential to sustain large-scale groundwater development due to the underlying geology. However, the Devonian

Fairfield Group and wide variety of Precambrian fractured-rock aquifers in these areas could provide reliable stock water supplies.

CONTENTS

1. Introduction

1.1. Background

Innovative Groundwater Solutions Pty Ltd. (IGS) was commissioned by Australian Capital Equity Pty Ltd. (ACE) to identify groundwater development opportunities for five different pastoral leases in the West Kimberley region of Western Australia. ACE currently own three of these pastoral leases, namely Napier Downs, Mount House and Glenroy stations, and negotiations are progressing with Bunuba traditional owners to sublease the adjacent Fairfield and Leopold Downs stations.

1.2. Aims & Objectives

The principal aim of this study was to provide a high-level, strategic yet science-based assessment of the potential groundwater development opportunities for the five pastoral leases. In order to achieve this aim, the following objectives were set:

1. Collate and synthesise all available data to identify key groundwater resources;
2. Interpret recently acquired geophysical data to better define aquifer extents and thicknesses;
3. Estimate the potential scale of groundwater development for each aquifer/pastoral lease; and
4. Outline the steps required to provide further confidence in groundwater resource potential, including field investigations.

2. Methodology

The approach for this desktop study was to collate and analyse all relevant existing information on aquifer thicknesses and extents, current levels of groundwater allocation, and historical measurements of groundwater quality and bore yields. Three primary datasets were available in addition to published literature:

- Regional geology mapping
- Airborne Electromagnetic survey
- Historical bore database

2.1. Regional Geology Mapping

The latest state-wide 1:500 000 basement geology map for Western Australia (GSWA, 2016) provides the foundation for this study. Whilst the mapping is regularly revised as new information comes to hand for different regions, it remains the most valuable tool for desktop assessments in data spare areas such as the West Kimberley.

2.2. AEM Survey

As part of the Water for Food Initiative, the Government of Western Australia, Department of Water commissioned Geoscience Australia to conduct a SkyTEM airborne electromagnetic (AEM) survey during September – October 2015. Approximately 5,300-line kilometres were flown over the West Kimberley region, covering the Fitzroy, May and Meda river catchments (Figure 1). The need for this survey was identified through the Lower Fitzroy River Groundwater Review, which was undertaken by IGS for the Water for Food Initiative (Harrington and Harrington, 2015). Unfortunately for this study the AEM survey extent only covers part of Napier Downs Station (Figure 1).

While the aim of the survey was to map the conductivity structure of the geological formations within the study area, interpretation to date has been sporadic and piecemeal on a project-by-project basis. The bulk electrical conductivity of the subsurface is a function of three key parameters:

- lithology, in particular clay-mineral content;
- water content, in particular unsaturated versus saturated rocks; and
- groundwater salinity.

In general, geologic formations that exhibit very low conductivity will tend to be coarse grained (thus highly permeable) and low salinity aquifers, while formations that exhibit very high conductivity will be finer grained (thus less permeable) aquitards with high salinity groundwater.

2.3. Historical Bore Data

Historical bore data is stored in the Government of Western Australia, Department of Water and Environmental Regulation (DWER) WIN database, which was downloaded for the current study area using the Spatial Download Tool at http://atlases.water.wa.gov.au/idelve/dowdataext/download/default.html.

3. Groundwater Resource Appraisal

The five pastoral leases that are the focus of this study can be considered as three distinct areas based on their very different underlying geologies and thus groundwater potential. Accordingly, the assessment of potential groundwater opportunities has been broken down in this chapter as follows (i) Napier Downs Station, (ii) Fairfield and Leopold Downs stations, and (iii) Mount House and Glenroy stations.

3.1. Napier Downs Station

3.1.1. Regional Geology & Hydrogeology

Between 25 and 30% of the total area of Napier Downs Station is underlain by Grant Group sediments of the Canning Basin, confined to the southwestern corner of the property (see Figure 2). Another 50% of the total area, north of a line running diagonally from the northwest corner to the southeast corner, is defined by much older, igneous and metamorphic rocks including the Paperbark Supersuite (granites), Marboo Formation (metasandstone and phyllite), Whitewater Volcanics, and Ruins Dolerite. The remaining 20 to 25% of the total area, running diagonally through the middle of the property, is comprised of Devonian-age sedimentary rocks including the Fairfield Group (limestone, shale and siltstone) and various reef limestone complexes.

The Grant Group comprises mainly sandstones and siltstones and is likely to be the most prospective regional-scale aquifer encountered on all of the pastoral leases (Harrington and Harrington, 2015). Groundwater salinity is generally fresh, ranging from 300 mg/L to 1,500 mg/L as total dissolved salts (TDS). Bore yields for the Grant Group aquifer range from being just adequate for stock water supply up to values suitable for supplying large irrigation infrastructure. Lindsay and Commander (2005) report bore yields for Ellendale diamond mine of up to 2,000 m^3/day (23 L/s) although DWER (2017) quote an unpublished source that suggests Grant Group bores at the mine have achieved up to 132 L/s (11,000 m^3/day).

DWER (2017) reports the results of drilling and constructing a test production bore in the Grant Group at Kimberley Downs Station, followed by a 48-hour aquifer pumping test in late 2016. The production bore was constructed with 255 mm ID steel casing and a stainless-steel screened interval from 94 – 112 m below ground level (BGL). Standing water level (SWL) was recorded at 21.00 m BGL. The aquifer pumping test revealed the bore was capable of supplying at least 25 L/s with a pumping water level of >60 m. Observations also suggested the bore may have potential to supply up to 40 L/s if it were further developed.

Besides the Grant Group, the only other geological formations that have significant water bearing capacity are the Devonian reef limestone aquifers. Water quality is similar to, if not slightly fresher than, that observed in the Grant Group although the water chemistry is more calcium-carbonate dominated and therefore can present calcification issues with irrigation infrastructure if not managed. Bore yields are highly variable but examples from

GoGo Station south of Fitzroy Crossing demonstrate that properly constructed production bores in the reef limestones are capable of supplying 50 L/s.

The Devonian Fairfield Group and much older fractured-rock aquifers are generally much lower yielding and more variable in water quality; hence they are only used for small stock and domestic supplies.

3.1.2. AEM Survey Interpretation

Nine of the 2015 AEM survey lines were selected for hydrostratigraphic interpretation of the conductivity-depth sections; the locations of these lines are shown in Figure 1, Figure 2 and Figure 3, with the latter incorporating the top 200 – 300 m of each conductivity-depth section. The interpretations are presented in Appendix B with key findings summarised as follows:

- Line 200006: thick sequence of prospective (blue coloured) Grant Group immediately to the right (i.e. north) of the Napier Downs boundary for about 5 km before transitioning into less prospective (green coloured) Fairfield Group. Note younger sediments of the Canning Basin overlying Grant Group to the left (i.e. south) of the station boundary.
- Line 200205: as above, although Grant Group more extensive and the potentially prospective Devonian reef limestone is also present at the far right/north.
- Line 200302: thick sequence of prospective (blue coloured) Grant Group immediately to the right (i.e. north) of the Napier Downs boundary for about 5 km, noting that this extends past the limit of the AEM section.
- Line 200503: thinner and less extensive Grant Group. Very low prospectivity (red coloured) zone at shallow depth and dipping southwards not consistent with 1:500k geology map; possibly Fairfield Group as one historical drilling log (Hawkestone Creek, Table 1) suggests Devonian formation was encountered at 170 m below Grant Group.
- Line 200801: thick sequence of prospective (blue coloured) Grant Group immediately to the right (i.e. north) of the Napier Downs boundary for about 10 km before transitioning into less prospective (green coloured) Fairfield Group.
- Line 200901: very thick sequence of prospective (blue coloured) Grant Group immediately to the right (i.e. north) of the Napier Downs boundary for 5 – 10 km before transitioning into less prospective (green/red coloured) Fairfield Group. Devonian reef limestone is also present at the far right/north.
- Line 201001: variably thick sequence of prospective (blue coloured) Grant Group immediately to the right (i.e. north) of the Napier Downs boundary for about 6 km before transitioning into very low prospectivity (green/red coloured) Fairfield Group.
- Line 300001: very small (<1 km) area of Grant Group underlying Alluvium associated with the Lennard River. Most of the line/section north of the Napier Downs boundary is low prospectivity (green-red coloured) Fairfield Group. Devonian reef limestone is present at the far right/north.
- Line 300101: north of the Napier Downs boundary is very low prospectivity (yellow-red coloured) Fairfield Group.

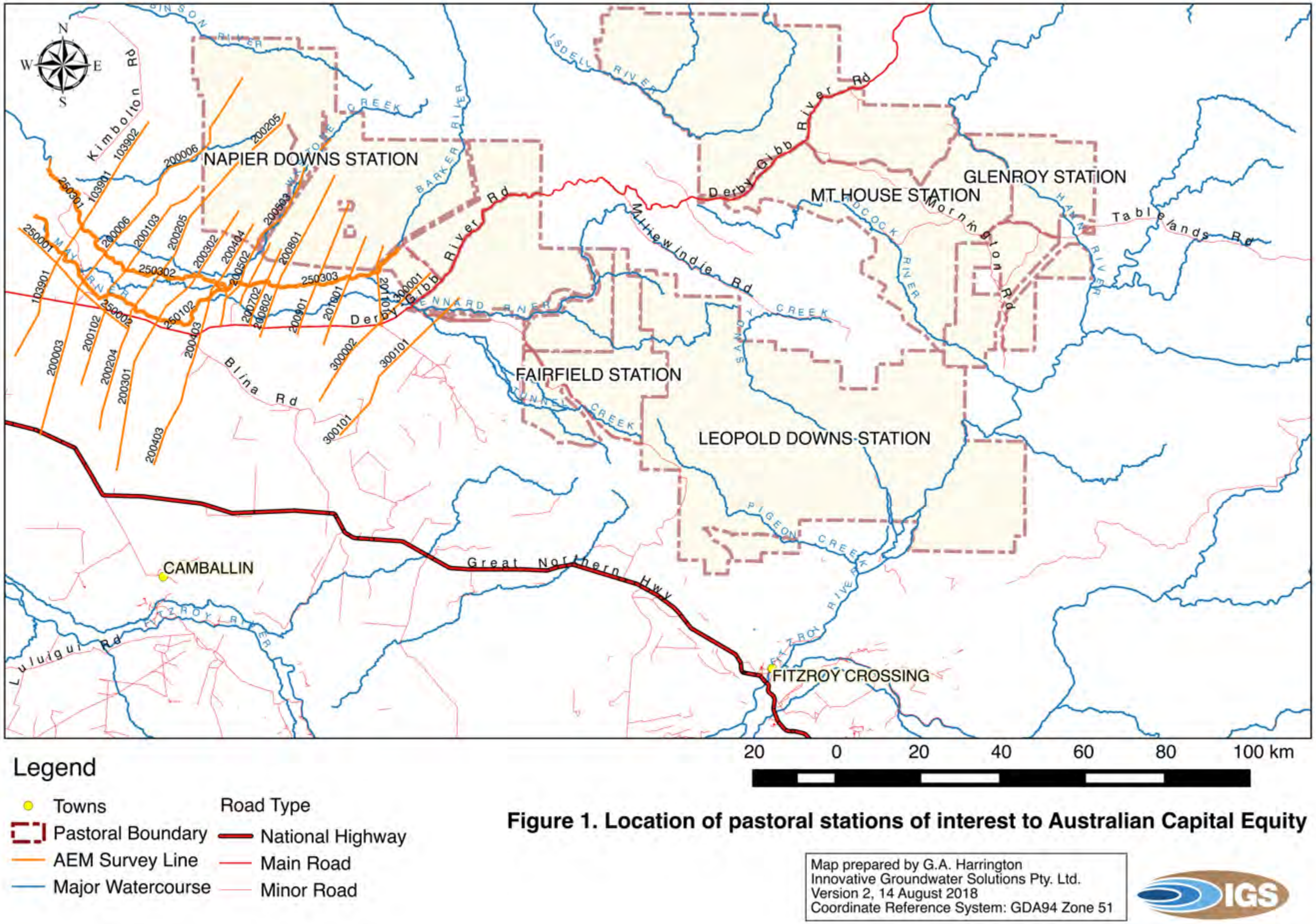

Figure 1. Location of pastoral stations of interest to Australian Capital Equity

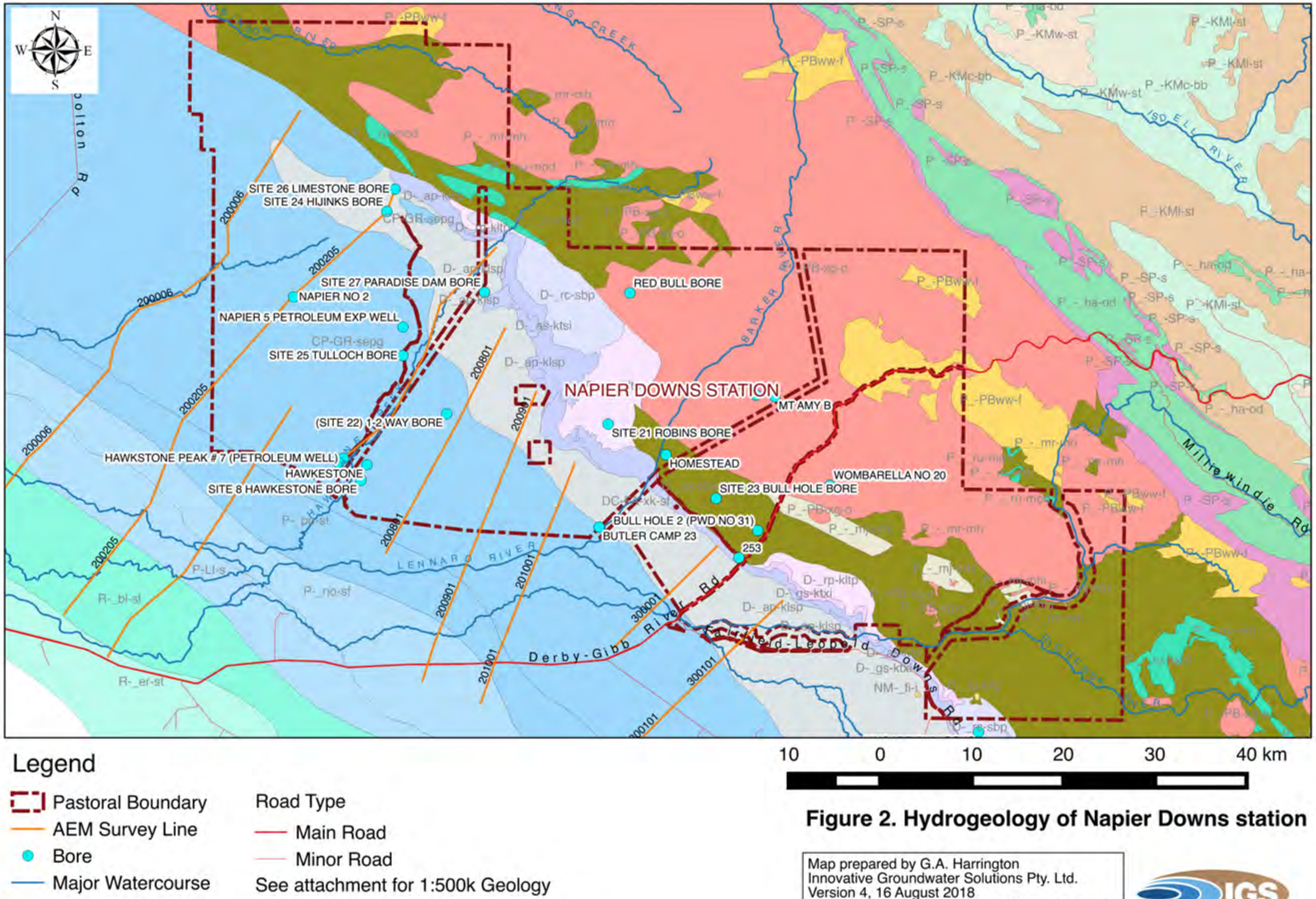

Figure 2. Hydrogeology of Napier Downs station

Map prepared by G.A. Harrington
Innovative Groundwater Solutions Pty. Ltd.
Version 4, 16 August 2018
Coordinate Reference System: GDA94 Zone 51

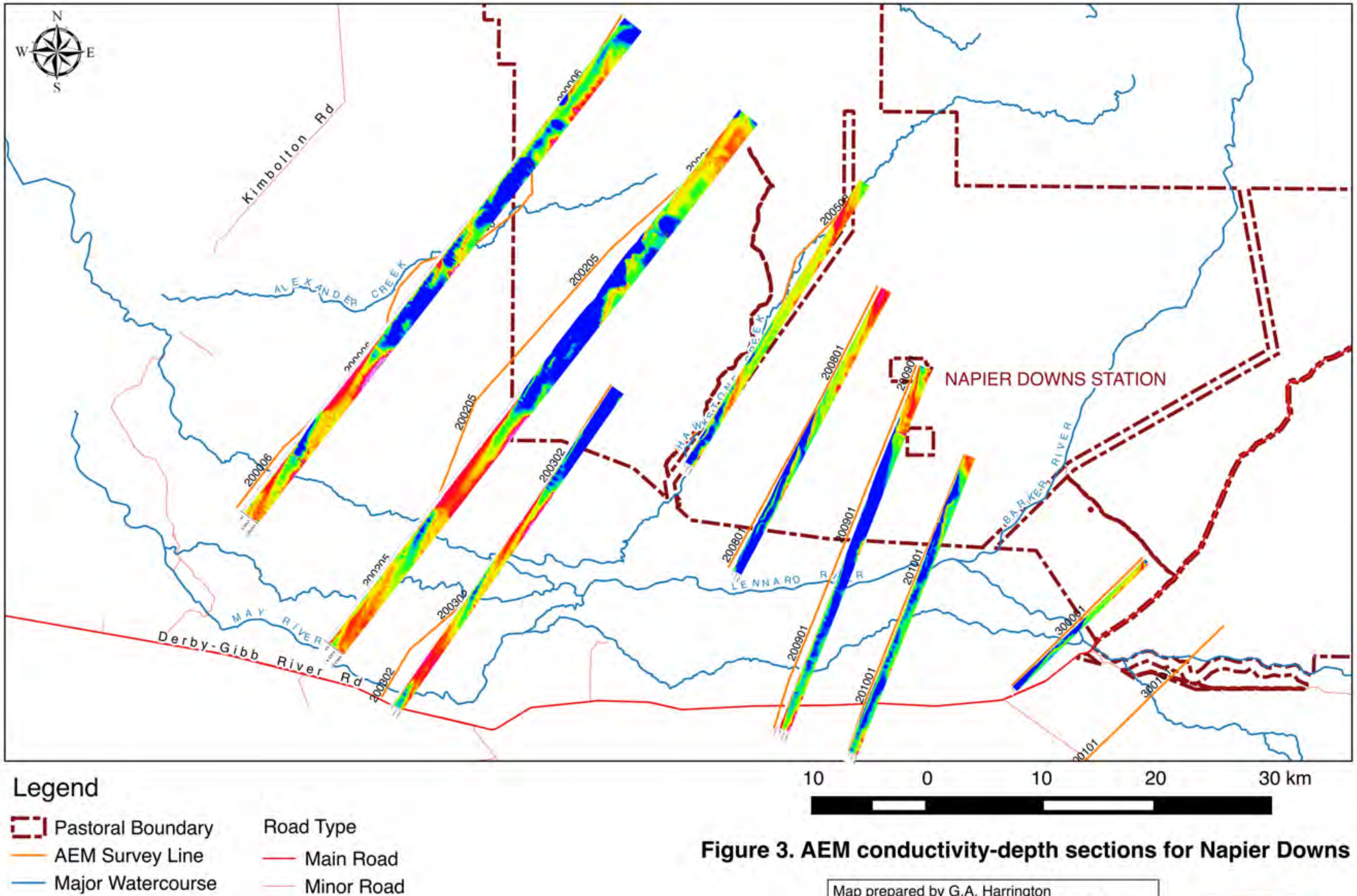

Figure 3. AEM conductivity-depth sections for Napier Downs

Map prepared by G.A. Harrington
Innovative Groundwater Solutions Pty. Ltd.
Version 1, 14 August 2018
Coordinate Reference System: GDA94 Zone 51

Table 1 Napier Downs Station bores registered in the DWER database

AWRC SITE NAME	ZONE	EASTING	NORTHING	Date Drilled	Drilled Depth (m)	Yield (m^3/day)	Water Level (m BGL)	TDS (mg/L)	Site Comments
(SITE 22) 1-2 WAY BORE	51	661381	8098388	NA	29.57	10.911	NA	NA	LIMESTONE WATER AT 75FT
SITE 21 ROBINS BORE	51	679019	8097259	1959	28.04	NA	NA	NA	DUD
SITE 8 HAWKESTONE BORE	51	652015	8091163	NA	41.45	NA	NA	NA	NO INFORMATION
HAWKESTONE	51	652679	8092806	NA	34.14	NA	10.67	120 on 08-08-87	VISITED BY GEOLOGIST R CROWE 1976 WHO RECORDS SALINITY IN FLOW TO BE 250PPM. SUB ARTESIAN GRANT FM
SITE 26 LIMESTONE BORE	51	655738	8122923	NA		NA	NA	NA	DUD, NO INFORMATION
HOMESTEAD	51	685329	8093907	1966	32.92	99.287	NA	NA	DEEPENED FROM 86' WATER CUT AT 39'. SILTATION PROBLEMS. DEPTH ORIGINALLY RECORDED AS: 86/108FT. Bore inlet from 29.26 to 32.92m
SITE 23 BULL HOLE BORE	51	690812	8089193	NA	24.38	NA	NA	NA	GRANITE AT 80FT DUD.
HAWKSTONE PEAK # 7 (PETROLEUM WELL)	51	650108	8093516	26/11/62	1188	NA	NA	360 on 08-08-87	SEE PETROLEUM WELL COMPLETION REPORT FOR FURTHER INFORMATION. DRILLED: 17/10/62-26/11/62
SITE 25 TULLOCH BORE	51	656610	8104733	NA	51.21	NA	NA	375	WATER AT 135FT & THERE IS A GOOD SUPPLY
BUTLER CAMP 23	51	678035	8086056	NA	32.31	NA	14.17	231	MOVING SAND - BORE SILTATION & BLOCKAGE. REC BY: FARBRIDGE
MT AMY A	51	695199	8100424	1966	13.11	0	NA	NA	ALLUVIUM OVER WEATHERED GRANITE, HIGH KAOLIN CLAY CONTENT. REC BY: FARBRIDGE
SITE 27 PARADISE DAM BORE	51	665518	8111677			NA	NA	NA	NO INFORMATION
253	51	693306	8082715	NA		NA	NA	320 on 03-09-87	BORE IS OPERATING. SUBMERSIBLE PUMP.
BULL HOLE 2 (PWD NO 31)	51	695359	8085694	1961	36.58	NA	NA	NA	DUD. REC BY: FARBRIDGE
SITE 24 HIJINKS BORE	51	654860	8120484	NA	72.24	NA	NA	NA	DUD
MT AMY B	51	697238	8100261	1966	21.34	0	NA	NA	ALLUVIUM OVER WEATHERED GRANITE HIGH KAOLIN CLAY CONTENT. REC BY: FARBRIDGE

AWRC SITE NAME	ZONE	EASTING	NORTHING	Date Drilled	Drilled Depth (m)	Yield (m^3/day)	Water Level (m BGL)	TDS (mg/L)	Site Comments
RED BULL BORE	51	681403	8111584	1959	53.34	NA	6.1	340 in 1959	REC BY: FARBRIDGE
WOMBARELLA NO 20	51	703247	8090611	1959	57.91	21.821	NA	NA	NOT EQUIPPED. PWD PLAN OF STATION STATES DEPTH 170FT & CLASSIFIES IT AS A DUD. FARBRIDGE REC 1967/5 STATES TD. REC BY: FARBRIDGE
NAPIER NO 2	51	644671	8111141	NA		NA	NA	1240	ANALYSIS DATA - TDS ORIGINALLY RECORDED AS: 1240-1760PPM. TEST INTERVAL: 4025-4232, FM & AGE: UNNAMED DEVONIAN, DATE: 12/69, RW OHM (M): 7.50, TEMP DEG F: 68, C1-ION PPM: 240, NACL PPM: 396, TDS 1240; TEST INTERVAL: 4750-4915
HAWKESTONE CREEK	51	649580	8093046	NA	198.12	NA	NA	NA	VISITED BY GEOLOGIST R CROWE 1976 WHO RECORDS BORE IS ABANDONED. 10 MILES NNE MT MARMION-FAILURE. WATER AT APPROX 140FT; 0-170 GRANT FORMATION THEN DEVONIAN.
NAPIER 5 PETROLEUM EXP WELL	51	656620	8107866	1970	1657	NA	NA	180 on 08-08-87	SEE S596 FOR FURTHER DETAILS
NAPIER HOUSE NEW HMSTD	51	685329	8093907	NA	30.48	NA	10.67	240	REC BY: FARBRIDGE

3.1.1. Historical Bore Records

A total of 22 bores are currently registered in the DWER database (Table 1) as being located on Napier Downs Station, with the majority of these drilled into (and in some cases through) either the Grant Group or Devonian sediments. This limited dataset shows groundwater salinities ranging from 180 – 375 mg/L as TDS and most bores having very low yields (less than 100 m^3/day or 1 L/s). Many of the bores constructed in the fractured-rock aquifers were reported as “dud”.

3.2. FAIRFIELD AND LEOPOLD DOWNS STATIONS

3.2.1. Regional Geology & Hydrogeology

Almost the entire combined area of Fairfield and Leopold Downs stations is underlain by Precambrian-age Paperbark Supersuite granites and Marboo Formation metamorphic rocks (Figure 4). Both geologies present very limited opportunities for groundwater development beyond small stock supplies.

The western approximately one-third of Fairfield Station is underlain by Devonian Fairfield Group sediments, which also offer limited groundwater prospects. However, a small area in the far southwest corner of Leopold Downs Station is dominated by Devonian reef limestone complexes (Figure 4). This area probably has the greatest prospects for future groundwater development on either station, as reflected in the current distribution of bores that have been constructed in limestones and calcareous sandstones.

3.2.2. Historical Bore Records

A total of 18 bores are currently registered in the DWER database (Table 2) as being located on Fairfield and Leopold Downs stations, with the majority of these drilled into Devonian sediments. As was the case for Napier Downs, this dataset is limited but shows a range of groundwater salinities from 370 – 1,000 mg/L as TDS with the highest values (730, 830 and 1,000 mg/L) being associated with granite and metamorphic rocks. Bore yields are equally variable and there is no data to indicate that a bore completed in the reef limestones in this area could supply large-scale irrigation infrastructure.

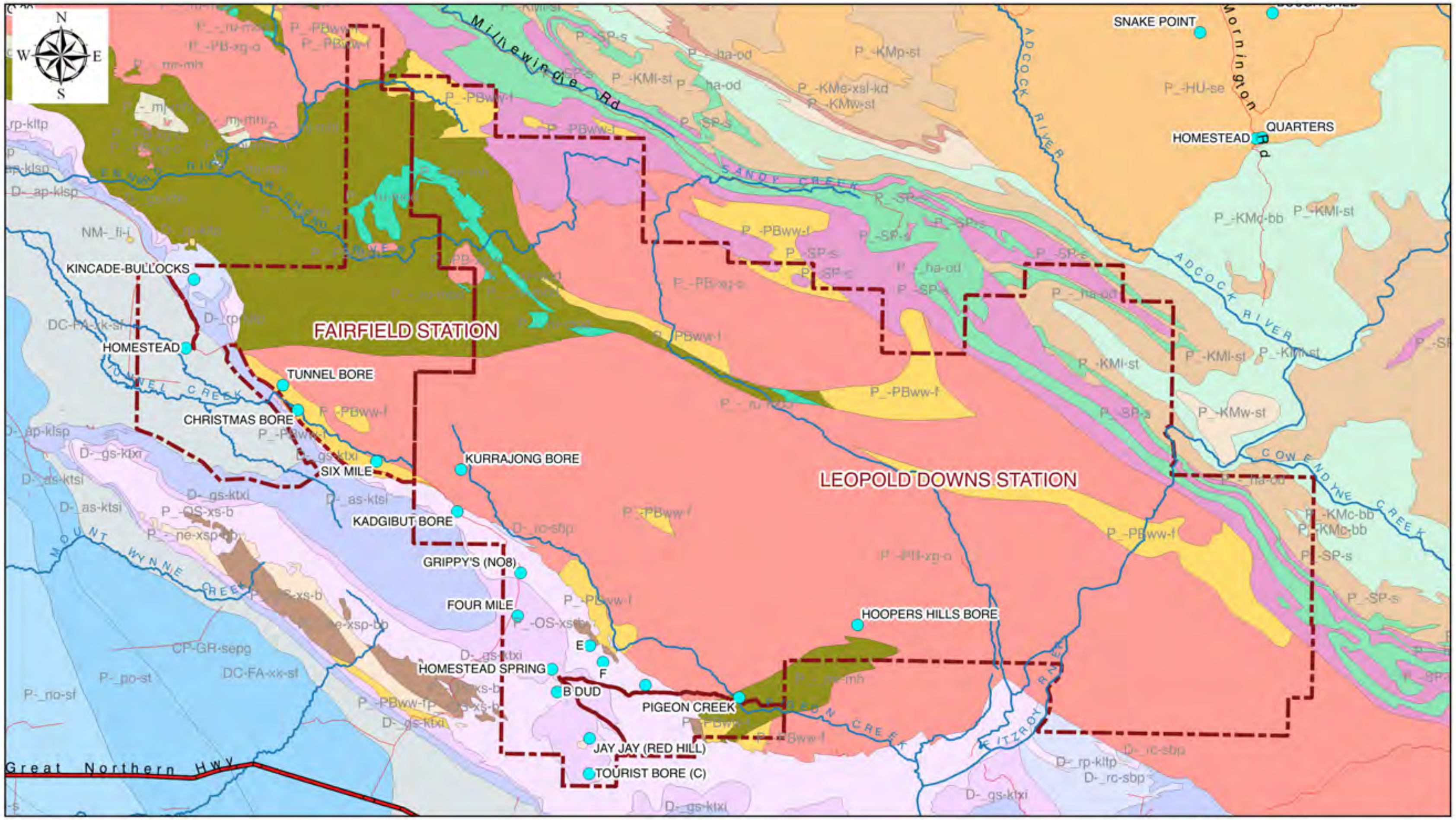

Figure 4. Hydrogeology of Fairfield and Leopold Downs stations

Map prepared by G.A. Harrington
Innovative Groundwater Solutions Pty. Ltd.
Version 4, 16 August 2018
Coordinate Reference System: GDA94 Zone 51

Table 2 Fairfield Station and Leopold Downs Station bores registered in the DWER database

AWRC SITE NAME	ZONE	EASTING	NORTHING	Date Drilled	Drilled Depth (m)	Yield (m^3/day)	Water Level (m BGL)	TDS (mg/L)	Site Comments
KURRAJONG BORE	51	747185	8043932	NA	19.51	43.642	NA	730	CHEM LAB ANAL NO: 12229, 15/11/66 WATER CLEAR, SMALL SUPPLY FORKS. REC BY: FARBRIDGE
E	51	760553	8025707	NA	NA	NA	NA	NA	NO INFORMATION, BORE WITH MILL
HOMESTEAD SPRING	51	756613	8023270	NA	22.86	NA	NA	NA	UNDIFFERENTIATED DEVONIAN
GRIPPY'S (NO8)	51	753369	8033268	1951	49.38	87.285 in 1951	19.81 in 1951	NA	SUPPLY ORIGINALLY RECORDED AS: 600-800 GPH. REC BY: FARBRIDGE
JAY JAY (RED HILL)	51	760515	8016092	NA	53.64	NA	NA	1000	TO 600' IN BLACK MUD. WATER AT 170'. REC BY: FARBRIDGE
HOOPERS HILLS BORE	51	788319	8027860	NA	23.47	43.642	22.25	431	SUPPLY ORIGINALLY RECORDED AS: 300-400 GPH. REC BY: FARBRIDGE
SIX MILE	51	738409	8044775	NA	NA	NA	NA	550	REC BY: FARBRIDGE. ALLUVIUM & KUNKAR; LIMESTONE, BASEMENT GRANITE, ENGINE POWERS MILL.
F	51	761915	8024002	NA	NA	NA	NA	NA	BORE WITH MILL; NO INFORMATION
KINCADE-BULLOCKS	51	719471	8063664	1964	76.2	10.911 in 1964	30.48 in 1964	NA	NOT EQUIPPED. REC BY FARBRIDGE
CHRISTMAS BORE	51	730250	8050113	1964	18.59	109.106 in 1964	NA	425 in 1964	DRILLED TO 52' MUD IN BOTTOM, REDRILLED, REDRILLED TO 61'. REC BY: FAIRBRIDGE
PIGEON CREEK	51	776043	8020341	NA	67.06	54.553	NA	540	CHEM LAB ANAL 2/2/66 CLEAR WATER DEEPENED FORMERLY BOTTOMED IN GRANITE. GSWA REG NO 12219 LAB ANAL 6740. REC BY: FARBRIDGE.
TUNNEL BORE	51	728698	8052691	NA	24.99	163.659	9.14	830 In 1987	VISITED BY PETER GESTE 3/9/87 - WINDPUMP. GRANITE, QUARTZ, WATER CUT AT 65'. REC BY: FARBRIDGE. SEPT 1987.
FOUR MILE	51	753063	8028809	1939	42.67	NA	NA	370 in 1939	DEVONIAN
TOURIST BORE (C)	51	760474	8012424	NA	NA	NA	NA	NA	FAILURE; THROUGH THICK LIMESTONE
KADGIBUT BORE	51	746790	8039575	NA	15.24	54.553	NA	570	SUPPLY RECORDED AS: +500GPH. ALKALINE TASTE, PIPES FUMED WITH LIME. REC BY: FARBRIDGE. QUARTZ, GRANITE. SURFACE LIMESTONE POSSIBLY RESIDUAL UP TO 10' THICK OVER GRANITE & METAMORPHICS.
AWRC SITE NAME	ZONE	EASTING	NORTHING	Date	Drilled	Yield	Water Level	TDS	Site Comments

				Drilled	Depth (m)	(m^3/day)	(m BGL)	(mg/L)	
SIX MILE FINGER BORE	51	766313	8021625	NA	23.16	43.642	13.87	553	BMR NOTES STATE SUB ARTESIAN, UNDIFFERENTIATED DEVONIAN
HOMESTEAD	51	718636	8056541	NA	182.88	NA	NA	522	DEPTH ORIGINALLY RECORDED AS: 600'/540'. REC BY: FARBRIDGE
B DUD	51	757151	8020903	NA	NA	NA	NA	NA	DUD.

3.3. Mount House and Glenroy Stations

3.3.1. Regional Geology & Hydrogeology

Almost the entire combined area of Mount House and Glenroy stations is underlain by Precambrian metamorphic rocks of either the Mount House Group (tillite, sandstone and siltstone) or the Carson Volcanics (basalts and volcaniclastic rocks) (Figure 5). Relatively small areas of metamorphic King Leopold Sandstone also outcrop along parts of the northern and western boundaries of Mount House Station. All three geologies may be able to provide reliable groundwater supplies where the formations are heavily fractured, however they will generally only yield supplies suitable for stock watering purposes. Greatest prospects are likely to be along river and creek lines as these are generally associated with major fault/fracture zones as well as having associated alluvial deposits that may provide reasonable bore yields.

3.3.2. Historical Bore Records

A total of 37 bores are currently registered in the DWER database (Table 3) as being located on Mount House and Glenroy stations. Few of these bores have records for water level or salinity, however the data available (albeit 50 – 70 years old) indicates depth to water is generally less than 10 m and salinity as TDS is generally between 305 and 535 mg/L. The only exception is Orange Camp Bore where a salinity of 3,500 mg/L was recorded back in 1945.

Bore yields are mostly low in the range 0 – 200 m^3/day (approximately 0 - 2 L/s), however a particularly notable exception is bore “NO 23A” on the edge of the Carson Volcanics where a yield of 1309 m^3/day (approximately 15 L/s) was recorded in 1967.

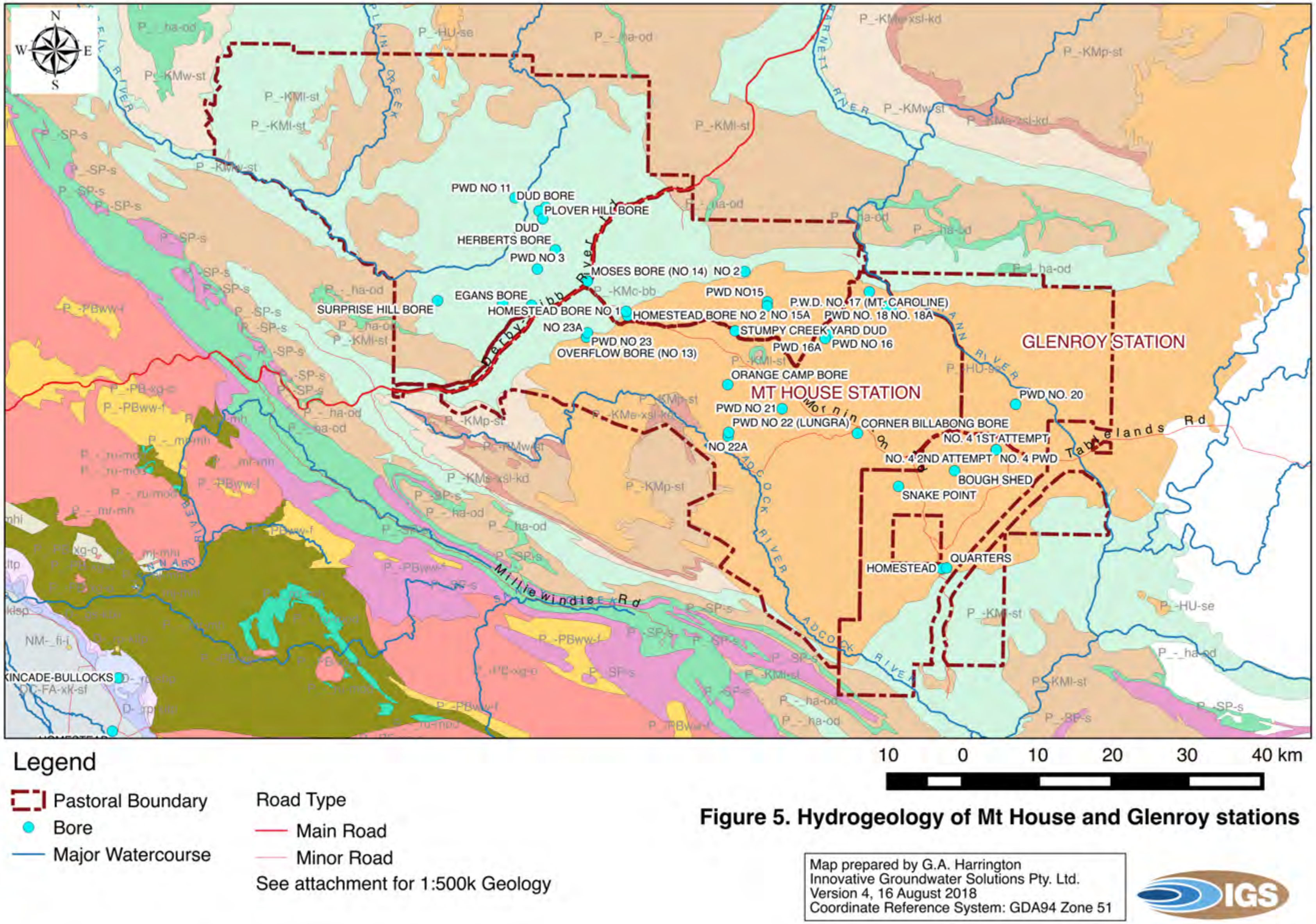

Figure 5. Hydrogeology of Mt House and Glenroy stations

Table 3 Mount House Station and Glenroy Station bores registered in the DWER database

AWRC SITE NAME	ZONE	EASTING	NORTHING	Date Drilled	Drilled Depth (m)	Yield (m3/day)	Water Level (m BGL)	TDS (mg/L)	Site Comments
PWD NO15	51	806308	8113922	1967	45.72	0 in 1967	NA	NA	SMALL QUANTITY OF WATER AT 50', NOT ENOUGH TO FLOW FROM BORE
PWD NO 16	51	814453	8109482	1967	50.29	0 in 1967	NA	NA	NO WATER SO MOVED RIG TO LOWER
PWD NO 11	51	772539	8127842	1967	38.1	81.83 in 1967	NA	NA	SMALL AMOUNT OF WATER AT 40FT INCREASED TO 750 GPH AT 75FT; NO FURTHER INCREASE TO 125FT.
NO. 4 PWD	52	198759	8094683	1967	30.48	109.106 in 1967	NA	NA	SUCCESSFUL
EGANS BORE	51	774745	8113469	1960	19.81	104.742 in 1960	14.63 in 1960	NA	WATER CUT AT 58'. TESTED WITH SAND PUMP BUT COULD NOT LOWER LEVEL AT 51'. REC BY: A D ALLEN
MOSES BORE (NO 14)	51	782220	8116701	NA	23.16	152.748	6.1	NA	WATER STRUCK AT 64' RISING TO 49' LEVEL; TESTED 1400 GPH LEVEL HOLDS AT 20'; VERY GOOD QUALITY WATER 71'4" COLUMN.
NO 2	51	803302	8117971	1966	17.01	NA	NA	NA	SMALL QUANTITY OF GOOD WATER CAME IN AT 49', ROSE UP TO 46', ROCK TOO HARD TO DRILL AT 56'.
NO 15A	51	806287	8113356	1967	30.48	436.424 in 1967	6.1 in 1967	NA	WATER STARTED FLOWING AT 50' INCREASING AT 73' THEN ANOTHER INCREASE AT 85', PWD HAS NO POSITION.
HERBERTS BORE	51	777915	8120872	7/7/62	22.86	109.106 in 1962	9.75 in 1962	NA	FIRST WATER AT 35FT ROSE TO 32FT. SUPPLY IMPROVED AT 68FT PUMPING AT 1000GPH & PUMPING LEVEL STOPPED AT 30FT FROM BOTTOM OF BORE. SUPPLY ORIGINALLY RECORDED AS: 1000 GPH+ DD23FT. RECORDED BY: A ALLEN
HOMESTEAD	52	191978	8078624	NA	18.29	109.106	NA	410	LOG OF STRATA: SECTION 23-60M DOUBTFUL - A.D.A. LOG TAKEN FROM REC 1966/16 GS 146/66.
PWD NO. 20	52	201171	8100834	NA	76.2	0	NA	NA	ALL SHALE, NO SIGN OF WATER

AWRC SITE NAME	ZONE	EASTING	NORTHING	Date Drilled	Drilled Depth (m)	Yield (m3/day)	Water Level (m BGL)	TDS (mg/L)	Site Comments
CLANCYS BORE	51	770882	8113753	1965	33.83	93.831 in 1965	9.6 in 1965	535 in 1965	SUPPLY ORIGINALLY RECORDED AS: +860 GPH. HIT SMALL SUPPLY OF WATER AT 40' ABOUT 600 GPD. MORE WATER AT 65' & 109'. FINAL TEST 800 GPH OR BETTER; BORE STILL HELD 15' OF WATER AFTER 3 HOURS PUMPING. ANAL 37 GRAINS TDS; 27.5 COMMON SALT APPROX. RE
HOMESTEAD BORE NO 2	51	787602	8112059	1955	23.47	87.285 in 1955	9.75 in 1955	305 in 1955	SUPPLY ORIGINALLY RECORDED AS: +800 GPH. SWL ORIGINALLY RECORDED AS: APPROX 32FT. REC BY: AD ALLEN.
DUD BORE	51	776639	8126594	NA	10.97	NA	NA	NA	NA
NO. 4 2ND ATTEMPT	52	198759	8094683	1966	17.07	NA	NA	NA	SMALL QUANTITY OF GOOD WATER AT 49' CAME UP TO 46'; ABANDONED; ROCK TO HARD TO DRILL.
NO 22A	51	801053	8095924	1967	27.43	58.917 in 1967	NA	NA	WATER AT 40' INCREASED AT 60'; DRILLED TO 90' TOO ABRASIVE; PWD DO NOT HAVE POSITION FOR 22A
PWD NO 21	51	808274	8099618	1967	76.2	NA	NA	NA	SMALL AMOUNT OF WATER AT 180'; NO INCREASE WITH DEPTH; ABANDONED.
PLOVER HILL BORE	51	775739	8126080	1965	16.15	196.391 in 1965	8.53 in 1965	505 in 1965	WATER FIRST STRUCK AT 32FT MORE AT 41FT. STATIC LEVEL 23FT FROM TOP, PUMPING LEVEL 38FT FROM TOP. ANALYSIS 35 GRAINS TDS COMMON SALT 26 GRAINS APPROX. RECORDED BY: A ALLEN
SURPRISE HILL BORE	51	762162	8114075	1965	20.27	174.570 in 1965	7.01 in 1965	535 in 1965	DEPTH ORIGINALLY RECORDED AS: 66' & LOG OF STRATA RECORDED DEPTH AS: 66'6". 100 GPH AT 100'; 1600 GPH 55'-57'. WATER CUT AT 25FT. PH 6.3 AT 28 DEG. REC BY: A ALLEN. WS FILE 155/51; FIRST WATER AT 25FT; SECOND WATER AT 25'(?), GOOD SUPPLY. TES
HOMESTEAD BORE NO 1	51	787401	8112640	1945	19.81	87.285 in 1945	9.75 in 1945	NA	SUPPLY ORIGINALLY RECORDED AS: +800 GPH. SWL ORIGINALLY RECORDED AS: APPROX 32FT. DRILLED: 1945 DEEPENED 1955. REC BY: A D ALLEN

AWRC SITE NAME	ZONE	EASTING	NORTHING	Date Drilled	Drilled Depth (m)	Yield (m3/day)	Water Level (m BGL)	TDS (mg/L)	Site Comments
OVERFLOW BORE (NO 13)	51	787531	8108448	NA	21.64	157.113	NA	NA	SOME WATER AT 20' AT 66' MORE WATER; TESTED AT 1440 GPH COULD HAVE 2000 GPH. Inlet 15.54 m to 21.64 m
PWD 16A	51	814033	8109023	1967	83.82	0	NA	NA	NO WATER; PWD HAS NO POSITION
SNAKE POINT	52	185846	8089443	1960	52.43	94.268 in 1960	5.18 in 1960	NA	A.D. ALLENS REC1966/16, STATES GLENRAY STN. BORE ORIGINALLY 104' BUT DEEPENED TO 172' TO INCREASE SUPPLY.
PWD NO 22 (LUNGRA)	51	801131	8096457	1967	18.29	NA	NA	NA	SMALL QUANTITY OF WATER AT 50'; TOO ABRASIVE; ABANDONED.
STUMPY CREEK YARD DUD	51	801984	8110035	NA	93.57	21.821	10.67	NA	SWL ORIGINALLY RECORDED AS: APPROX 35FT. REC BY: A D ALLEN.
PWD NO. 18	52	184206	8113415	1967	7.62	0	NA	NA	DUD; SAND TO 25; NO WATER
BOUGH SHED	52	193283	8091698	NA	50.9	130.927	7.01	NA	A.D. ALLENS RPT 1966/16 SUPPLY 43', SWL 30', YIELD 330 GPH; 54' SWL?; YIELD 480 GPH; 105' SWL? YIELD 1100 GPH. W.S. FILE: T.D. 160'; OUTPUT 500 GPH WITH CONSTANT LEVEL OF 155' FROM SURFACE OF GROUND, GOOD WATER. LOG AS ABOVE BUT TO 160'. LOG
NO 23A	51	782075	8109195	1967	48.77	1309.272 in 1967	15.24 in 1967	NA	SMALL QUANTITY OF WATER AT 40'; LARGE QUANTITY AT 147'.
PWD NO 23	51	782226	8109787	1967	30.48	0	NA	NA	ABANDONED; NO WATER.
CORNER BILLABONG BORE	51	818363	8096332	NA	50.9	109.106	7.01	NA	WATER CUT AT 43' & 167' SWL 30' & 23'. ANOTHER BORE 12' AWAY ABANDONED BECAUSE OF INSUFFICIENT SUPPLY (APPROX 80"). REC BY: A D ALLEN. WS FILE 155/51; SEEPAGE OF WATER AT 30'; TEST CARRIED OUT AT 43' APPROX 330 GPH. AT 54' 480 GPH; AT 105' 110
P.W.D. NO. 17 (MT. CAROLINE)	52	181130	8115270	1967	38.1	141.838 in 1967	15.24 in 1967	NA	AT 80FT FLOW OF WATER WHICH INCREASED DOWN TO 125FT.
NO. 18A	52	183544	8113402	1967	68.58	NA	NA	NA	OPEN CIRCLE. WATER AT 110' INSUFFICIENT

AWRC SITE NAME	ZONE	EASTING	NORTHING	Date Drilled	Drilled Depth (m)	Yield (m3/day)	Water Level (m BGL)	TDS (mg/L)	Site Comments
NO. 4 1ST ATTEMPT	52	198759	8094683	1966	39.01	8.729 in 1966	NA	NA	SOME WATER AT 68' SUPPLY ON 80 GPH NO INCREASE IN SUPPLY 68 TO 128' THOUGH VERY GOOD QUALITY; ABANDONED; OWNERS CALLED THIS NO. 1
PWD NO 3	51	775528	8118304	1966	50.29	38.187 in 1966	NA	NA	DUD; AT 50' 320 GPH; NO IMPROVEMENT
ORANGE CAMP BORE	51	801001	8102837	1945	45.72	87.285 in 1945	9.75 in 1945	3500 in 1945	TDS ORIGINALLY RECORDED AS: APPROX 3500PPM. DRILLED: 1945 DEEPENED 1960.
DUD	51	776239	8125026	NA	10.67	NA	NA	NA	DUD. RECORDED BY: A ALLEN
QUARTERS	52	192621	8078739	NA	18.29	109.106	NA	NA	NA

4. Groundwater Development Opportunities

Two different aquifer systems offer the greatest opportunities for future groundwater development on Napier Downs Station, namely the Grant Group sandstone and the Devonian reef limestone. The Devonian reef limestone may also be prospective in the southwestern corner of Leopold Downs Station. In both cases, further investigations are warranted to determine whether bore yields and groundwater quality are sufficient to enable irrigation at a scale that is economically viable.

For approximately 50% of Napier Downs Station, 95% of Fairfield Station, 90% of Leopold Downs Station, and all of Mount House and Glenroy stations, there is very limited opportunity for large-scale irrigation development owing to the nature of the underlying geology. There may be some localised opportunities associated with heavily fractured-rock aquifers or shallow alluvial aquifers along creek lines, however these resources should be viewed as a windfall rather than a strategic target.

Table 4 summarises the potential scale of groundwater development from each of the main aquifer types on each station. The volumes indicated are speculative but are intended to provide insight to the relative opportunity offered by each groundwater resource. Table 4 also provides an estimate of the potential area of fodder crops that could be irrigated, based on a typical range of 15 – 20 ML/ha/yr. for crop water use in the West Kimberley. Finally, the table provides an estimate of potential dry matter production based on assumed yields from properly managed crops of either Rhodes Grass or Forage Sorghum being 25 – 35 tonnes/ha/yr.

Table 4 Potential scale of groundwater development

Pastoral Lease	Aquifer	Potential for Groundwater Development		
		Scale and Indicative Volume (GL/yr)	Area of Irrigation (ha.)	Dry matter production (tonnes/yr.)
Napier Downs	Grant Group	Large 2-5 GL/yr.	100 – 330	2 500 – 11 550
	Devonian reef	Moderate 1-2 GL/yr.	50 – 130	1 250 – 4 550
	Fairfield Group	Low <1 GL/yr.	< 50	< 1 250
	Fractured rocks	Very low	-	-
Fairfield	Fairfield Group	Very low	-	-
	Precambrian fractured rocks	Very low	-	-
Leopold Downs	Devonian reef limestone	Moderate 1-2 GL/yr.	50 – 130	1 250 – 4550
	Precambrian fractured rocks	Very low	-	-
Mount House	Precambrian fractured rocks	Very low	-	-
Glenroy	Precambrian fractured rocks	Very low	-	-

In the Canning-Kimberley Groundwater Area, the current volume of groundwater allocated from the Grant Group is 1,123,259 kL/yr. (i.e., approximately 1.1 GL/yr.), with the largest allocations to POZ Minerals Limited (0.36 GL/yr.) and Water Corporation (0.35 GL/yr.). Previously, Kimberley Diamond Company held a licence for 11.926 GL/yr. from the Grant

Group for its operations at Ellendale Mine (Harrington and Harrington, 2015). The current allocation limit for the Grant Group is 100 GL/yr. (DOW, 2014).

In the Canning-Kimberley Groundwater Area, the current volume of groundwater allocated from the Devonian Limestone is 1,762,500 kL/yr. (i.e., approximately 1.8 GL/yr.), with the largest allocation to GoGo Station (1.5 GL/yr.) for irrigation of fodder crops. The current allocation limit for the Devonian Limestone is 5.458 GL/yr. (DOW, 2014).

The bulk of this report has focussed on groundwater availability, in particular the ability of bores constructed in each of the different aquifer types to supply water at sufficient rate and of suitable quality for large-scale irrigation. Whilst this information is critical for planning a development and then securing an annual water entitlement or allocation to take groundwater, the latter is also subject to sustainability constraints. These constraints are generally in the form of minimising impacts to existing groundwater users (licensed and unlicensed) and groundwater dependent ecosystems (GDEs). Thus, siting of production bores needs to take this into consideration.

5. Conclusions & Recommendations

Besides some airborne geophysical survey results for the southwestern portion of Napier Downs, there is very limited meaningful historical groundwater data for the five stations of immediate interest to ACE. However, knowledge obtained for the main aquifers elsewhere in the region, coupled with the scant data that is available in bore records, suggests the greatest opportunities for groundwater development are the Grant Group sandstone aquifers and the Devonian reef limestone aquifers. The extent of the Grant Group aquifer is restricted to a broad area in the southwest corner of Napier Downs, while the combined extent of various Devonian reef formations is much smaller and is confined to the centre of Napier Downs and small pockets in the southwest corners of Fairfield and Leopold Downs. The remainder of Napier Downs (approximately 50% in the NE), Fairfield (>75% in the north and east) and Leopold Downs (>90%) stations, as well as all of Mount House and Glenroy stations, is dominated by hard, fractured-rock aquifers. Whilst local bore yields and water quality in these aquifers can be sufficient for stock water supply or road construction, there is very low probability of constructing a bore with yields suitable for large-scale irrigation (i.e., at least 30-50 L/sec).

In order to provide improved confidence in the local groundwater development opportunities at Napier Downs Station, and potentially also at Leopold Downs Station, the following steps are recommended.

1. Undertake a bore audit and basic water (level and quality) testing. At the same time visit and sample any potential groundwater-dependent ecosystems (e.g., permanent pools or wetlands) as these may become constraints for future licence decisions.
2. Acquire soil suitability maps to correlate with known areas of prospective aquifers and identify drilling targets.
3. Undertake exploratory drilling of the Grant Group sandstone aquifer and potentially the Devonian reef limestone aquifer. Ideally install at least one test production bore and one nearby monitoring bore in each suitable development area.
4. Carry-out aquifer pumping test(s) to determine safe bore yields and to estimate aquifer hydraulic properties, which will inform subsequent modelling (see below).
5. Undertake a formal Risk Assessment to evaluate risks of impact to existing users and the environment, and thereby determine likelihood of a water licence being granted.

Provided the outcomes from this body of work support a decision to proceed with an irrigated agriculture project, it will be necessary to commence the approvals processes with relevant WA Government departments as soon as possible. From a water perspective there will need to be an application to DWER for a groundwater extraction licence, which will trigger the requirement for a formal Hydrogeological Assessment report, amongst other supporting information. The scope of the Hydrogeological Assessment report is largely guided by an existing Operational Policy (DOW, 2009), however technical experts from Government are also likely to request specific information, testing and/or modelling approaches. Regardless, ACE should not expect any surprises or “show stoppers” at this stage due the preparatory investigations already completed through the work program outlined above.

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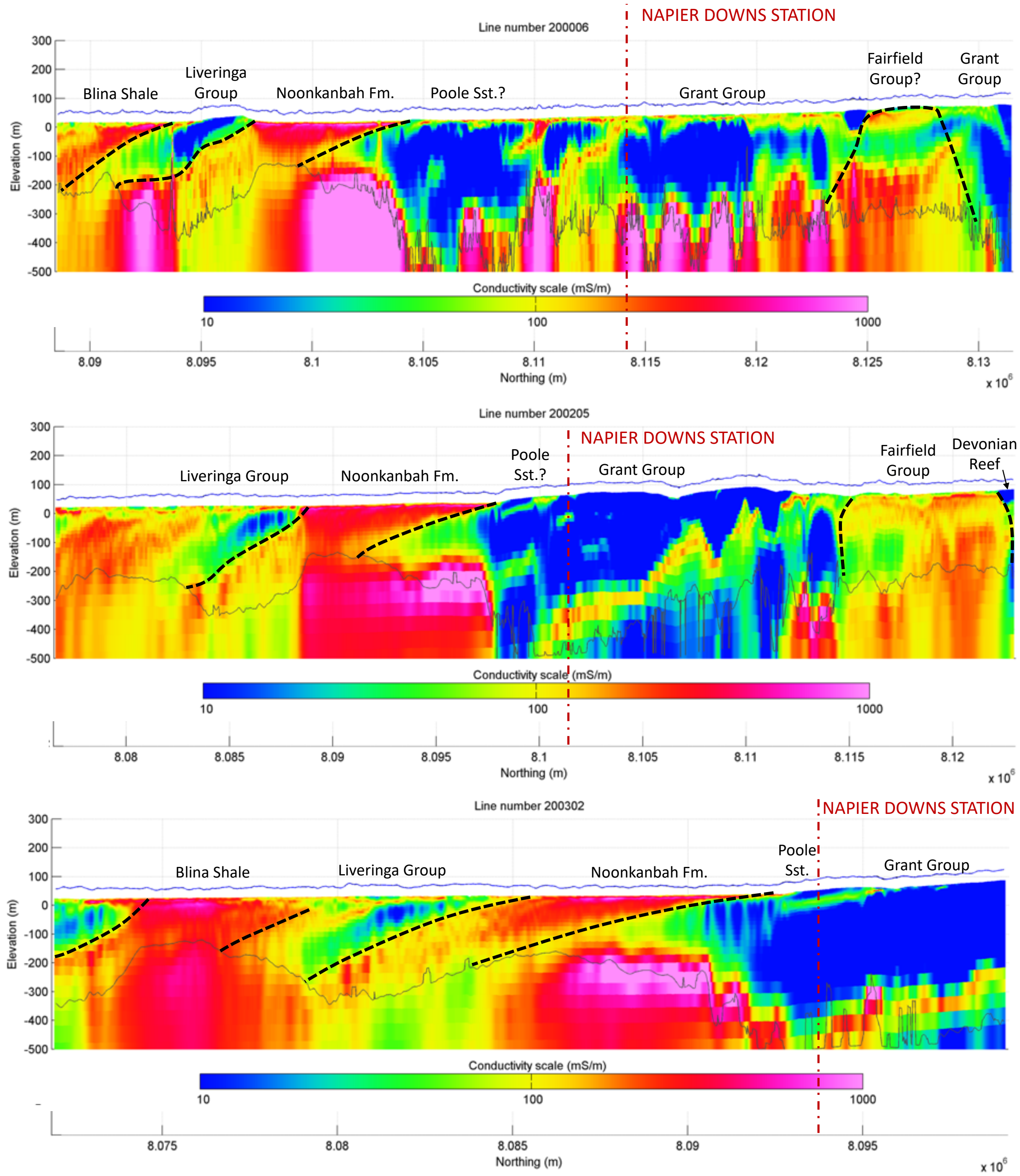
APPENDIX A. Legend items for 1:500k Geology Maps

Legend

GSWA 1:500k Bedrock Geology (dominant units shown on map only)

- J-_wa-st; Wallal Sandstone; Sandstone; minor siltstone and conglomerate
- R-_er-st; Erskine Sandstone; Fine-grained sandstone; lesser sandy shale, minor conglomerate
- R-_my-sl; Munkayarra Shale; Claystone and shale
- R-_bl-sl; Blina Shale; Siltstone and shale; minor phosphatic horizons
- R-_mi-sr; Millyit Sandstone; Fine- to coarse-grained sandstone; minor conglomerate
- P-LI-s; Liveringa Group; Sandstone and siltstone, minor conglomerate, and coal
- P-_no-sf; Noonkanbah Formation; Siltstone, shale, and sandstone; minor carbonate
- P-_po-st; Poole Sandstone; Quartz sandstone and minor siltstone
- CP-GR-sepg; Grant Group; Sandstone, siltstone, diamictite, conglomerate, and shale; largely glacigene
- DC-FA-xk-sf; Fairfield Group; Limestone, shale, siltstone, sandstone
- D-_as-ktsi; Famennian reef complexes, marginal slope and basin facies; Limestone, calcareous sandstone and mudstone; lesser siliciclastic sandstone and conglomerate
- D-_ap-klsp; Famennian reef complexes, platform facies; Limestone, lesser sandstone and siltstone, bedded (backreef) to massive (reef); includes Windjana and Nullara Limestones
- D-_rc-sbp; Devonian conglomerates associated with reef complexes; Frasnian and Famennian (locally ?Givetian) boulder to cobble conglomerate and sandstone
- D-_gs-ktxi; Givetian--Frasnian reef complexes, marginal slope and basinal facies; Limestone, calcareous sandstone, and mudstone; common breccia and mass flow deposits; lesser siliciclastic sandstone and conglomerate
- D-_rp-kltp; Givetian--Frasnian reef complexes, platform facies; Limestone with lesser siltstone and sandstone, commonly cyclic; includes Pillara Limestone and Cadjebut Formation (reefal precursor)
- P_-HU-se; Mount House Group; Tillite, sandstone, siltstone, and minor stromatolitic dolomite
- P_-_ha-od; Hart Dolerite; Dark-grey dolerite and gabbro, and pink to pale-grey, medium- to coarse-grained granophyre
- P_-KMy-sta; Yampi Formation; Pink-brown arkose and feldspathic sandstone; minor siltstone, hematitic quartz sandstone, glauconitic sandstone
- P_-KMp-st; Pentecost Sandstone; Quartz sandstone, pebbly sandstone, siltstone, and claystone
- P_-KMe-xsl-kd; Elgee Siltstone; Red-brown and grey siltstone and mudstone, stromatolitic dolostone, sandy dolostone, oolitic dolostone, and sandstone
- P_-KMw-st; Warton Sandstone; White to buff quartz sandstone and feldspathic sandstone; siltstone interbeds; minor hematitic sandstone
- P_-KML-xs-bb; Kimberley Group, lower; Quartz sandstone and feldspathic sandstone; siltstone and mudstone; basalt; minor dolostone and conglomerate; includes King Leopold Sandstone and Carson Volcanics
- P_-KMc-bb; Carson Volcanics; Massive and amygdaloidal basalt and basaltic volcaniclastic rock; interbedded quartz sandstone, feldspathic sandstone, siltstone, and chert
- P_-KMl-st; King Leopold Sandstone; White to pale-brown, medium- to coarse-grained quartz sandstone and pebbly quartz sandstone; minor siltstone and granule to pebble conglomerate
- P_-SP-s; Speewah Group; Sandstone, siltstone, and claystone; minor rhyolitic volcaniclastic siltstone
- P_-_ru-mod; Ruins Dolerite; Coarse- to fine-grained metadolerite; equigranular to porphyritic
- P_-PB-xg-o; Paperbark Supersuite; Granite, microgranite, gabbro, layered mafic--ultramafic intrusions, and felsic volcanic rock
- P_-PBww-f; Whitewater Volcanics; Porphyritic rhyolite to dacite; coherent lavas, subvolcanic intrusions, and pyroclastic deposits; commonly crystal rich; minor volcanic breccia, lapilli tuff, and volcaniclastic rock; locally foliated
- P_-_mr-mh; Marboo Formation; Thin-bedded, turbiditic metasandstone and quartz--chlorite--muscovite phyllite; hornfelsed adjacent to granite intrusions

APPENDIX B. Hydrostratigraphic interpretation of AEM survey conductivity-depth sections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Noonkanbah Fm.
Poole Sst.?
Grant Group
Fairfield Group?
Grant Group
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Conductivity scale (mS/m)
Northing (m)
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Liveringa Group
Noonkanbah Fm.
Poole Sst.?
Grant Group
Fairfield Group
Devonian Reef
Elevation (m)
Conductivity scale (mS/m)
Northing (m)
Line number 200302
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Liveringa Group
Noonkanbah Fm.
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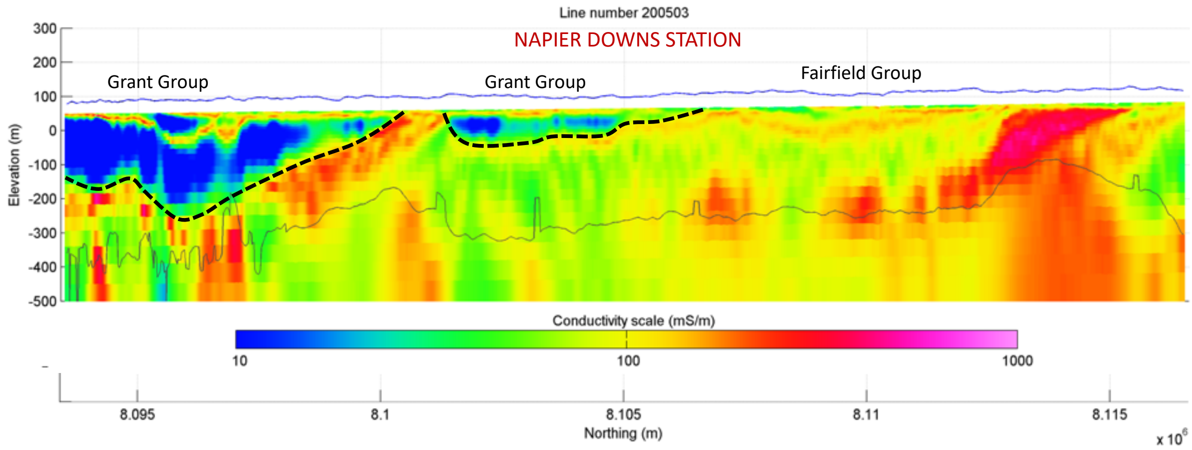
Grant Group
Elevation (m)
Conductivity scale (mS/m)
Northing (m)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Grant Group
Fairfield Group
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8.11
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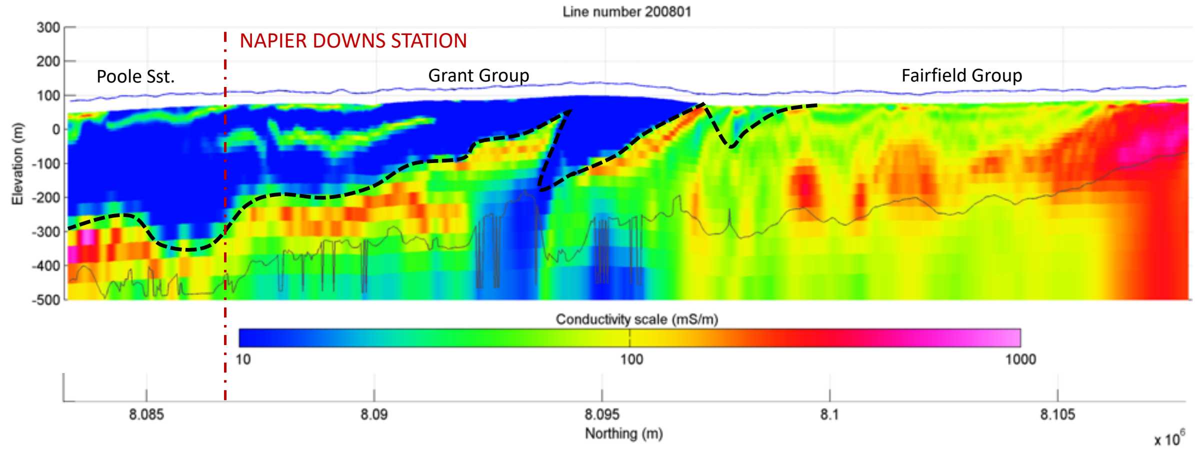
x 10^6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Grant Group
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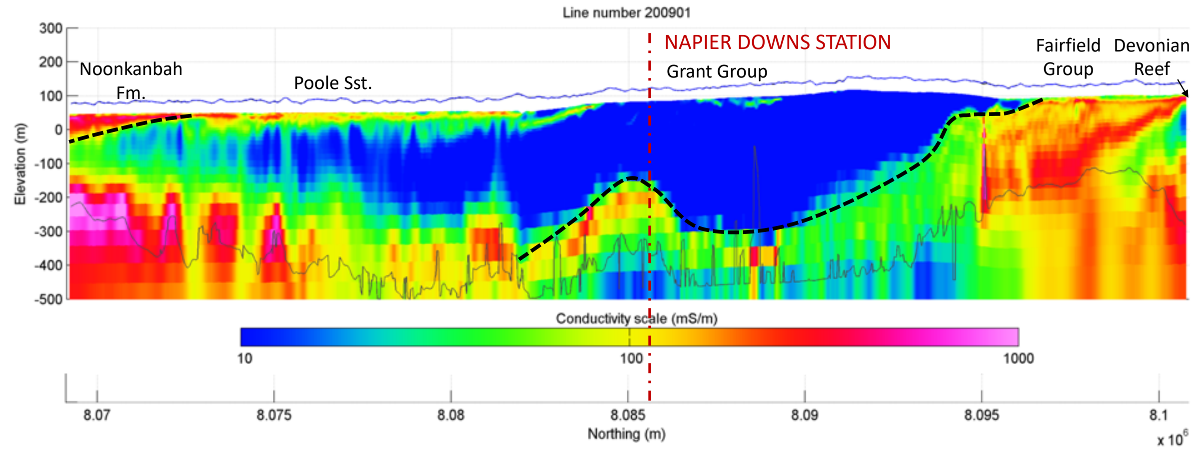
Northing (m)
x 10^6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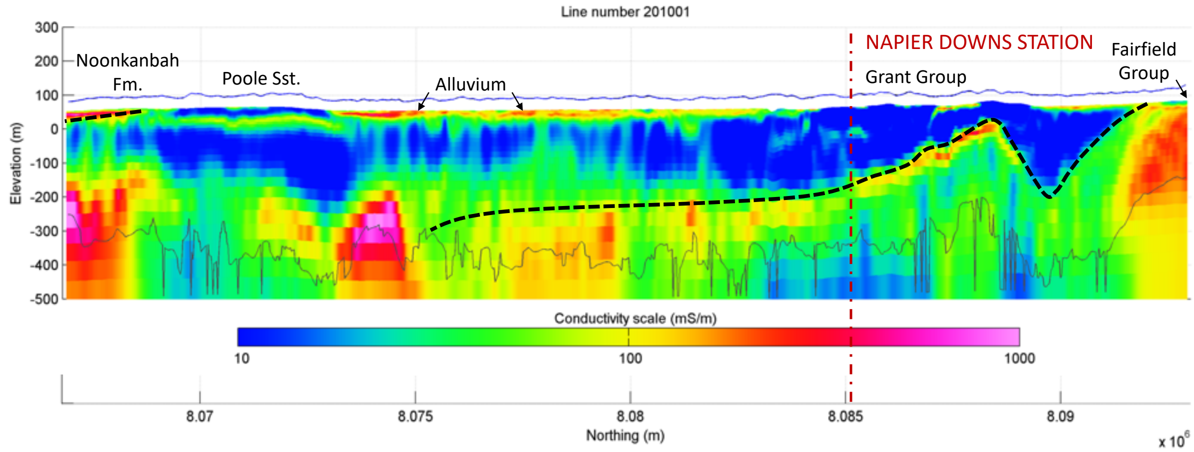
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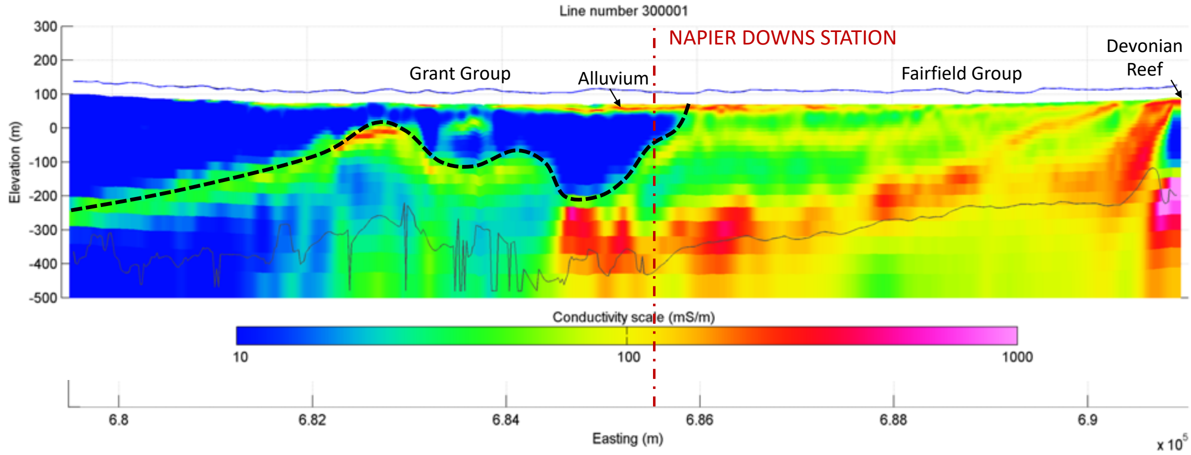
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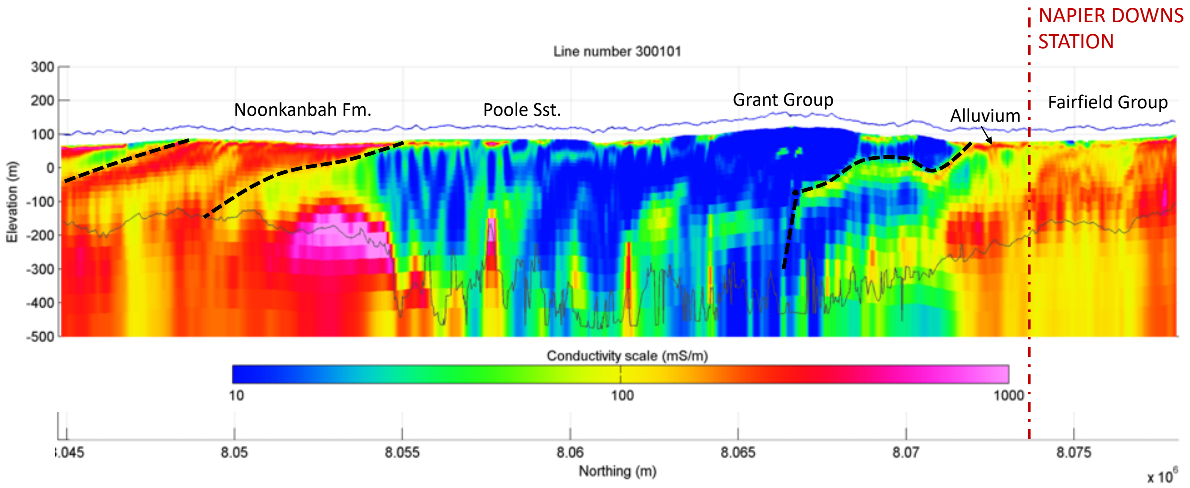
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Elevation (m)
Conductivity scale (mS/m)
10
100
1000
Northing (m)
x 10^6

Appendix B

IGS (2018b, 2019a, 2019b) – Surface Water

Water resource development opportunities to support cattle operations in the West Kimberley region

A report prepared for Australian Capital Equity Pty Ltd.

21 November 2018

Version 1.0

Commercial in Confidence

Innovative Groundwater Solutions Pty Ltd.

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Water resource development opportunities to support cattle operations in the West Kimberley region

A report prepared for Australian Capital Equity

by

Innovative Groundwater Solutions

21 November 2018

Document control

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Executive Summary

This report documents the findings of a second desktop assessment undertaken by Innovative Groundwater Solutions Pty Ltd. on behalf of Australian Capital Equity Pty Ltd. - Kimberley operations (ACE-K). The first report focussed on groundwater development opportunities across three ACE-K pastoral leases as well as two neighbouring stations held by Bunuba traditional owners. This second study has investigated broader water resource development opportunities to support and potentially enhance existing cattle operations on the three ACE-K stations. The scope included rainfall runoff, river water and groundwater resources, and their potential for either stock water supply or future irrigation development.

Mean annual rainfall is approximately 800 mm/yr. for Napier Downs Station and considerably higher – around 950 mm/yr. – for Mount House and Glenroy stations. More than 90% of annual rainfall occurs during the wet season, however inter-annual variability is very high. On average, approximately 17% of annual rainfall forms runoff to creeks, rivers and ultimately discharge into the Timor Sea. The remainder is either lost to evaporation, taken up by vegetation and transpired, or infiltrates the soil to recharge the water table aquifers.

Feedback received from station managers in response to a series of questions posed by IGS demonstrates the high reliance on bores and dams to provide stock water through the dry season, particularly following poor wet seasons. Some areas could carry larger numbers of stock; however, water is not the only limitation. Napier Downs Station is already well watered and has few supply issues, other than temporary shortages around the homestead when cattle are yarded nearby. Mount House Station requires additional fencing and infrastructure to enable improved stocking rates.

Whilst there may be opportunities to construct small (e.g., <100 ML) catchment dams in hilly terrain to capture wet season runoff for stock water, the risk of dam failure due to flash flooding and the high annual losses due to evaporation means these options are limited to critical areas of the stations where no alternatives are available. Large in-stream dams present similar challenges and are unlikely to achieve regulatory approvals due to stakeholder concerns about impacts to environmental or cultural values brought about by altering the natural flow regime of major rivers.

Using historical streamflow gauging records for the Lennard River at Mt. Joseph and the Isdell River at Dales Yard, this assessment has demonstrated the greatest opportunity to utilise surface water resources to enhance cattle operations is diversion of river/overland flow to off-stream storages during high flow conditions. The most significant risk of such development is the high inter-annual variability in wet season rainfall, and thus reliability of river water. Nevertheless, the available data indicates that capturing just 1% of the long-term average maximum daily flow for several days each wet season would provide sufficient volume to meet the annual water requirements of a fodder crop grown under a 40-hectare pivot. Diverting water into off-stream storages under high-flow conditions ensures the net take only represents a very small proportion of the total flow in the river, which is a scientifically defensible basis for obtaining a surface water licence, as any impacts to environmental values either locally or downstream will be negligible and immeasurable. The areas where this type of development may be worth investigating further are the Barker River on Napier Downs, and the Isdell River on Mount House where soils and landscape systems are the most suitable for irrigation.

The most reliable source of water for future irrigation development across all three stations is groundwater from the Grant Group aquifer on Napier Downs. This assessment has used Department of Primary Industries and Regional Development “best available soils” mapping to reveal extensive areas of overlap between Grant Group aquifer and soil-landscape systems of high and moderate pastoral potential. Accordingly, the next step is to commence discussions with relevant Government of Western Australia departments to understand the regulatory approvals processes before embarking on any on-ground investigations.

CONTENTS

1. Introduction

1.1. Project Scope

Innovative Groundwater Solutions Pty Ltd. (IGS) was commissioned by Australian Capital Equity Pty Ltd. (ACE) to investigate water resource opportunities for three pastoral leases in the West Kimberley region of Western Australia, namely Napier Downs, Mount House and Glenroy stations. The purpose of the desktop study was to identify potential water sources that may be developed to enhance the existing cattle operations on the stations, either directly for stock water supply or indirectly for irrigation of fodder crops. The scope of the study included rainfall/runoff, surface water in rivers and creeks, and groundwater, noting that IGS has recently completed an initial scoping study on the groundwater development opportunities (IGS, 2018).

1.2. Background Hydrology & Hydrogeology

The climate and hydrology of the Kimberley region is dominated by distinct wet and dry seasons. On average more than 90% of annual rainfall occurs during the wet season months of December through to April, with the remainder occurring in the dry season. Inter-annual variability in rainfall and runoff is extremely high. Across the region, mean annual potential evapotranspiration (APET) is more than 3,500 mm/yr. (BOM, 2018) and far exceeds mean annual rainfall of between 600 – 1200 mm/yr.

As a result of this seasonality, all surface water resources are highly ephemeral. The Lennard River catchment drains Napier Downs Station with significant tributaries of Hawkstone Creek and the Barker and Richenda rivers (Figure 1). The north-westward draining Isdell River is the most significant watercourse on Mount House Station, with Plain Creek a major tributary (Figure 2). Mount House and Glenroy stations also have access to the Adcock and Hann rivers, which are tributaries of the westward draining Fitzroy River.

The hydrogeology of the three stations is outlined in IGS (2018) with further details on the regional aquifers provided in Harrington and Harrington (2015). Generally, Napier Downs Station can be divided into three distinct hydrogeological zones: the southwest corner that is underlain by highly prospective Grant Group aquifers of the Canning Basin, a strip of low-moderate prospectivity Devonian-age sedimentary rocks that include reef limestone complexes running diagonally through the middle of the property, and the north-eastern half that is characterised by low-yielding fractured rock aquifers associated with the Kimberley Plateau. Mount House and Glenroy stations are dominated by the latter, although all three properties likely have shallow alluvial aquifers adjacent the major watercourses.

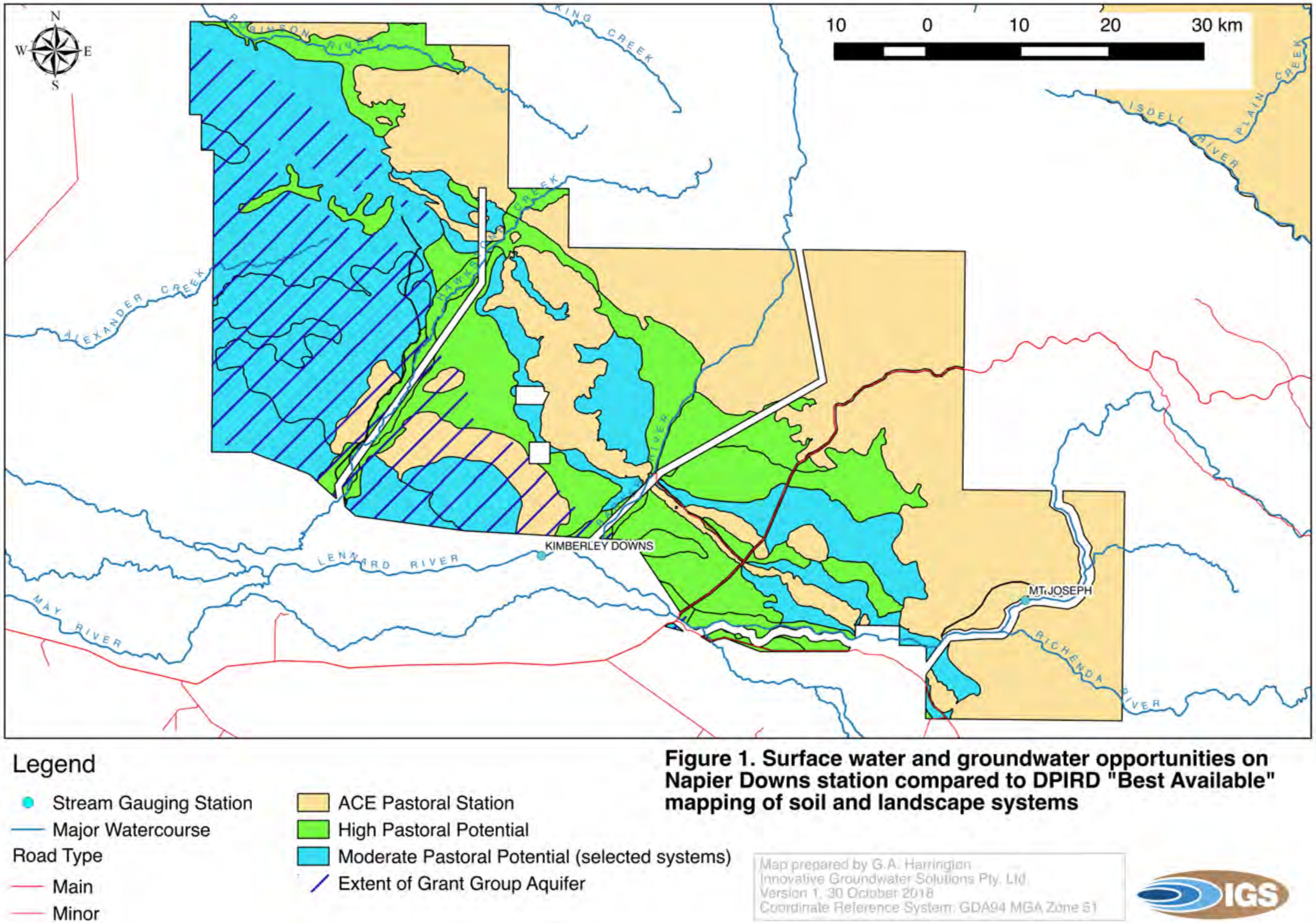
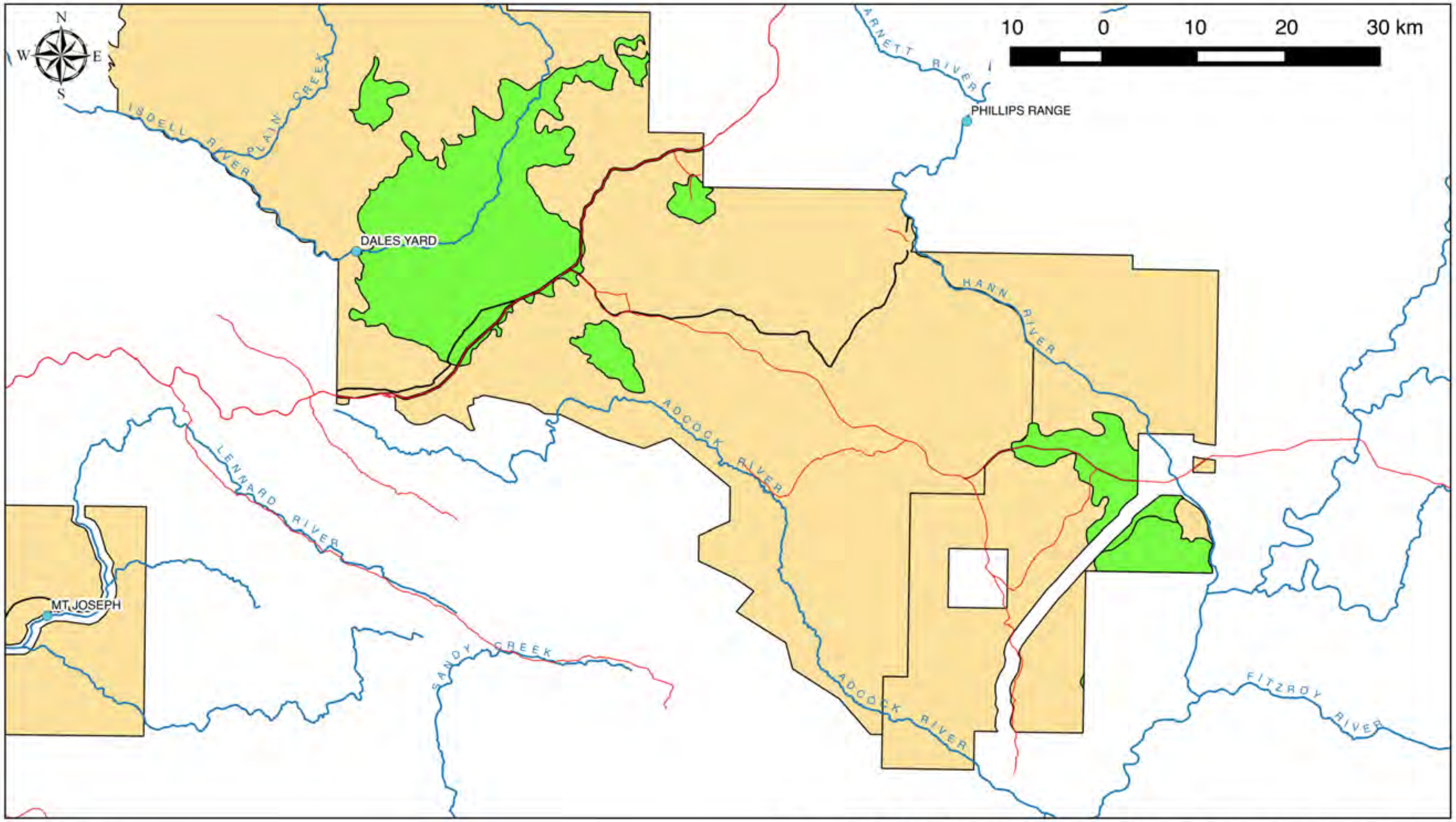


Figure 1. Surface water and groundwater opportunities on Napier Downs station compared to DPIRD "Best Available" mapping of soil and landscape systems



Legend

- Stream Gauging Station
- Major Watercourse

Road Type

- Main
- Minor
- ACE Pastoral Station
- High Pastoral Potential

Figure 2. Surface water opportunties on Mt House and Glenroy stations compared to DPIRD "Best Available" mapping of soil and landscpe systems

Map prepared by G.A. Harrington
Innovative Groundwater Solutions Pty. Ltd.
Version 1, 30 October 2018
Coordinate Reference System: GDA94 MGA Zone 51

2. Methodology

This desktop study involved a collation and synthesis of available data, followed by a questionnaire for station managers to identify water demands for the current cattle operations and future opportunities and constraints.

2.1. Synthesis of Historical Data

Historical monthly and annual rainfall data was downloaded from the Bureau of Meteorology website (BoM, 2018) for the Napier Downs (003019), Windjana (003094), Mount House Station (003017) and Mount House Airstrip (003098) sites. Surface runoff estimates were obtained through review and analysis of results from the CSIRO Northern Australia Sustainable Yields (NASY) project (Petheram et al., 2009).

Historical stream flow records were requested through the Government of Western Australia, Department of Water and Environmental Regulation (DWER) Water Information Reporting portal (DWER, 2018). The only current stream gauging site of relevance to Napier Downs Station is “Mount Joseph” on the Lennard River (Figure 1); there is no historical information for either the Barker River or Hawkstone Creek. Likewise, the only current gauging site of relevance to Mount House Station is “Dales Yard” on the Isdell River (Figure 2); any gauging sites on the Adcock or Hann rivers are located significant distances either upstream or downstream of the station boundaries (e.g., Dimond Gorge on the Fitzroy River).

In order to assess water resource opportunities for irrigation development, an important consideration is the suitability of soils and landscape attributes (e.g., terrain) to enable such development. The recent CSIRO Northern Australia Water Resources Assessment (NAWRA) program has produced detailed mapping of land versatility and soil suitability for irrigation, however the study area for that project only extended slightly beyond the Fitzroy River catchment boundary, and thus no mapping products are available for ACE stations. Accordingly, this desktop study has used the “Soil-landscape mapping Western Australia – Best available soils” electronic dataset (Version April 2018) from the Department of Primary Industries and Regional Development (DPIRD).

2.2. Interviews With Station Managers

The following questions were posed to the Operations Manager for ACE-K and the station managers in order to collate practical, first-hand knowledge:

1. What is the current herd size and therefore demand for water throughout the year (e.g., number/distribution of troughs etc.)?
2. What proportion of the current demand is sourced from (a) bores, (b) river/creek water directly, (c) river/creek water by pumping, (d) runoff dams?
3. Is there a noticeable change in water quality and/or yield from any of these sources throughout the year?

4. Are there areas that could carry greater numbers of stock if more/better quality water was available for some/all of the year?
5. Where do you see opportunities to increase/improve water supplies?
6. Do you have rain gauges at the homesteads (or elsewhere) to provide data on annual/wet season rainfall variability?
7. Are there areas of the station where clay soils might support building of catchment (i.e. runoff) dams?
8. Are you aware of any other constraints to groundwater or surface water use (e.g., environmental, cultural etc.)?

3. Water Source Options

3.1. Rainfall & Runoff

3.1.1. Napier Downs Station

The Napier Downs BoM station (003019) was opened in 1912 and has a good long-term record, although it has numerous periods of missing data including 1912 (5 months), 1945 (11 months), 1950 (7 months), 1951 (8 months), 1953 (9 months), 1954 (9 months), 1962 (10 months), 1963 (3 months), 1964 (11 months), 1966 – 1968 (no data), 1969 (10 months), 1970 (3 months), 1980 (1 month), 1981 (10 months), 1982 (9 months), 1983 (9 months), 1987 (10 months), 1988 – 1989 (no data), 1990 (11 months), 2016 (3 months), and 2017 (3 months).

Mean annual rainfall for the Napier Downs BoM station (003019) for the period 1913 – 2015 was 778 mm/yr., although annual rainfall totals are not available for 21 of those years. Figure 3 provides a plot of cumulative deviation from mean monthly rainfall (CDMMR) that identifies periods of above or below average rainfall trends. An upward slope indicates a period of above average monthly rainfall, while a downward slope indicates a period of below average monthly rainfall. Generally, there has been above average rainfall since the 1994/1995 wet season.

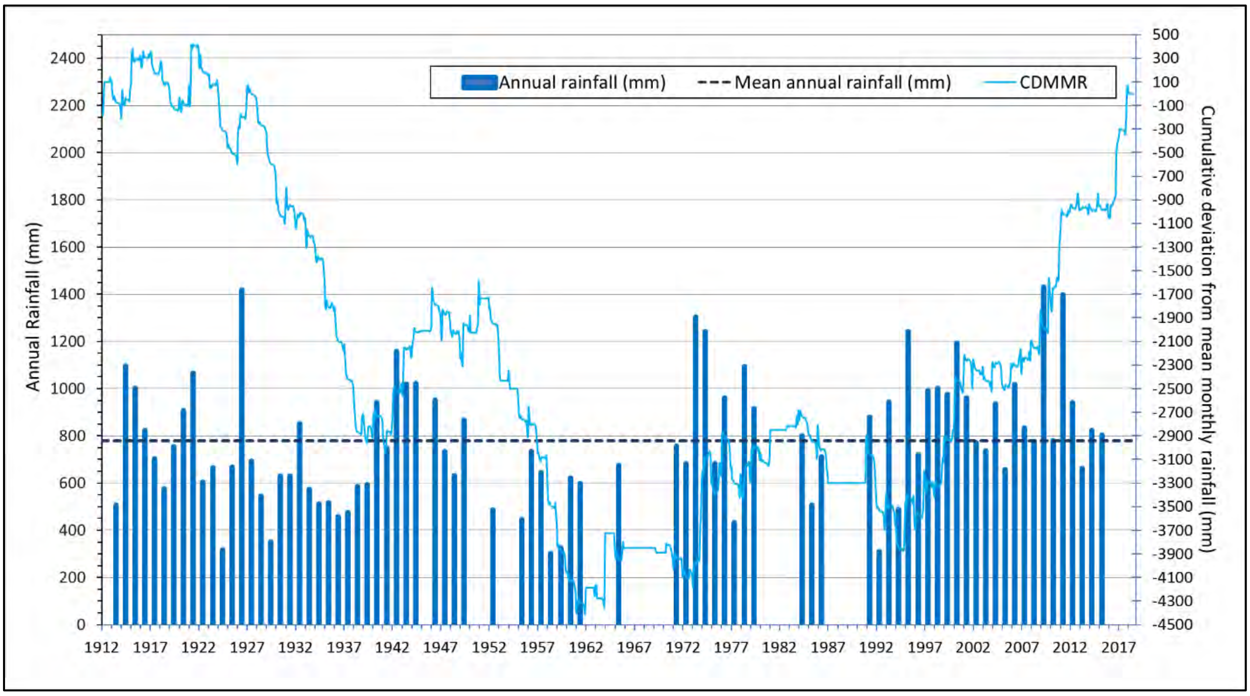


Figure 3. Annual rainfall and cumulative deviation from mean monthly rainfall, Napier Downs BoM station 003019.

The Windjana BoM station (003094) was opened on 28 January 1997 but no data is available before 2009 and there is missing data for 2009 (5 months), 2011 (1 month), 2015 (1 month), and 2017 (1 month). Mean annual rainfall for the period 2010-2016 was 758 mm/yr., although annual rainfall totals are not available for 2 of those years.

Mean annual runoff for the Lennard River catchment during the period 1930-2007 was estimated to be 2,073 GL/yr. compared to mean annual rainfall of 11,795 GL/yr. for the same period (Petheram et al., 2009). When averaged across the entire catchment area, these figures equate to 140 mm/yr. runoff from 799 mm/yr. rainfall (i.e., a runoff coefficient of 17.5%). The remainder of the annual rainfall is either lost to evaporation, taken up by vegetation, or recharged to groundwater.

3.1.2. Mount House Station

The Mount House Station BoM site (003017) was opened in 1923 and has a very good long-term record, with the only missing data in 1923 (10 months), 2001 (2 months), 2002 (1 month), 2003 (2 months), 2004 (1 month), 2005 (1 month), 2006 (1 month), 2007 (2 months), 2009 (1 month), 2010 (5 months), and 2011 (2 months).

Mean annual rainfall for the Mount House BoM site (003017) for the period 1924 – 2017 was 758 mm/yr., however annual rainfall totals are not available for 10 of those years. Figure 4 reveals generally below average rainfall from 1924 to 1972, although several above average periods occur during that time, and generally below average rainfall from 1972, with some below average periods during that time.

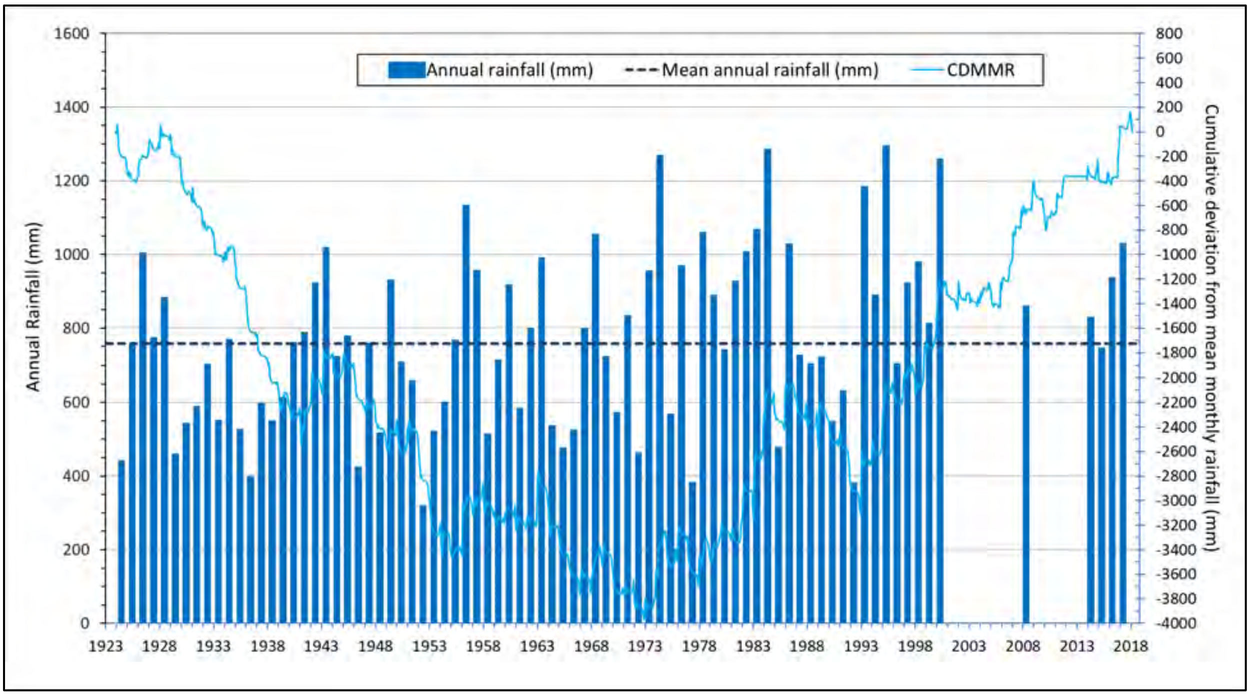


Figure 4. Annual rainfall and cumulative deviation from mean monthly rainfall, Mount House Station BoM site 003017.

The Mount House Airstrip BoM station (003098) was opened on 11 September 2002 after moving equipment from the homestead to the airstrip for ease on servicing in the wet season. It has a very good short-term record with the only missing data for 2004 (1 month). Mean annual rainfall for the period 2003 – 2017 (excluding 2004) was 915 mm/yr (Figure 5), which is 157 mm higher than the long-term average at the Mount House Station BoM site (003017).

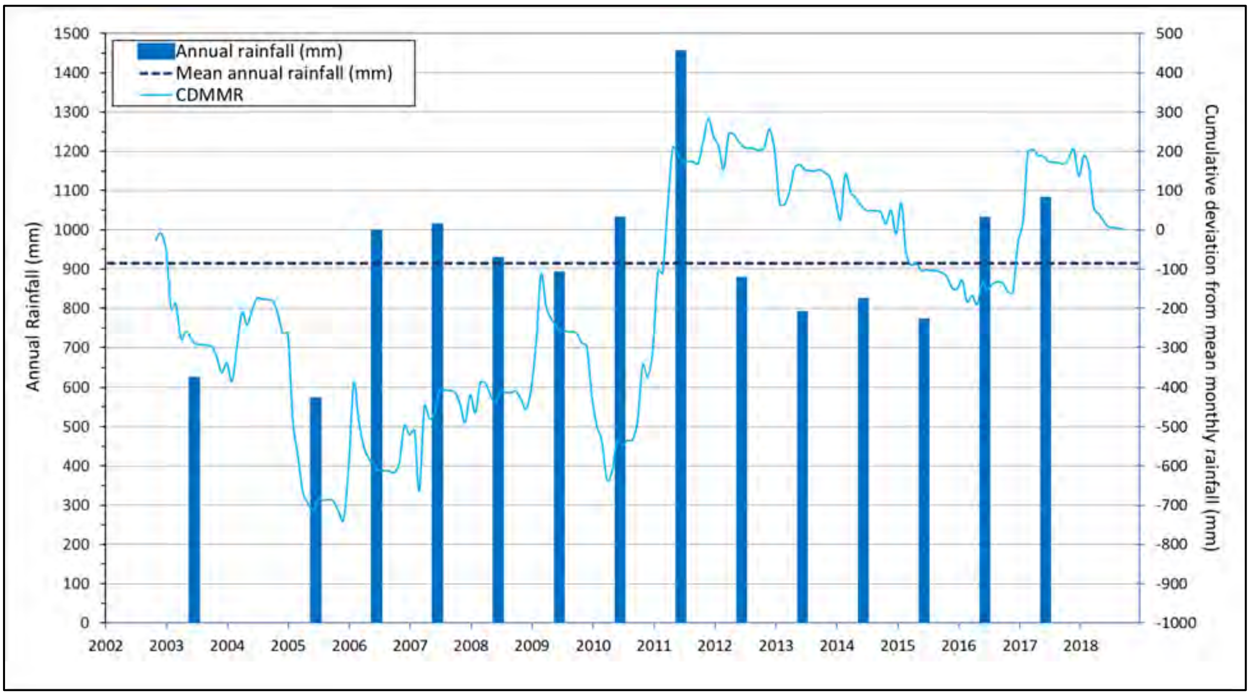


Figure 5. Annual rainfall and cumulative deviation from mean monthly rainfall, Mount House Airstrip BoM station 003098.

Mean annual runoff for the Isdell River catchment during the period 1930-2007 was estimated to be 3,330 GL/yr. compared to mean annual rainfall of 19,945 GL/yr. for the same period (Petheram et al., 2009). When averaged across the entire catchment area, these figures equate to 167 mm/yr. runoff from 1001 mm/yr. rainfall (i.e., a runoff coefficient of 16.7%). The remainder of the annual rainfall is either lost to evaporation, taken up by vegetation, or recharged to groundwater.

3.1.3. Glenroy Station

No historical rainfall or runoff data are available for Glenroy Station; however, the annual averages are likely to be similar to Mount House given similar topography and geology.

3.2. River & Creek Flow

The Mt. Joseph stream gauging station on the Lennard River is located near the upstream boundary of Napier Downs Station (Figure 1) and thus flows recorded at this site will be less than those encountered further downstream due to the runoff contribution from additional catchment area. The site has 53 years of historical record from 1966-2018, although a full annual record is only available for 49 years. For this period the mean and median annual flow is 271 GL/yr. and 256 GL/yr. respectively. Daily streamflow is highly seasonal, with cease-to-flow conditions generally occurring early in each dry season. However, maximum daily flows during each wet season have historically ranged from less than 10 GL/d. to more than 250 GL/d (Figure 6). The maximum daily flow each wet season is, on average, approximately 46.0 GL/d. and the 10th percentile for all wet seasons is 6.2 GL/d. (Figure 7). In other words, 90% of wet seasons have recorded at least one day with a flow in excess of 6.2 GL/d.

The Dales Yard stream gauging station on the Isdell River is located near the downstream boundary of Mount House Station (Figure 2) and thus flows recorded at this site are a good indication of water availability to support new development. The site has 52 years of historical record from 1967-2018, although a full annual record is only available for 37 years. For this period the mean and median annual flow is 396 GL/yr. and 291 GL/yr. respectively. Daily streamflow is highly seasonal, with cease-to-flow conditions generally occurring early in each dry season. However, maximum daily flows during each wet season have historically ranged from less than 5 GL/d. to more than 200 GL/d (Figure 6). The maximum daily flow each wet season is, on average, approximately 41.3 GL/d. and the 10th percentile for all wet seasons is 4.2 GL/d. (Figure 7). In other words, 90% of wet seasons have recorded at least one day with a flow in excess of 4.2 GL/d.

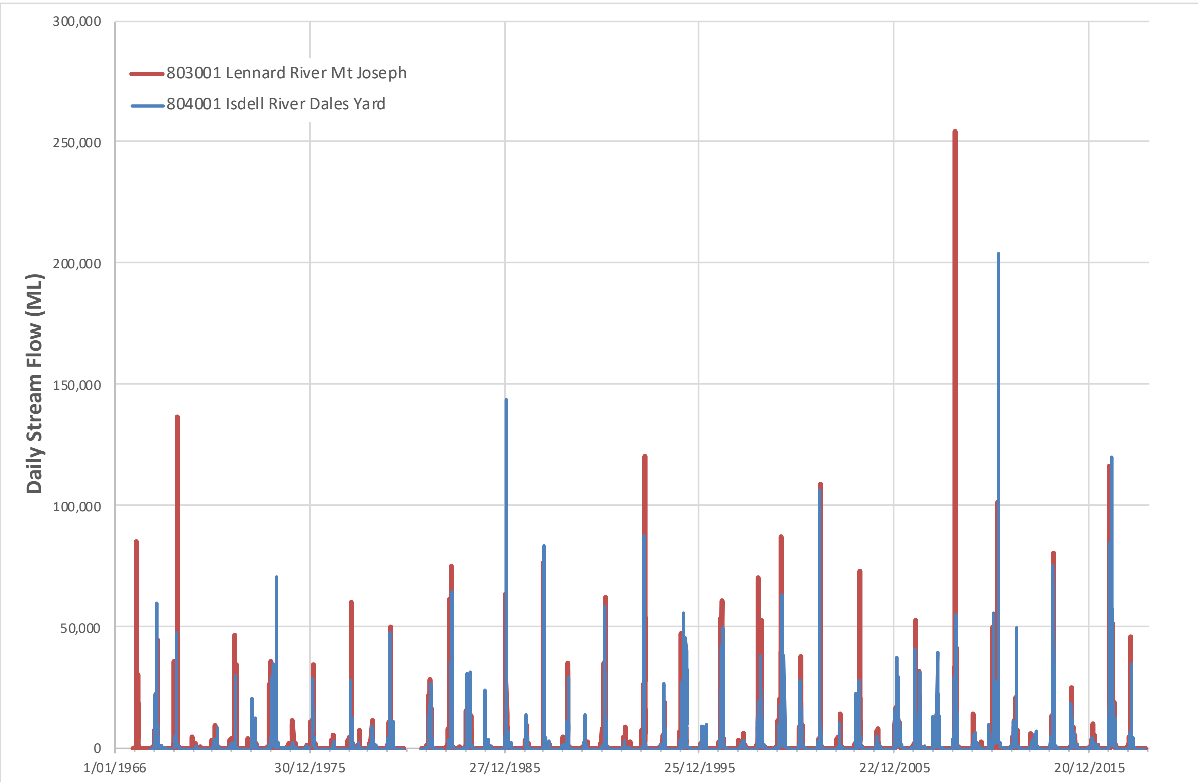


Figure 6. Daily streamflow records for gauging stations on the Lennard River at Napier Downs and the Isdell River at Mount House.

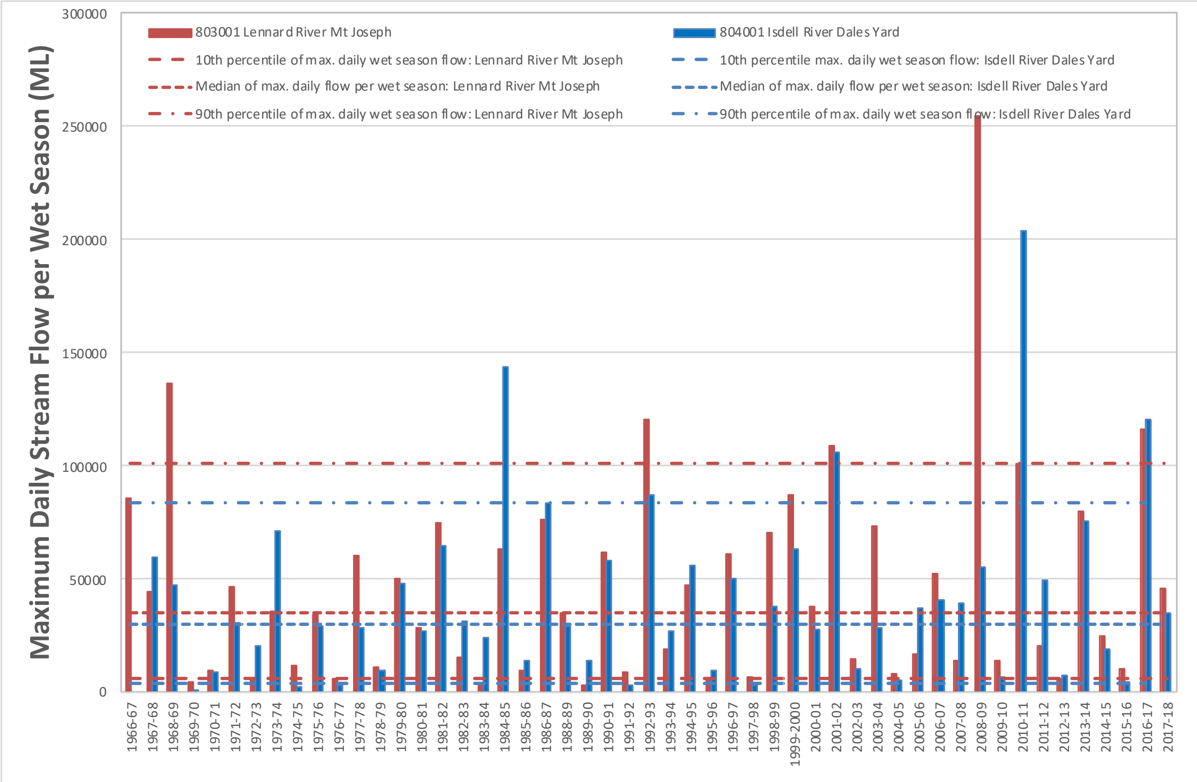


Figure 7. Maximum daily river flow recorded for each wet season, and the 10th, 50th (median) and 90th percentile values for the entire monitoring record.

3.3. Groundwater

The recent report by IGS (2018) has identified the regional-scale Grant Group aquifer beneath the southwest corner of Napier Downs Station (Figure 1) as having the greatest potential for supporting future irrigation development. The Devonian reef limestone aquifers further to the southeast may also offer some opportunities, however these are likely to be local-scale aquifers and thus smaller prospects. Elsewhere on Napier Downs, and throughout all of Mount House and Glenroy stations, groundwater resources are limited to shallow, fractured-rock systems that have low storage and highly variable bore yields. These aquifers are really only suitable for stock or domestic supplies.

3.4. Summary of Current Demands & Local Opportunities

Table 1 provides a summary of responses provided by the ACE-K operations and station managers. It shows the importance of natural surface waters in the wet season and strong reliance on mainly bores but also runoff dams in the dry season.

Table 1 Feedback received from Operations and Station managers

	NAPIER DOWNS	MOUNT HOUSE / GLENROY	OVERALL
1. Current Herd / Water Demand	Approx. 21,000 head	Approx. 34,000 head	40 L/hd./d. dry season 60 L/hd./d. wet season
2. Source Breakdown	Up to 60% natural (surface) waters following good wet, No river pumps 50% bores 50% dams (3)	From May onwards: 50% natural surface water 50% split b/n bores (26), dams (6) and river pumps (1) for 50+ water points	Wet season average: 70% natural surface water 30% water points Dry season average: 20% natural surface water 80% water points
3. Yield & Water Quality Changes	Some bores in Devonian reef fork late in the dry season	Natural surface water becomes rank late in year	-
4. Immediate Needs	Temporary shortages around homestead when cattle yarded nearby	Some areas where need more water but bores unsuccessful so dams may be an option	-
5. Future Opportunities	-	Some areas could carry larger numbers of stock but need water as well as fencing	-
6. Rain Gauges	Yes	On order to install throughout property	Both homesteads have gauges and extensive records
7. Suitability for Dams	Could construct more but not over sandstone as they leak, bores are better option	-	-
8. Surface Water Constraints	Pools change in location, depth and extent each dry season	Department restrictions on pumping from rivers	-

4. Soil & Landscape Suitability

The suitability of soils and landscape attributes (e.g., terrain) to support irrigation development on ACE-K pastoral stations has been mapped using DPIRD's "Soil-landscape mapping Western Australia – Best available soils" electronic dataset (Version April 2018) in the absence of detailed site-specific information. It is worth noting that the metadata statement for this dataset indicates the survey reliability to be "Very Low" for the Kimberley region; thus, it may be useful for strategic planning purposes but would need to be verified with field surveys as part of any detailed feasibility studies.

Previous mapping of carrying capacity for each of the stations by Department of Agriculture and Food WA (DAFWA, 2011) grouped Land Systems according to their pastoral potential. Areas of "High" pastoral potential on Napier Downs Station include the following land systems: Djada, Duffield, Fossil, GoGo and Leopold, all of which contain extensive areas of black cracking clay soils (Figure 1). Accordingly, these land systems would also be highly suitable for irrigated agriculture. Several other land systems that may lend themselves to irrigation on Napier Downs Station were included as part of the "Moderate" pastoral potential category: Neillabublica, Sisters and Yeeda (Figure 1).

Areas of "High" pastoral potential on Mount House and Glenroy stations include the following land systems: Cowendyne, Gladstone and Isdell, which contain areas of cracking clay soils amongst undulating country of either red earths or loamy soils (Figure 2). All other land systems on these two stations, including those in the "Moderate" pastoral potential category, are unlikely to be suitable for irrigation.

5. Water Resource Development Opportunities

5.1. Surface Water

Given the moderate to high average annual rainfall on ACE-K pastoral stations, it could be perceived that there are vast opportunities to divert rainfall runoff and river flow for beneficial use, whether for stock water supply or irrigated agriculture. However, the strong seasonality and inter-annual variability in rainfall, coupled with very high evaporation rates, make these prospects highly challenging.

The potential benefits of constructing small (e.g., <100 ML) catchment dams in hilly terrain to capture wet season runoff for stock water are likely to be far outweighed by the risk of dam failure due to flash flooding and the annual losses due to evaporation. Larger in-stream dams present similar problems and require inordinate capital investment. They also present significant challenges in terms of obtaining regulatory approvals due to stakeholder concerns about impacts – perceived or actual – to environmental or cultural values brought about by altering the natural flow regime of major rivers.

The greatest opportunity to utilise surface water resources to enhance cattle operations on these stations is diversion of river and overland flow to off-stream storages during high flow conditions. This would ideally be achieved through flood water diversion utilising the natural topographic gradient, however depending on location, it may be necessary to pump water from drainage lines into off-stream storages. Whilst high flow conditions are obviously the ideal times to maximise natural diversion, the main reason for diverting water into off-stream storages under these conditions is to ensure the net take only represents a very small proportion of the total flow in the river. This presents a scientifically defensible basis for obtaining a surface water licence, as any impacts to environmental values either locally or downstream will be negligible and immeasurable.

In the case of Napier Downs Station, the only historical streamflow gauging record that can be used to estimate potential diversion volumes is from Mt. Joseph on the Lennard River, which is not ideal for two reasons. Firstly, the gauging station is located on a part of Napier Downs where the soils and landscape are unlikely to be suitable for irrigation. Secondly, it is located immediately upstream of Windjana Gorge, one of the most iconic natural features in the Kimberley with immense cultural and environmental values. Hence, the likelihood of being granted a surface water allocation in this area is very low. Nevertheless, the streamflow record from Mt. Joseph provides insight to what may be achievable on the Barker River to the northwest. By way of example, capturing just 1% of one day of Lennard River flow at the average wet season maximum daily flow rate would yield 0.46 GL in off-stream storage, which is more than half of the annual volume of water required to irrigate fodder crops with a 40-hectare pivot.

In the case of Mount House Station, the historical streamflow gauging record for Dales Yard on the Isdell River is very useful because it is located immediately downstream of a large area of soils and landscape systems that have high pastoral potential (Figure 2). Following the same logic as the example provided above for Napier Downs Station, capturing just 1% of one day of Isdell River flow at the average wet season maximum daily flow rate would yield 0.41 GL in off-stream storage, which is about half of the annual volume of water required to irrigate fodder crops with a 40-hectare pivot. This estimate does not account for evaporation losses from the off-stream storage facilities, which are likely to be significant and difficult to estimate. Even if one assumes 50% losses, capturing 1% of only half the average wet season maximum daily flow for eight days would provide ample water to run a 40-hectare pivot for a year.

In the case of Glenroy Station, there are no nearby historical streamflow gauging records and there is only a relatively small area of soils and landscape systems that have high pastoral potential (Figure 2). Surface water development opportunities for this station are also limited by the fact they are located in the headwaters of the Fitzroy River catchment, where increasing environmental attention and political commitments are likely to prevent future large-scale diversions for irrigation.

5.2. Groundwater

While there are some potential surface water development opportunities for both Napier Downs and Mount House stations, the most reliable source of water and least challenging option to obtain regulatory approvals is groundwater from the Grant Group aquifer on Napier Downs. Figure 1 shows the extensive areas of alignment between the mapped aquifer extent and soil-landscape systems of high and moderate pastoral potential. Accordingly, these additional datasets – albeit of low reliability for detailed planning purposes – support previous estimates by IGS (2018) that the Grant Group aquifer could potentially support between 100-330 hectares of irrigation using between 2-5 GL/yr. of groundwater.

6. References

BoM (2018) http://www.bom.gov.au/climate/data/

DAFWA (2011). Pastoral potential maps for Napier Downs, Glenroy Station and Mt House Station, prepared by Anne Marie Huey, January-February 2011, Department of Agriculture and Food.

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Harrington, G.A. and Harrington, N.M. (2015). *Lower Fitzroy River Groundwater Review*. A report prepared by Innovative Groundwater Solutions for Department of Water WA, 15 May 2015.

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Petheram, C., Rustomji, P. and Vleeshouwer. J. (2009). *Rainfall-runoff modelling across northern Australia*. A report to the Australian Government from the CSIRO Northern Australia Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, Australia.

Memo

Date: 10 April 2019

To: James McMahon, Chief Operating Officer, Australian Capital Equity

From: Dr. Glenn Harrington, Director & Principal Hydrogeologist, IGS

Subject: **Additional technical data for consideration of surface water opportunities**

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1. Dam Size Calculations

Annual crop water requirement = 6 pivots @ 40 ha/pivot x 16 ML/ha/yr = 3,840 ML/yr.
Annual pan evaporation rate = 3.6 m/yr (average 10 mm/day)

For a dam with vertical walls – i.e. a "turkey nest"
(NB. this is reasonable assumption for large irrigation storages but not appropriate for small stock water dams as they are generally constructed with sloping internal walls/base draining into a centralised sump)

(1) If dam length is 100 m and width is 80 m (i.e. surface area = 0.8 ha), then
- Depth required is 483.6 m
- Total dam volume is 3,868.8 ML (3.9 GL)

(2) If maximum constructed depth of dam is 6 m, then
- Area required is 160 ha (e.g. 1.6 km x 1.0 km)
- Total dam volume is 9,600 ML (9.6 GL)

Alternatively, for an annual crop water requirement of 6,000 ML/yr. (6.0 GL/yr)

(3) If dam length is 100 m and width is 80 m (i.e. surface area = 0.8 ha), then
- Depth required is 753.6 m
- Total dam volume is 6,028.8 ML (6.0 GL)

(4) If maximum constructed depth of dam is 6 m, then
- Area required is 250 ha (e.g. 2.5 km x 1.0 km)
- Total dam volume is 15,000 ML (15.0 GL)

2. River Flow Reliability

The second of two recent technical reports prepared by IGS (21 Nov. 2018) has reported the only current stream gauging site of relevance to Napier Downs Station is "Mount Joseph" on the Lennard River; there is no historical information for either the Barker River or Hawkstone Creek. Likewise, the only current gauging site of relevance to Mount House Station is "Dales Yard" on the Isdell River; any gauging sites on the Adcock or Hann rivers are located significant distances either upstream or downstream of the station boundaries (e.g., Dimond Gorge on the Fitzroy River) and are therefore not meaningful for analysis of historical flows.

For the Lennard River at Mount Joseph, the historical record of daily flows covers 53 years from 1966-2018 and indicates that 90% of wet seasons have recorded at least one day with a flow in excess of 6.2 GL/day (72 cumecs). Likewise, for the Isdell River at Dales Yard, the historical record of daily flows covers 52 years from 1967-2018 and indicates that 90% of wet seasons have recorded at least one day with a flow in excess of 4.2 GL/day (49 cumecs).

However, river flows of these magnitudes (4.2 – 6.2 GL/day) are unlikely to be harvestable due to (i) river levels being too low to enable gravity-fed diversion of flow to off-stream storages, and (ii) WA Government licensing rules that will only allow harvesting a small fraction of the total flow and only during times of high flow. Hence, it is prudent to calculate the probability of receiving higher maximum daily flows each wet season to understand the reliability of achieving harvestable flows. The following table provides these metrics.

Percentile	Percentage of wet seasons with at least one day exceeding max. flow	Maximum wet season daily flow (GL/day)	
		Lennard River - Mount Joseph	Isdell River - Dales Yard
10th	90%	6.2	4.2
20th	80%	9.6	9.2
30th	70%	14.2	17.5
40th	60%	19.4	27.6
50th	50%	35.2	29.9
60th	40%	46.9	38.8
70th	30%	61.3	49.7
80th	20%	75.1	60.7
90th	10%	101.3	84.1
100th	0%	254.3	204.2

Here follows an example of how this data can be used. Suppose the target volume to be captured for storage is 15 GL based on the dam size calculations presented in section (1), and that this target volume is diverted over 10 days at an average rate of 1.5 GL/day. Now suppose that this daily diversion represents only 2% of the total daily flow, which would mean the latter needs to be 75 GL/day. The table above indicates that flows in excess of 75 GL/day have only occurred in the Lennard River at Mount Joseph in 20% of previously recorded wet seasons. For the Isdell River at Dales Yard the percentage is even lower – around 15% of previously recorded wet seasons. Note that these are absolute best-case scenarios as they assume the target daily flow is sustained for 10 days.

Similar calculations could be performed with alternative assumptions about target volumes, daily diversions, percentage take etc. Regardless, the example provided demonstrates there is very low inter-annual reliability for harvesting significant volumes from either river.

3. Other Considerations

All surface water dams leak either horizontally through the banks or vertically into to the subsurface. Whilst theses losses can be minimized through careful selection, installation and maintenance of liner materials (e.g. imported clay or synthetic rubber), they thus must be accounted for when designing the capacity of the storage.

The McGowan Labor Government is actively delivering on its election commitments to expand the Fitzroy River National Park, and to develop a management plan of the Fitzroy catchment incorporating a water allocation plan to ensure the long-term health of the river and sustainable economic development. The foundation to these activities is a commitment that the river and its tributaries will not be dammed. Accordingly, the likelihood of ACE receiving any support – let alone formal approval – from the WA Government to build an instream dam to aid surface water diversions is next to zero, regardless of whether the site is in the Fitzroy catchment or elsewhere in the West Kimberley.

Memo

Date: 16 May 2019

To: James McMahon, Chief Operating Officer, Australian Capital Equity

From: Dr. Glenn Harrington, Director & Principal Hydrogeologist, IGS

Subject: **Flood mapping data for consideration of surface water opportunities**

Introduction

Preliminary desktop investigations by IGS identified groundwater resources from the Grant Group aquifer as presenting the greatest opportunity for irrigation development on ACE Kimberley pastoral leases (*IGS Report #1, 22 October 2018*).

This finding was supported by further analysis involving historical river flow data for the Lennard River at Mount Joseph (Napier Downs Station) and for the Isdell River at Dales Yard (Mount House Station), which showed the high seasonality and inter-annual (i.e. year-to-year) variability in river flows (*IGS Report #2, 21 November 2018*).

Most recently, IGS has calculated the probability of receiving sufficient daily flows each wet season to achieve a target storage volume of 15 GL over 10 days (*IGS Memo, 10 April 2019*). That basic analysis demonstrated that flows in excess of 75 GL/day have only occurred in 20% (1 in 5) previously recorded wet seasons for the Lennard River at Mount Joseph, and in 15% (about 1 in 7) previously recorded wet seasons for the Isdell River at Dales Yard.

As a final step in closing out the assessment of surface water opportunities, this Memo presents a brief summary of new work to assess two national scale datasets of flood mapping that were recommended by the WA Department for Water and Environmental Regulation (DWER). These are the Flood Hazard product offered through the FloodMap tool (Landgate) and the Water Observations from Space (WOfS) dataset compiled by Geoscience Australia.

Flood Hazard

The Flood Hazard product from Landgate appears to be a very simplistic assessment of potential for flood extent and water depth that is based solely on a digital elevation model (DEM) and does not consider historical river flow data or flooding frequency. Accordingly, maps of flood hazard for the southwest part of Napier Downs (see Figure 1) and Mount House-Glenroy (see Figure 2) suggest the key rivers might flood over large areas on a regular basis, which is inconsistent with historical observations including the fact that high flows in the Lennard River occur less than one in five years. Additionally, local knowledge of ACE-K staff that have lived on Napier Downs suggests the Lennard River Crossing has only flooded extensively on two occasions over the last 16 years. These observations indicate that the Flood Hazard map is not a reliable tool for informing development decisions in this area.

Water Observations from Space

The WOfS product from Geoscience Australia provides historical surface water observations derived from satellite imagery for all of Australia from 1987 to today. Key datasets of relevance to this project are the number or percentage of "clear" (i.e., cloud-free) images since 1987, and the number or percentage of "wet" (i.e., inundated) conditions since 1987. Data can be displayed for the entire 32-year period, annually or seasonally (November to March, April to October) and is at the scale of 25 m x 25 m pixels. Because "wet" conditions can only be detected from "clear" images, there is a potential to miss numerous occurrences of inundation during cloudy days (e.g., during the wet season).

A preliminary analysis of the datasets for ACE-K stations has revealed between five and 15 clear days each wet season (November to March). Only a small proportion (less than 10%) of these clear days show signs of floodplain inundation. Over the entire record since 1987, the proportion of wet conditions is even smaller at less than 5% for the majority of Napier Downs (Figure 3) and Mount House-Glenroy (Figure 4). The only areas where surface water is observed in more than 20% of clear days are the main watercourses (Lennard, Barker, Hann and parts of Isdell and Adcock rivers) and the major swamps and billabongs.

Conclusions

Based on the desktop analyses of surface water data and available flood mapping products conducted by IGS over the last six months, the following conclusions can be drawn:

1. Flow in the Lennard and Isdell rivers (as is characteristic of all rivers in the region) is highly seasonal and dominated by one or more large events each wet season;
2. Cumulative river flow is highly variable on a year-to-year basis with low reliability of achieving successive days of sufficient peak flows to enable diversion to off-stream storages;
3. Flooding frequency, which provides another insight to the likelihood of being able to harvest river flows each year, is very low for most rivers – between one in three and one in five years based on a rapid analysis of satellite data.
4. Flooding extents are highly variable and generally not correlated with the areas of best soils for irrigation or best access along existing station tracks.
5. When compared to the reliability of a groundwater supply, surface water development opportunities present significant risks in addition to the obvious challenges of water storage and environmental regulation.

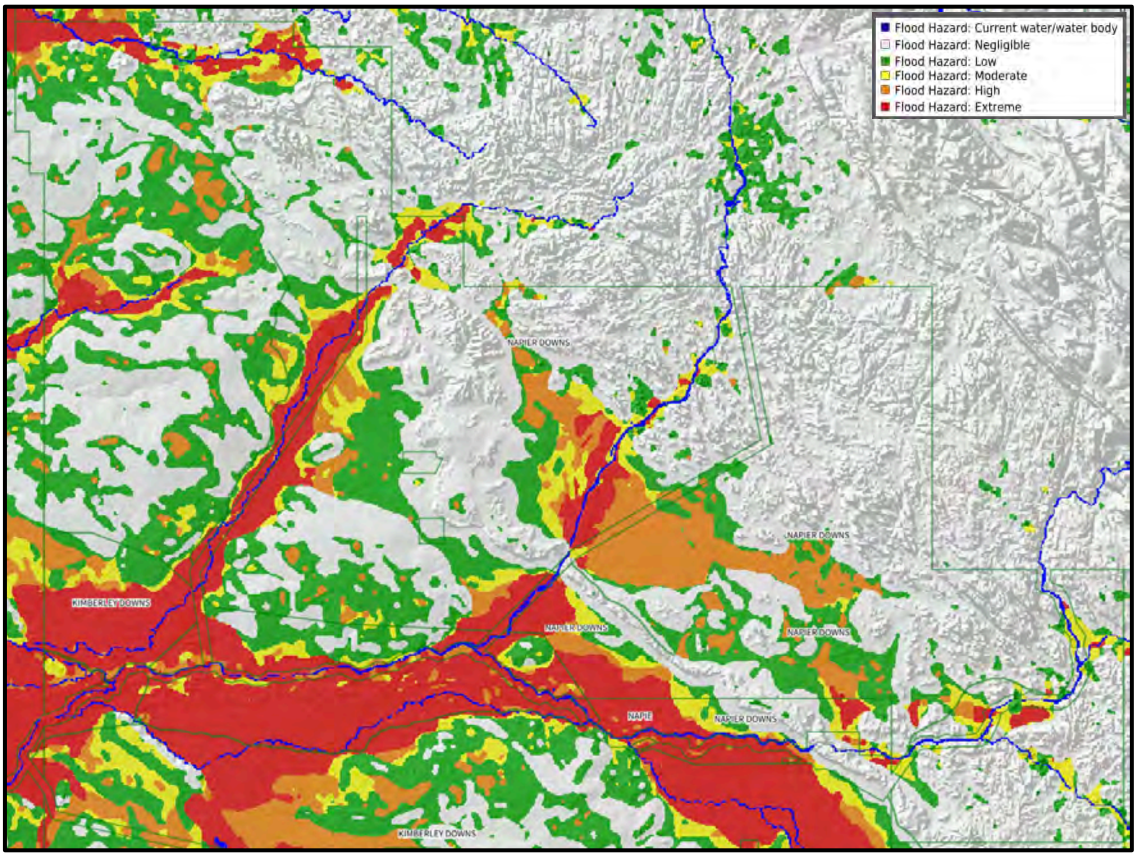

Figure 1. Flood Hazard for Napier Downs Station (source: FloodMap, Landgate).

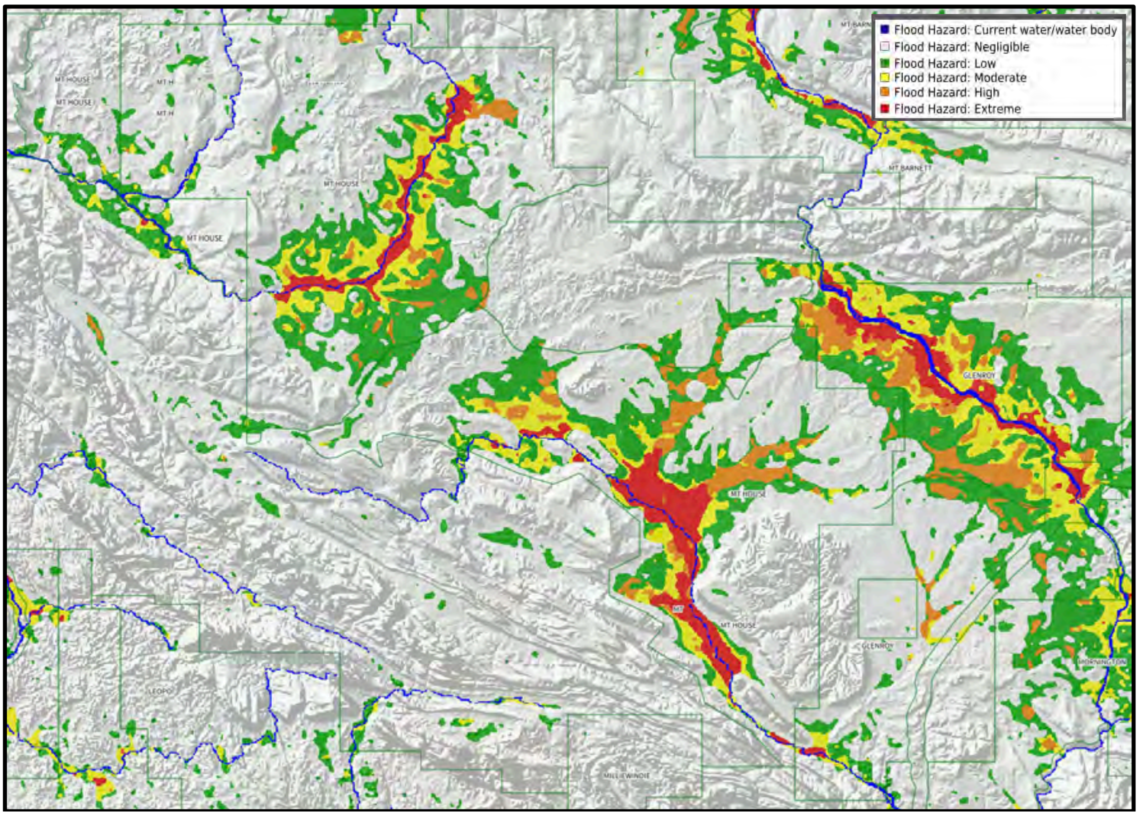

Figure 2. Flood Hazard for Mount House and Glenroy stations (source: FloodMap).

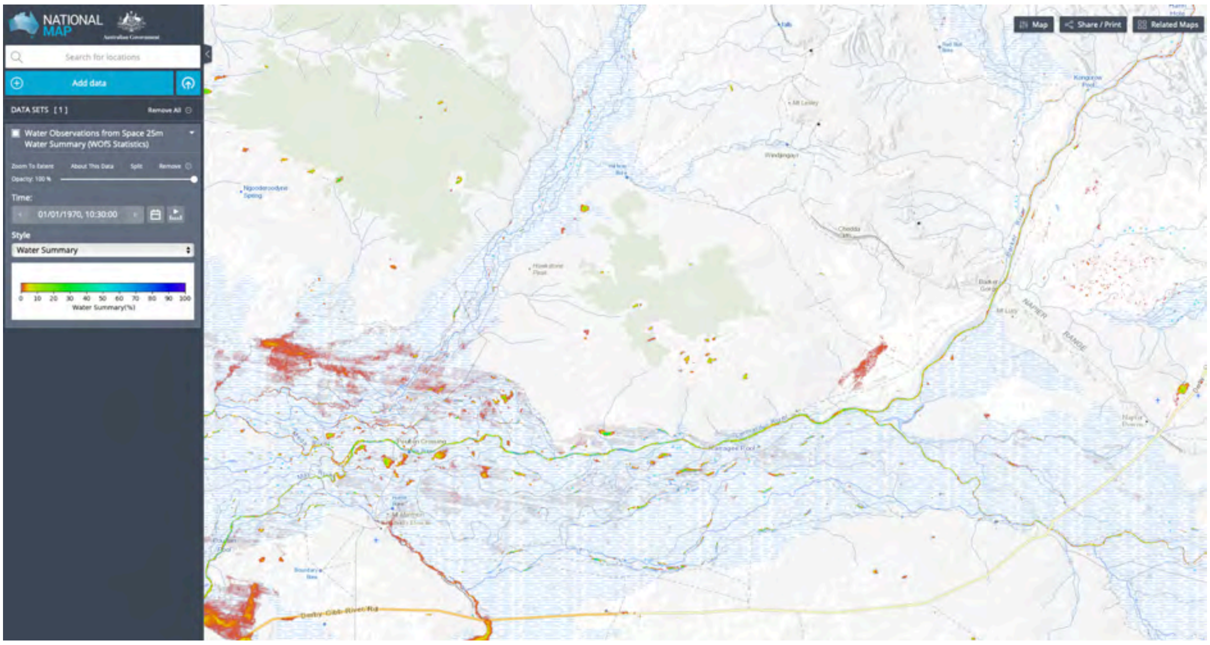

Figure 3. Southwest corner of Napier Downs Station showing percentage of clear satellite images obtained since 1987 when surface water was present (source: Water Observations from Space, Geoscience Australia).

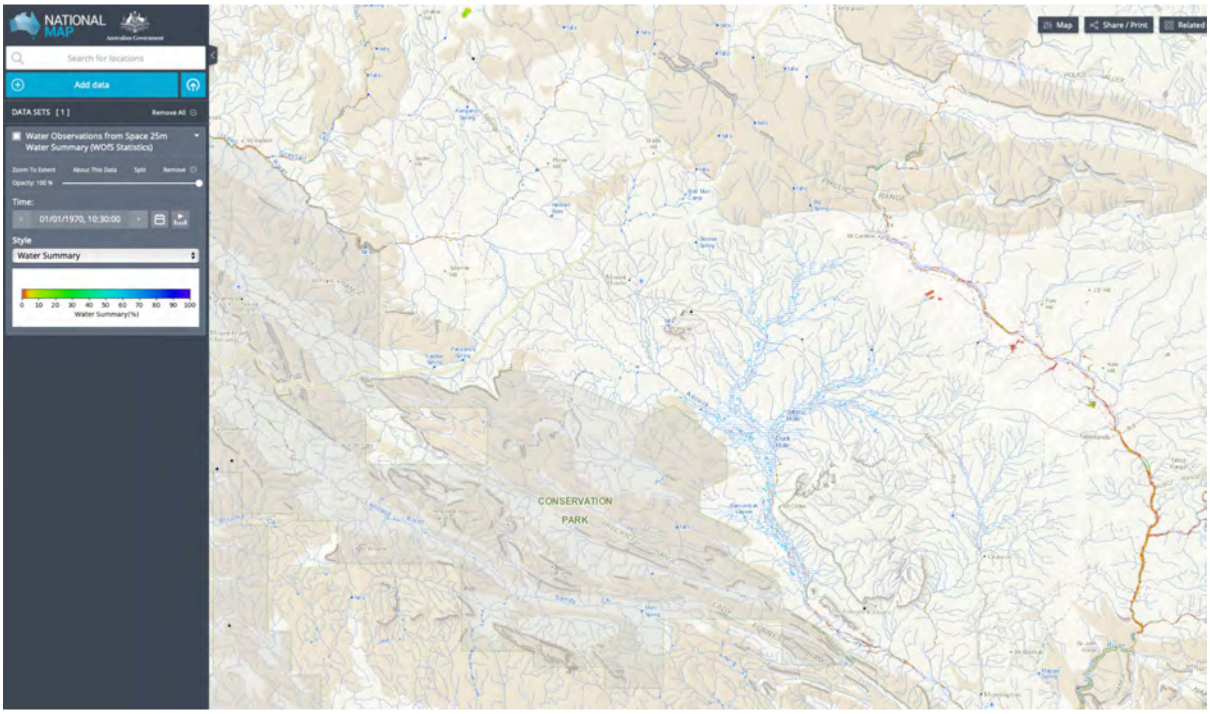

Figure 4. Mount House and Glenroy stations showing percentage of clear satellite images obtained since 1987 when surface water was present (source: Water Observations from Space, Geoscience Australia).

Appendix C

IGS (2019d) – Lennard Preliminary Risk Assessment

NAPIER DOWNS IRRIGATION PROJECT
Preliminary Groundwater Risk Assessment: Lennard River Site

A report prepared for Australian Capital Equity Pty Ltd.

1 August 2019

Version 1.0
Commercial in Confidence

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NAPIER DOWNS IRRIGATION PROJECT
Preliminary Groundwater Risk Assessment
Lennard River Site

A report prepared for Australian Capital Equity

by

Innovative Groundwater Solutions
1 August 2019

Document control

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DISCLAIMER

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Executive Summary

This Preliminary Risk Assessment was undertaken at the request of Department of Water and Environmental Regulation (DWER) in order to provide both Australian Capital Equity (ACE, the proponent) and the regulator (DWER and DLPH) with all available information on the risks of developing the Napier Downs Irrigation Project in the Kimberley region.

The project has already submitted an application 5C for a groundwater extraction licence for six gigalitres per annum from the Grant Group aquifer. Based on advice from industry professionals, this development will most likely occur over three stages. Stage 1 will comprise four 20-hectare pivots with a water allocation of 1.6 gigalitres per annum adjacent the Lennard River, where recent investigation drilling and soil testing has provided promising results.

The preliminary risk assessment has demonstrated that, at this stage, based on all of the discoverable information available, the project does not have any constraints in terms of ecological values, cultural heritage values, or potential hydrogeological impacts to existing groundwater users or the Lennard River. Additionally, the assessment has proposed a river set-back distance for Stage 1 production bores and pivots that is consistent with DWER policy and guidance documents that were provided to ACE at the time of the study.

This report forms a sound technical basis for the submission of applications for clearing and diversification permits, and a Form 1 to construct a production bore. Before proceeding to the next stage of installing and testing a trial production bore, which will require significant resources, the project needs in-principle approval that these permits are likely to be granted. This will also enable more formal engagement with Bunuba and Warrwa traditional owners.

CONTENTS

1. Introduction to the Napier Downs Irrigation Project

Australian Capital Equity – Kimberley Pty Ltd. (ACE-K) and its subsidiaries currently own and operate a number of pastoral leases in the Kimberley region, including Napier Downs, Mount House and Glenroy stations on the Gibb River Road. In an effort to enhance productivity and drought-proof the existing cattle enterprises on these stations, ACE-K are seeking regulatory approvals to commence irrigated agriculture, specifically year-round production of high-value fodder crops.

1.1. Recent Studies

Over the last twelve months, Innovative Groundwater Solutions Pty Ltd. (IGS) has been commissioned to undertake a number of desktop studies to provide a defensible scientific basis for proceeding with a 5C water licence application to Department for Water and Environmental Regulation (DWER). In October 2018, IGS (2018a) reported on the various groundwater development opportunities across the three pastoral leases and found the most prospective resource for large-scale irrigated agriculture to be the regional Grant Group aquifer that underlies large areas in the southwest corner of Napier Downs Station. The Devonian reef limestone aquifers further to the east and southeast may also offer some development opportunities, however these are likely to be local-scale aquifers and thus smaller prospects. Additionally, the cavernous reef limestones that form the Napier Range are known to have high cultural and environmental values. Elsewhere on Napier Downs and the other stations the groundwater resources are limited to shallow, fractured-rock aquifers that have low storage properties and highly variable bore yields, and thus are really only suitable for stock or domestic supplies.

A follow-up report by IGS in November 2018 examined historical rainfall, runoff and river flow gauging data for the ACE-K pastoral leases to investigate surface water development opportunities. Due to the very high inter-annual variability in rainfall and river flow, surface water resources are likely to be too unreliable for large-scale economic development on these stations (IGS, 2018b). Further constraints to surface water development in the West Kimberley region include the scale, capital expense and evaporation losses from storage infrastructure, and the current political appetite for damming rivers due to perceived impacts on environmental and cultural values (IGS, 10 April 2019; Appendix 1).

IGS (2018b) also mapped the suitability of soils and landscape attributes (e.g., terrain) using Department of Primary Industry and Regional Development (DPIRD) 'Soil-landscape mapping Western Australia – Best available soils' electronic dataset (Version April 2018). Previous mapping by Department of Agriculture and Food WA (DAFWA, 2011) had grouped Land Systems according to their pastoral potential. IGS (2018b) identified large areas of "High" and "Moderate" pastoral potential on ACE-K stations that would be highly suitable for irrigated agriculture. The mapped extent of the Grant Group aquifer beneath Napier Downs Station also coincides with large areas of soil-landscape systems with high and moderate pastoral potential (IGS, 2018b).

The early IGS studies were used as a foundation for ACE to write to DWER on 22 October 2018 requesting a meeting to share information, to understand the types of water licences that may be sought, and to get feedback on the feasibility of the proposed irrigation project. The meeting was held on 16 November 2018 and, as a consequence, Napier Corporation Pty Ltd. submitted an application to DWER on 4 December 2018 for a licence to take water to draw six gigalitres per annum (6 GL/yr) from the Canning-Grant groundwater resources for irrigation of 300 hectares of fodder crops (i.e., irrigation rate up to 20 ML/ha/yr).

Since submission of the application for a water licence, ACE-K have commissioned Phoenix Environmental Sciences Pty Ltd. (Phoenix) to provide a desktop environmental (biological) review for irrigation at either of two site options on Napier Downs Station (Phoenix, 2019). Option 1 is located adjacent the Gibb River Road and Lennard River; it overlies the Grant Group aquifer and provides year-round access via existing road infrastructure and suitable pindan soils that are rarely inundated. Option 2 is located further west on Napier Downs; it offers much larger opportunities for development of the Grant Group aquifer but is currently limited in terms of access due to a need to cross the Barker River and cracking black clay soils, both of which become impassable during the wet season.

A copy of the Phoenix (2019) environmental report is included as Appendix 2, with key findings summarised as follows:

- 17 significant flora species were identified as occurring within 40 km of each Option, although none were recorded within either area.
- High likelihood that either or both Options will contain conservation significant flora.
- Neither Option is impacted by any Priority Ecological Community (PEC), although the two are separated by PECs. Neither area intercepts the buffer zones of the PECs.
- Neither option is situated within a conservation reserve or Environmentally Sensitive Area (ESA). The nearest conservation reserve is Windjana Airstrip (14.5 km east of Option 1) and the nearest ESA is Windjana Gorge National Park (16.5 km east of Option 1).
- No Ramsar or other significant wetlands in the study area or wider desktop search area.
- No conservation significant vertebrate fauna has been recorded in either area, however one species (Gouldian Finch) has previously been recorded 900 m northwest of the Option 1 area.
- Four terrestrial invertebrates listed as Threatened under the State BC Act and three species listed as priority fauna by Department of Biodiversity, Conservation and Attractions (DBCA) were identified within a 100 km radius of the study area; all are land snails that were mainly associated with the Napier Range to the northeast.
- Records of 12 troglofauna and one stygofauna species were returned in database searches, but none of these are listed as Threatened or Priority. All of the troglofauna species are associated with caves in the Napier Range.
- No groundwater springs are recorded near either Option; the closest to Option 1 is Baralama Spring about 12 km to the east, and the closest to Option 2 is Ngooderoodyne Spring about 30 km to the west.

To progress the application for a water licence, DWER have requested that ACE prepare a Preliminary (groundwater) Risk Assessment (PRA) in line with their Interim Guidance document (DWER, 2019a). This report addresses the request from DWER and will inform all future hydrogeological testing and assessment methodologies for securing the water licence. Additionally, this report provides critical information to support the submission of applications for both native vegetation clearance and diversification permits.

1.2. Proposed Water Resources

While there are some potential surface water development opportunities on Napier Downs Station, including the Lennard and Barker rivers, the most reliable source of water for large-scale irrigation development is groundwater from the regional-scale Grant Group aquifer (IGS, 2018a). This is also likely to be the least challenging water supply option in terms of acquiring the necessary regulatory approvals (IGS, 2018b). Accordingly, the water licence application is for the Canning-Grant groundwater resource.

Option 1 (hereafter referred to as the Lennard River) is the preferred site for the first stage of irrigation development on Napier Downs for the reasons explained above. Figure 1 shows the proposed location of a trial production bore and four 20-hectare pivots to be established as Stage 1 of the irrigation development. It also shows the northern extent of the Grant Group aquifer, which is bounded by the relatively impervious (and thus low yielding) Fairfield Group that separates it from the Devonian reef limestones further north.

The Lennard River site does present a number of potential risks to connected water resources due to its proximity to the river; however, these risks can easily be monitored and managed with meaningful strategies. Notwithstanding the risk of the development impacting surface water-groundwater interactions, which will be explored in detail in the following sections of this report, the greatest risk is likely to be associated with nutrient and sediment runoff from irrigated agriculture to impact riparian and in-stream ecosystems. Section 3 ranks this and other risks and provides an overview of the proposed on-farm measures to mitigate the risk.

In May 2019 ACE contracted Direct Drilling (Kununurra) to drill an investigation borehole to confirm the presence of the Grant Group aquifer at this site (location shown in Figure 1). The hole was mud-rotary drilled to a total depth of 120 metres below ground and the strata encountered were consistent with other bores recently drilled in the area, including the Water for Food bores on Kimberley Downs Station (DWER, 2017). Fine-grained sandstone between 18 and 60 metres depth confirmed the presence of a 20-30-metre-thick saturated upper Grant Group aquifer. Silty clays were encountered from 60 to 89 m depth, followed by coarse sands and gravels from 102 metres to the bottom of the hole. The bore has been constructed as a dedicated monitoring bore to facilitate future aquifer pumping tests at the site and longer-term water licence compliance purposes. A combined lithological log and bore construction diagram has been prepared in Appendix 3. Following development of the bore, an airlift yield of at least six litres per second was achieved.

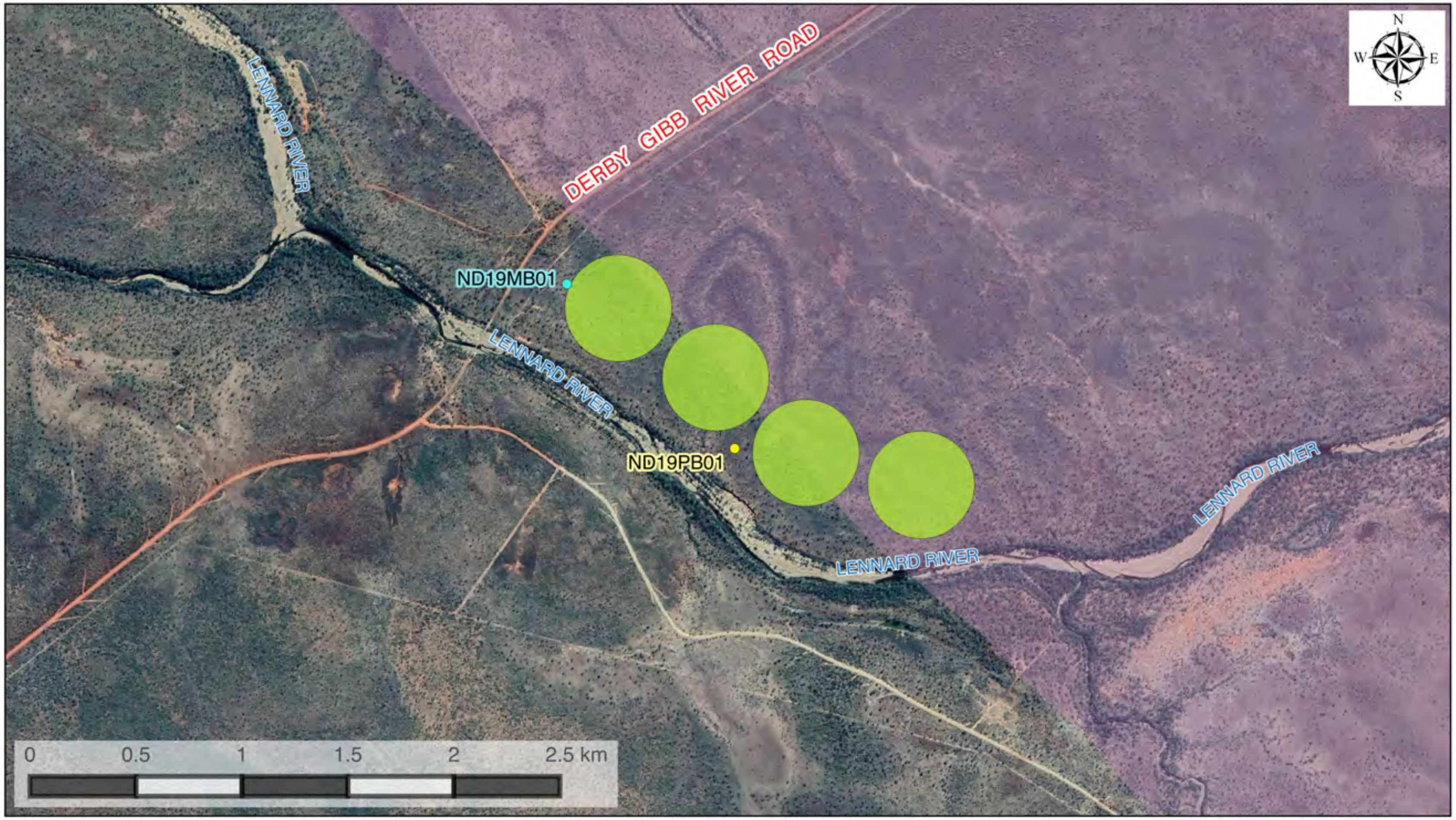

FIGURE 1. Location of recently drilled monitoring bore (ND19MB01) and proposed trial production bore (ND19PB01) as well as four proposed 20-hectare pivots for Stage 1 irrigation development. Note proximity to low-permeability Fairfield Group geology as shown by pale pink overlay.

Map prepared by G.A. Harrington
Innovative Groundwater Solutions Pty. Ltd.
Version 2, 30 July 2019
Coordinate Reference System: GDA94 MGA Zone 51

1.3. STAGING

The application 5C for a groundwater extraction licence is for an allocation of six gigalitres per annum from the Grant Group aquifer. Based on advice from industry professionals, this project will most likely be developed over three stages. Stage 1 will comprise four 20-hectare pivots (Figure 1) with a water allocation of 1.6 gigalitres per annum for use at Option 1 adjacent the Lennard River. This is the best site logistically (section 1.1) and is the minimum scale required for commercial benefit.

If the groundwater resource at Option 1 is not capable of supplying sufficient yields for Stage 2 and Stage 3, then Option 2 may be explored to enable full development of 300 hectares and a water licence of six gigalitres per annum. This scale offers the best commercial return for the project.

1.4. HISTORICAL, CURRENT AND FUTURE USERS

Kimberley Diamond Company previously held a licence for 11.926 GL/yr from the Grant Group aquifer for its operations at nearby Ellendale Mine (Harrington and Harrington, 2015).

As at 9 July 2019, the total volume of groundwater allocated from the Grant Group aquifer in the Canning-Kimberley Groundwater Area is 1,229,475 kL/yr (i.e., approximately 1.23 GL/yr) (source: DWER, 2019b). This volume is spread across 20 licences with the largest licenced allocations held by Gibb River Diamonds Limited (0.36 GL/yr issued on 19 May 2019) and Water Corporation (0.3 GL/yr for Fitzroy Crossing town water supply). In other words, more than 50% of the total allocated volume is associated with two licensees.

The nearest licenced allocations to the Lennard River site are held by Main Roads (0.099 GL/yr spread over multiple licence addresses), Buru Energy Limited (0.010 GL/yr spread over multiple licence addresses) and Gibb River Diamonds Limited (0.36 GL/yr spread over two licence addresses between 9 km and 19 km to the south). There are no known Aboriginal communities in the vicinity that use groundwater from the Grant Group. The only known unlicensed use is for isolated stock bores (IGS, 2018a).

The current allocation limit for the Grant Group is 100 GL/yr (DOW, 2014) which means the resource is significantly under-allocated and there is potential for future increases in allocation and use.

2. Groundwater Dependent Ecosystems

2.1. Number & Scale of GDEs

Phoenix (2019) determined there was a moderate potential for the occurrence of GDEs in the study area and recommended that riparian vegetation be a focus for future detailed surveys to identify whether groundwater dependent vegetation is present.

The nearest recorded springs are located 12 km east of Option 1 and 30 km west of Option 2 (Phoenix, 2019). The assemblages of Big Springs organic mound springs constitute a groundwater-dependent and Vulnerable threatened ecological community (TEC). However, these mound springs are located on the eastern shore of King Sound, approximately 97 km to the northwest of Option 1.

One species of stygofauna has previously been recorded at two locations more than 10 km northeast of Option 2 in the Napier Range. While previous studies have shown stygofauna to be present in the Broome sandstone aquifer much further west of Napier Downs Station (Rockwater, 2012), there is currently no publicly-available knowledge of stygofauna being present in the Grant Group aquifer. Moreover, there is generally limited information and knowledge on stygofauna and their water requirements throughout the Kimberley region.

In other areas of the Kimberley, sites of high indigenous cultural and/or heritage value are often associated with permanent springs or water holes that are groundwater dependent. A desktop cultural heritage search for the study area was conducted by ACE on 18 March 2019 using the Department of Planning, Lands and Heritage (DPLH) Aboriginal Heritage Inquiry System. The search results are provided in Appendix 4 and reveal no "Registered Heritage Areas" and no "Other Heritage Areas" within either Option (NB. the search area for Option 2 differs slightly from that used for environmental review by Phoenix, 2019). The search did reveal that an ethnographic heritage survey has been undertaken in 1991 over the Bunuba People's traditional country, which incorporates the area of Option 1.

The Kimberley Land Council Native Title map (https://www.klc.org.au/native-title-map) shows the Warrwa Combined Claim (WAD258/2012), as registered in the National Native Title Tribunal (NNTT) on 14 November 2014, covers the proposed Lennard River (i.e. Option 1) development site. ACE-K remains committed to ensuring both Bunuba and Warrwa peoples are properly consulted on the cultural values of the area. This consultation may include their direct engagement in heritage surveys prior to land disturbing activities.

2.2. POTENTIAL RISKS TO VALUES

Groundwater abstraction has the potential to impact GDEs in different ways depending on the type of ecosystem and its level of dependency on groundwater.

Terrestrial GDEs in the form of deep-rooted vegetation may be impacted if prolonged groundwater abstraction without sufficient time for water level recovery removes what was an important and either temporary or permanent water source for the vegetation. Riparian vegetation is often reliant on shallow soil water and perched groundwater that is recharged from periods of rainfall and river flow. Thus, it is important to identify what (if any) role the regional water table has on supporting such ecosystems.

Spring-fed GDEs may be impacted if drawdown in groundwater levels (or pressures) propagate laterally (or vertically) to these features. This is provided the source of water for the spring is the same as that being abstracted, or the two are in direct hydraulic connection. In these instances, impacts generally occur as a result of either reduced level, frequency or duration of inundation; reduced discharge flux; or indirect water quality changes.

Subterranean GDEs in the form of stygofauna may be impacted if groundwater abstraction causes a temporary or permanent loss of habitat in the saturated, low-salinity pore spaces. While the water requirements and resilience of stygofauna are very poorly understood, particularly in the Kimberley region, a commonly held view amongst experts is that these ecosystems can be protected by ensuring the rate and total magnitude of change in groundwater levels and water quality are small.

2.3. CAUSAL MECHANISMS AND PATHWAYS

Groundwater abstraction at the Lennard River site will lead to seasonal drawdown in groundwater pressure that is likely to extend radially outwards from the production bores somewhere between several hundreds of metres and a kilometre or two, with the magnitude of drawdown decreasing exponentially with distance.

Given the presence of a thick, low-permeability, clayey interval overlying the productive zone for the recently drilled monitoring bore ND19MB01 (section 1.2 and Appendix 3) it is possible that the main aquifer will be confined. If this is the case, then groundwater abstraction from the deep, productive interval of the aquifer (i.e. below 100 m depth) may not cause any measurable change in level of the water table in the overlying, unconfined part of the aquifer. In this case, there is limited potential for any undesirable impact on ecological assets that rely on the position of the water table. Future aquifer pumping tests will be used to support or refute this hypothesis.

If, however, the Grant Group behaves as an unconfined aquifer, whereby abstraction from depth causes in immediate and predictable drawdown in the water table, then it is worth considering the pathways to potential impact as this is effectively a worst-case situation. Detailed conceptual hydrogeological models have been developed in cross-section view to demonstrate three key features (Figure 2A and Figure 2B):

1. Hypothetical drawdown in the water table will be limited in extent to the north/northeast due to the presence of the low-permeability Fairfield Group, which effectively provides a hydraulic buffer for preventing impact to stygofauna and any other GDES in the Devonian Reef much further to the north.
2. The elevation of the bed of the Lennard River is between 5 – 10 metres above the inferred elevation of the water table, which is based on recent measurements of water level in the new monitoring bore (ND19MB01) and the WfF bore on Kimberley Downs. This demonstrates that groundwater is not connected to surface water along this reach of the river, and that pumping groundwater will not impact baseflow or the persistence of in-stream pools.
3. The topographic gradient north of the proposed development site slopes northwards, away from the Lennard River, thus providing a natural mechanism to prevent water laden with nutrients and/or agricultural chemicals reaching the River via runoff. A preliminary desktop assessment of flooding potential at the site also shows this is unlikely (IGS, 9 May 2019; Appendix 5).

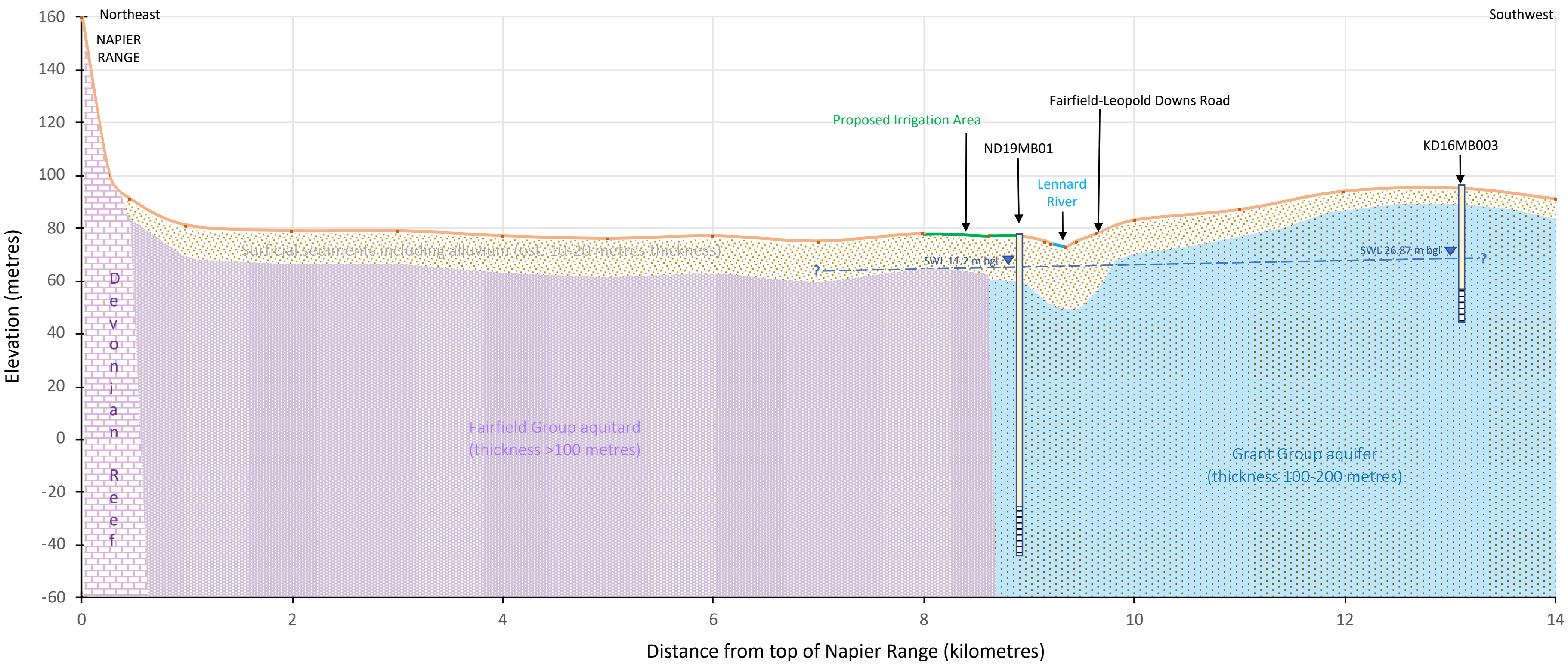

Figure 2A. Conceptual hydrogeological cross-section from the centre of Napier Range through to the Water for Food monitoring bore on Kimberley Downs Station (KD16MB003), showing location of proposed Napier Downs irrigation area adjacent Lennard River. Figure 2B on the following page is a zoom into the interval between 8 – 10 kilometres.

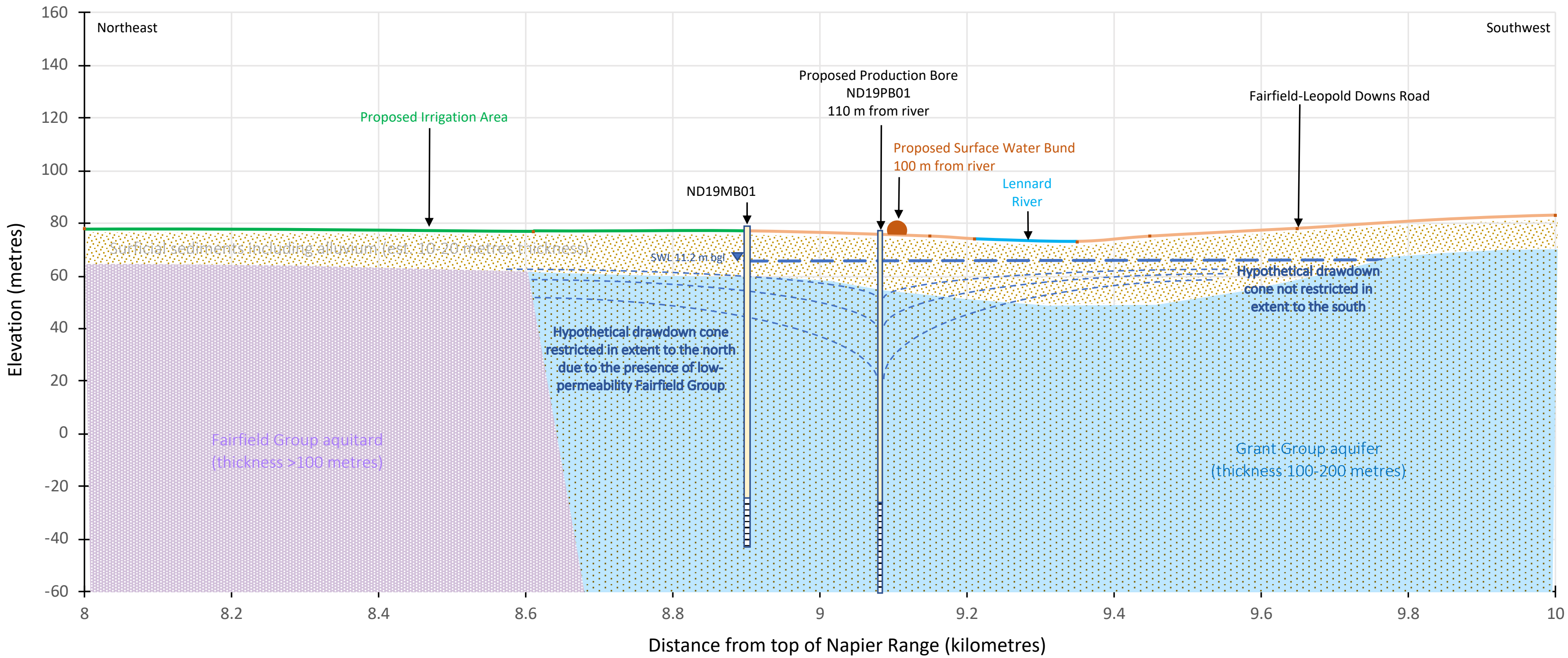

Figure 2B. Conceptual hydrogeological cross-section focussing on the proposed irrigation area adjacent Lennard River. Hypothetical drawdown cones are shown for illustrative purposes to demonstrate how drawdown in water level/pressure will be limited to the north, thereby circumventing impacts to ecologically and culturally sensitive sites within the Napier Range (see Figure 2A for location).

2.4. Proposed Modelling Approach

For data-poor areas such as the Option 1 development site, a H3 hydrogeological assessment would usually necessitate the development of a simple analytical modelling approach to predict possible drawdown impacts on potential or known groundwater dependent assets. However, due to the complexity of the hydrogeology at this site – particularly the presence of low-permeability Fairfield Group to the north, and the need to make predictions along a lineament of potential terrestrial GDEs associated with the Lennard River – it is likely that a three-dimensional numerical model will be required.

A test production bore is proposed to be drilled at the location shown in Figure 1, which will provide additional stratigraphic information to confirm the conceptual hydrogeological model for the site (Figures 2A and 2B) and enable a long-term aquifer pumping test to determine aquifer hydraulic properties. The information gleaned from these drilling and testing phases will be key inputs to the development of the numerical groundwater flow model.

Because there no other licensed or unlicensed groundwater users within at least 9-10 km of Option 1, there is no necessity to simulate cumulative drawdown impacts, or to come up with mitigation and management options for these other users.

3. Groundwater Risk Assessment

3.1. Approach

A Failure Modes Effects Analysis (FMEA) has been adopted to assess the risks associated with each process of every phase of the project, including investigative drilling, aquifer testing and characterisation, groundwater abstraction and discharge in the form of crop irrigation. The FMEA spreadsheet tool was provided to IGS by DWER in 2018 and ranks potential activities with a Risk Priority Number (RPN) that is derived from the product of user-defined scores for severity, likelihood and detectability of impacts to the environment.

3.2. Results

Whilst the FMEA tool is highly qualitative and subjective, it rapidly identified the four highest risks for the proposed Option 1 development adjacent the Lennard River to be:

1. Fertiliser application causing nutrient runoff which could in-turn impact surface water quality (RPN=40)
2. Groundwater extraction causing lowered water tables which in-turn could impact terrestrial GDEs if present (RPN=32)
3. Pest plant and insect spraying causing pollutant runoff which could in-turn impact surface water quality (RPN=30)

The next highest risks with a common RPN score of 24 were associated with a range of activities having potential to cause spillages (e.g., diesel) which could in-turn impact groundwater and/or surface water quality.

3.3. Proposed Risk Mitigation Measures

The greatest risk posed by this project is not groundwater related but instead due to the potential for surface water runoff from the irrigated area into the Lennard River, which in turn could lead to sediment erosion and nutrient loading to the river. Despite the natural topography sloping towards the north (i.e., away from the river) and a low likelihood of flooding, it is proposed that a buffer zone or set-back distance be established, and that a bund mound be constructed to protect riparian vegetation and instream biological values.

The only potential groundwater risk is for abstraction from bores to cause lowered water tables and impact riparian groundwater-dependent vegetation. A field survey of riparian vegetation to identify any groundwater-dependent species has already been proposed (Phoenix, 2019) and it is recommended that ACE commit to ongoing monitoring of this potential GDE.

3.4. Set-Back Distance

Five different documents provided by DWER have been carefully reviewed in order to determine an appropriate set-back distance from the Lennard River for pivots and irrigation infrastructure such as production bores, pumps, pipes, fertigation sheds etc.

1. *Operational Policy 4.3 – Identifying and establishing waterways foreshore areas* (Department of Water, September 2012).
   This document describes the process for identifying and managing foreshore areas to "*avoid flooding risks to properties and infrastructure, risks to public health, or harm to social values or the environment*". However, it is by no means prescriptive and lacks any detail on how to determine the foreshore area, instead referring to *Guidelines for identifying and establishing waterways foreshore areas* (Department of Water in preparation) or the following document until these guidelines are finalised.
2. *Determining foreshore reserves* (Water Note 23, Water and Rivers Commission, 2001).
   This document is also vague and aspirational rather than detailed or prescriptive.
3. *Nutrient and irrigation management plans* (Water Quality Protection Note 33, Department of Water, June 2010).
   This document provides guidance on acceptable practices for managing water and nutrient application to vegetated land in order to maintain downstream water resource values. When it comes to buffer zones the reader is referred to document (5) below.
4. *Tropical Agriculture* (Quality Protection Note 101, Department of Water, October 2007).
   This document provides guidance on issues of environmental concern. It applies to agricultural crops but not pastoral agriculture in rangelands, and therefore is deemed irrelevant to this project.
5. *Vegetation buffers to sensitive water resources* (Water Quality Protection Note 6, Department of Water, February 2006)
   This document provides guidance for establishing and maintaining vegetation buffers to reduce the risk of contaminant impact on water quality. However, the focus is mainly on public drinking water source areas (PDWSAs), other water supply sources, declared Waterways Management Areas in southwest WA and wetlands. Moreover, the default buffer dimensions that are recommended (Table 1 in that document) are suited to the South West of WA and "*have not been derived from rigorous local scientific studies*". Nevertheless, the minimum recommended buffer distance where multiple contaminant barriers are used outside of PDWSAs is 100 metres.

Based on a review of the above literature, there is no clear or scientifically defensible guidance on what is an appropriate set-back distance for a large ephemeral river in northern Australia. Accordingly, a 100-metre wide buffer is proposed for this project on the basis that it would encompass all of the riparian vegetation (Figure 1) and allow for a swollen extent of the river during high flow events (Figure 2A/2B).

4. Conclusions & Recommendations

This Preliminary Risk Assessment has provided a transparent and technically defensible rationale for establishing the proposed irrigated fodder project at the Option 1 site adjacent the Lennard River.

The assessment has demonstrated that, at this stage, based on all of the information available, the project does not have any constraints in terms of ecological values, cultural heritage values, or potential hydrogeological impacts to existing groundwater users or the Lennard River.

Additionally, the assessment has proposed a river set-back distance for Stage 1 production bores and pivots that is consistent with DWER policy and guidance documents that were provided to ACE at the time of the study.

Accordingly, this report forms a sound technical basis for the submission of applications for clearing and diversification permits, and a Form 1 to construct a Production Well.

ACE requests an expedient review of this report by DWER and written acceptance of the following matters in order to provide certainty for proceeding with the next stage of investigation, which will include drilling of the production bore and aquifer testing:

- Appropriateness of the proposed set-back distance (100 m);
- Suitable location for the trial production bore (110 m from river, Figures 1 and 2B);
- Appropriateness of proposed modelling approaches (section 2.4); and
- Any other requirements for testing or analysis to include in the H3 hydrogeological assessment report.

5. References

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Appendix D

IGS (2019e) – Lennard River Pool Survey

Napier Downs Station
Lennard River Pool Survey 2019

A report prepared for Australian Capital Equity

9 December 2019

FINAL REPORT

Document control

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Napier Downs Station
Lennard River Pool Survey 2019

A report prepared for Australian Capital Equity

by

Innovative Groundwater Solutions

9 December 2019

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This report is solely for the use of Australian Capital Equity and may not contain sufficient information for purposes of other parties or for other uses. Any reliance on this report by third parties shall be at such parties' sole risk.

The information in this report is considered to be accurate with respect to information provided and conditions encountered at the site at the time of investigation. IGS has used the methodology and sources of information outlined within this report and have made no independent verification of this information beyond the agreed scope of works. IGS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that the information provided to IGS was false.

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EXECUTIVE SUMMARY

Napier Downs Corporation has lodged an application with the Department for Water and Environmental Regulation for a licence to abstract groundwater at 6,000,000 kL per annum from the Canning-Grant aquifer for the purposes of irrigation. In order to provide defensible scientific information to support this application, Australian Capital Equity commissioned Innovative Groundwater Solutions to undertake a radon-222 survey of permanent pools on the Lennard River. This work was deemed important to establish which, if any, of the pools were groundwater dependent and therefor present potential future development constraints.

A run-of-river survey of remaining pools along the Lennard River was conducted on 13 November 2019, focusing on the reach between the potential 'Lennard' irrigation site adjacent the Gibb River Road and the downstream 'Hawkstone' and 'Scrubby' potential development sites. Sampled pools adjacent the Lennard site reveal a strong contribution of groundwater input, which contradicts recent hydraulic head measurements that suggested the surface water and groundwater are disconnected. Accordingly, further work is required to better characterise groundwater-surface water interactions at this site because it remains the priority for irrigation development given year-round accessibility.

One of two sampled river pools nearest the potential Hawkstone 2A/2B/2C sites is likely to have a high level of groundwater dependence. However, groundwater pumping from the regional aquifer at least 9-10 km north of the river would be ample to mitigate any drawdown impacts from large-scale groundwater pumping in an unconfined aquifer. Accordingly, a thoughtfully placed development in the Hawkstone area would account for the balance of whatever volume out of the 6 GL/yr. allocation could not be abstracted at the Lennard site.

The two sampled pools nearest the potential Scrubby site have a low likelihood of groundwater dependence. When coupled with the significant distance between the site and the river, it is clear that additional groundwater pumping from the regional aquifer at Scrubby (i.e., beyond the combined 6 GL/yr. at Lennard/Hawkstone) would not detrimentally impact the river and its permanent pools.

CONTENTS

1. Introduction

1.1. Background

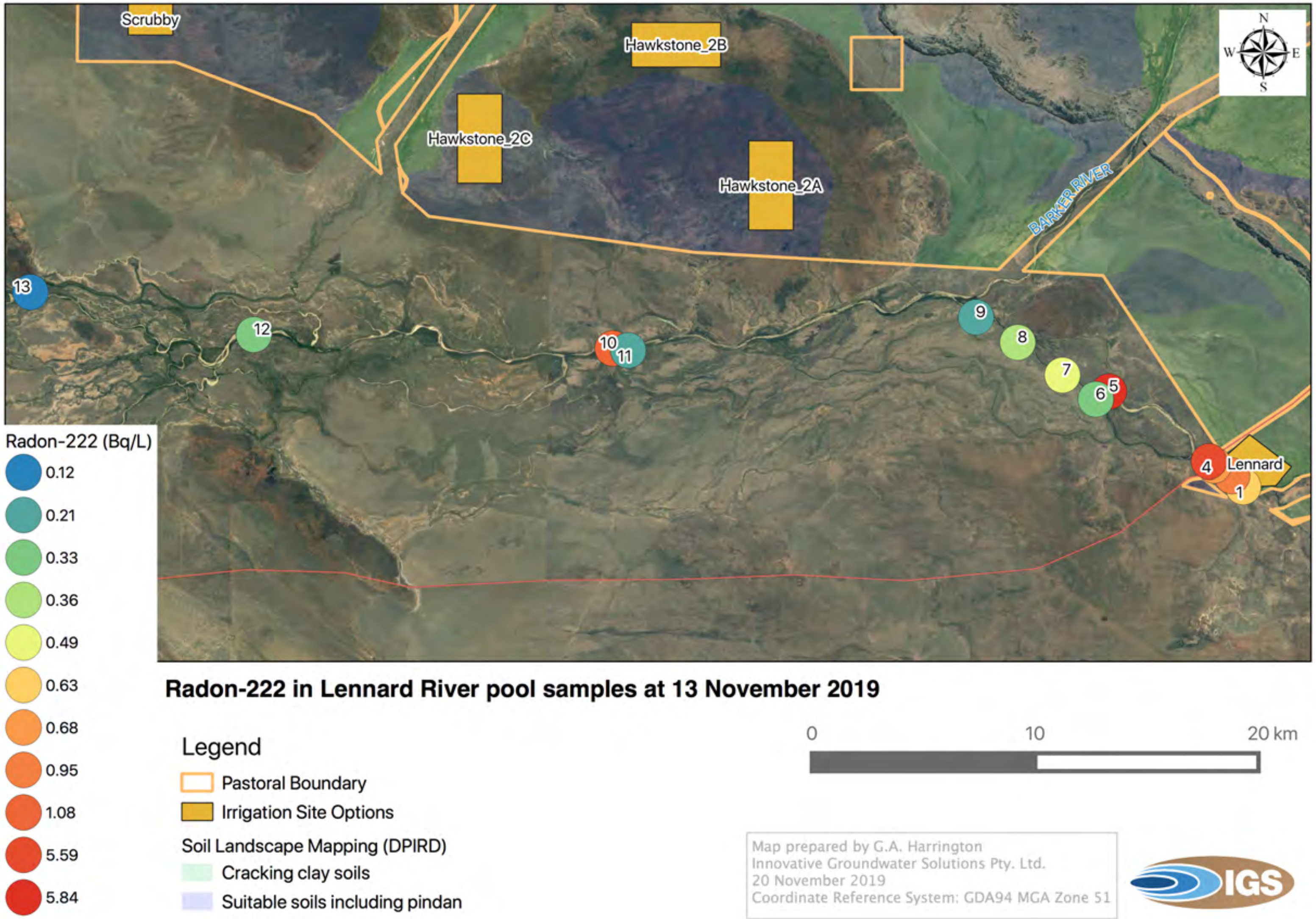
Napier Downs Corporation has lodged an application with the Department for Water and Environmental Regulation (DWER) for a licence to abstract groundwater at 6,000,000 kL per annum (6 GL/yr.) from the Canning-Grant aquifer for the purposes of irrigation. At the request of DWER, Australian Capital Equity (ACE) commissioned Innovative Groundwater Solutions (IGS) to prepare a preliminary risk assessment (PRA) report to support the licence application (IGS, 2019).

The PRA report identified impacts to potential groundwater dependent ecosystems (GDEs) in the form of permanent pools in the Lennard River as the main risk to the project. Accordingly, a river pool survey was acknowledged as the critical next step for the Napier Downs irrigation project to provide independent scientific evidence to demonstrate which (if any) dry season pools are in fact groundwater fed.

Existing information in the form of a measured groundwater level immediately adjacent the Lennard River suggests the surface water and regional water table are disconnected at that site (Option 1 or 'Lennard' site – see Figure 1). However, given the significant cultural and environmental values of the river, further defensible scientific investigations are required to confirm there is no connection at this site, and to investigate alternative sites.

In the absence of drilling multiple monitoring bores along the river to map groundwater levels relative to the river bed/pool levels, which is both difficult and cost prohibitive, the best method to establish whether groundwater discharge is occurring is to measure naturally occurring radon-222 in the river pools. Radon-222 is a radioactive gas that is produced in the aquifer but has very low concentrations in the atmosphere. When groundwater discharges into a surface water environment (e.g., river, pool or wetland) the radon activity begins to decrease over time due to both degassing into the atmosphere and radioactive decay. Hence, surface water that is devoid of radon is indicative of negligible groundwater discharge; conversely, surface water with elevated radon is indicative of active groundwater discharge. Low radon activities in surface water can occur as a result of diffusion out of the river bed sediments, rather than active groundwater discharge, so this process needs to be considered when interpreting data (Cook et al. 2008)

Given the remote and inaccessible terrain and the presence of saltwater crocodiles throughout most of northern Australia's river systems, the safest and most efficient (time and cost) method for acquiring radon-222 samples over large areas is by helicopter. The author was involved in pioneering a method to sample water for a broad range of chemistry and isotopes from a helicopter whilst it hovers over river pools – the first time this was done anywhere in the world was on the Fitzroy River in 2010 (Harrington et al., 2011; Gardner et al., 2011; Harrington et al, 2013). The author was at CSIRO at the time and since then he has successfully executed the same methods on projects in the Mitchell River, Cape York Peninsula (NCGRT) and several follow-up investigations on the Fitzroy River both for CSIRO (Taylor et al., 2018) and DWER – then DOW (Harrington and Harrington, 2016).


Scrubby
Hawkstone_2B
Hawkstone_2C
Hawkstone_2A
BARKER RIVER
N
W
E
S
13
12
10
11
9
8
7
6
5
4
1
Lennard
Radon-222 (Bq/L)
0.12
0.21
0.33
0.36
0.49
0.63
0.68
0.95
1.08
5.59
5.84
Radon-222 in Lennard River pool samples at 13 November 2019
Legend
Pastoral Boundary
Irrigation Site Options
Soil Landscape Mapping (DPIRD)
Cracking clay soils
Suitable soils including pindan
0
10
20 km
Map prepared by G.A. Harrington
Innovative Groundwater Solutions Pty. Ltd.
20 November 2019
Coordinate Reference System: GDA94 MGA Zone 51

1.2. Objectives & Scope

The objective of the current project was to synoptically sample any suitable remaining pools in the bed of the Lennard River at the end of the 2019 dry season before any significant localised rainfall and prior to surface flow being generated from up-catchment rainfall runoff.

As this was an initial reconnaissance mission, only a limited number samples were planned to be collected between upstream of the ‘Lennard’ site and downstream of the ‘Hawkstone’ site (Figure 1).

2. Methodology

Samples were collected on the morning of Wednesday 13th November 2019 using a Robinson R44 helicopter chartered from Kimberley Air Services, Derby. The helicopter was flown at low altitude along the full study reach of the river beginning at the upstream end. One sample was taken from every pool that was considered to be suitable in size (>25 m^2) and of sufficient depth (>10 cm) for obtaining meaningful results.

Samples were collected either by hovering the helicopter about 1-2 m above the pool surface or by landing on a nearby section of dry river bed and manually deploying equipment. The decision as to which method was used on each pool considered safety, time and logistics of handling samples in the helicopter.

At each site, the location was recorded using a handheld Garmin GPS. Field water quality was measured using a YSI ProPlus handheld meter equipped with Electrical Conductivity (EC), pH, temperature and dissolved oxygen probes that were calibrated two days prior. Water samples for radon-222 analysis were collected by lowering a 12V submersible pump approximately 20 cm below a buoy and pumping into 1.25 L PET bottles. Once all samples had been collected they were treated using mineral oil extraction as per the method described in Leaney and Herczeg (2006).

Radon-222 samples were shipped in small plastic vials to ANSTO, Lucas Heights NSW for subsequent analysis by liquid scintillation counting and correction to account for radioactive decay since the time of sampling.

3. Results & Discussion

An estimated 50-60 in-stream pools were observed between just upstream of the Lennard area to just downstream of Scrubby area, however the majority (i.e., more than two thirds) of these pools were very small, shallow, murky green "puddles" deemed unsuitable and/or unnecessary for sampling.

A total of 13 pool sites were sampled comprising four adjacent the Lennard area, five between the Lennard and Hawkstone areas, two immediately downstream (i.e. west) of the Hawkstone area, and two adjacent the Scrubby area (Figure 1). The five sites sampled between Lennard and Hawkstone areas were targeted because they were significant in size and/or depth. In contrast, none of the sites that had previously been proposed to the south of Hawkstone contained sufficient water for meaningful sampling – hence the decision to sample two large, clear and heavily vegetated pools immediately downstream of this area.

Water colour and turbidity varied dramatically across the 13 sites, ranging from very clear pools to murky green and brown pools (Table 1). Water quality was less variable with similar values for pH, dissolved oxygen and temperature, and all but one sample was fresh with a salinity as electrical conductivity (EC) in the range 257 – 555 μS/cm.

Radon-222 activities were a lot more variable with values in the range 0.12 to 5.84 Bq/L (Figure 1 and Table 1) and the three highest values (1.08, 5.59 and 5.84 Bq/L) were totally unexpected. To put these activities in context, dry season river samples collected along extensive reaches of the Fitzroy River in June 2017 yielded radon-222 activities in the range 0.01 – 1.15 Bq/L (Taylor et al, 2018) and these values were either similar to or slightly higher than measurements at many of the same sites in May 2010 (Harrington et al., 2011; Gardner et al., 2011; Harrington et al., 2013). Another study in the lower reaches of the Fitzroy River at the end of the 2016 dry season yielded radon activities in the range 0.02 – 0.37 Bq/L (Harrington and Harrington, 2016). Therefore, results from the current study on the Lennard River are generally much higher than previously observed in the Kimberley region.

The three highest radon activities are clearly an indication of significant groundwater input to these pools (sites 4, 5, and 10). Low activities of up to 0.1 Bq/L or even 0.2 Bq/L in surface water may not be due to groundwater input but rather diffusion of radon out of the river bed sediments (e.g., Cook et al., 2008). Accordingly, any sites with activities less than 0.5 Bq/L are considered to have LOW groundwater dependence. Sites with radon activity between 0.5 – 1.0 Bq/L are considered to have MODERATE groundwater dependence, and sites with radon activity above 1.0 Bq/L are considered to have HIGH groundwater dependence.

3.1. Lennard Site

The four pools sampled adjacent the Lennard Site (sites 1-4 in Figure 1) indicate a moderate to high level of groundwater dependence. This finding was unexpected because it contradicts the results of hydraulic head measurements in the nearby monitoring bore, which showed the regional water table to be 5-10 m below the elevation of the river bed (IGS, 2019).

Table 1. Location, appearance and water quality of pool sites at 13 November 2019. Colour coding signifies inferred low (blue), moderate (green) and high (orange) groundwater dependence.

Site	Easting Northing	Time	Appearance	EC (mS/cm)	pH	Temp. (^{o}C)	DO (mg/L)	^{222}Rn (Bq/L)
1	687956 8075217	08:12	Murky Brown	1014	7.46	27.9	3.2	0.63
2	687454 8075699	08:18	Murky Brown	406	7.46	26.5	2.6	0.95
3	686648 8076174	08:26	Light Brown	257	7.62	29.3	4.5	0.68
4	686423 8076335	08:31	Clear	351	7.20	27.6	2.4	5.59
5	681941 8079465	08:42	Clear	421	7.20	28.9	2.5	5.84
6	681350 8079117	08:45	Murky Green	428	7.50	27.5	4.6	0.33
7	679858 8080199	08:57	Light Green	368	7.56	29.2	2.9	0.49
8	677854 8081665	09:08	Dark Green	555	7.58	28.8	2.1	0.36
9	675988 8082792	09:13	Light Green	386	7.76	28.7	5.3	0.21
10	659710 8081399	09:29	Very clear, aquatic veg.	290	8.67	28.0	7.36	1.08
11	660406 8081308	09:35	Light Green, aquatic veg.	389	7.60	27.6	4.4	0.21
12	643634 8082015	09:52	Murky Green	375	7.73	27.2	4.7	0.33
13	633631 8083918	10:04	Murky Green	259	7.94	30.2	5.0	0.12

One plausible explanation for this result is that a shallow, perched aquifer above a clay layer may be providing a source of shallow groundwater to the pools, rather than the regional aquifer. In this case, any future groundwater pumping from the regional aquifer would be unlikely to cause drawdown in river pool levels. However, nutrients introduced through fertiliser application to irrigated crops would need to be carefully managed to avoid transport to the river via this shallow flow path.

Alternatively, considerable outcrops of Grant Group sandstone were observed in this reach of the river (see Appendix A) and not elsewhere, suggesting they may have a role in focussing preferential zones of groundwater discharge. In either case, further work would be required at the Lennard site to conclusively demonstrate that groundwater pumping from the regional aquifer would not detrimentally impact the river and its permanent pools.

3.2. Hawkstone Area

Only two pools worthy of sampling were observed along the extensive reach of Lennard River south of Hawkstone options 2A, 2B and 2C (sites 10-11 in Figure 1). One of these sites (site 11) is interpreted as having low likelihood of groundwater dependence, while the other site (site 10) is likely to have high groundwater dependence based on high radon-222 activity. The latter was an expected outcome as the surface water appeared clearer than any other pool sampled in this campaign, and it contained significant aquatic plant growth (see Appendix A).

The lack of any other significant pools in this reach suggests that groundwater pumping from the regional aquifer at any of the potential Hawkstone sites, but especially at site 2B, would not detrimentally impact the river and its permanent pools. As an outcome of this study, it is recommended that a single preferred Hawkstone site be located between the current 2A and 2B overlying the best available pindan soils. The closest point of this development footprint would be approximately 10 km from the Lennard River which, based on previous experience elsewhere in the Kimberley region, is ample to mitigate drawdown impacts for a 6 GL/year groundwater development in an unconfined aquifer.

3.3. Scrubby Area

Only two pools were worthy of sampling along the extensive reach of Lennard River south of the potential Scrubby option (sites 12-13 in Figure 1) and both of these revealed a low likelihood of groundwater dependence. These results, coupled with the significant distance (more than 10 km) between the potential development footprint and the Lennard River, demonstrate that groundwater pumping from the regional aquifer in this location would not detrimentally impact the river and its permanent pools.

4. Conclusions & Recommendations

A run-of-river pool survey of the Lennard River on Wednesday 13th November 2019, which was towards the end of a prolonged dry season that followed a below-average wet season, has provided the first ever scientific evidence for which pools may be groundwater fed. The primary basis for the interpretation is radon-222 activities, which provide a defensible tool for understanding groundwater input to surface water.

Based on the results of this survey, the following concluding remarks are provided for the three potential groundwater development areas on Napier Downs Station:

1) Sampled pools adjacent the Lennard area reveal an influence of groundwater input, which contradicts recent hydraulic head measurements on the regional water table. Two different conceptualisations have been offered for this result, however the implication is that further work is required to establish groundwater-surface water interactions at this site.
2) One of two sampled pools nearest the Hawkstone area is likely to have a high level of groundwater dependence. However, groundwater pumping from the regional aquifer at least 9-10 km north of the river would be ample to mitigate any drawdown impacts for a 6 GL/year groundwater development in an unconfined aquifer.
3) The two sampled pools nearest the Scrubby area have a low likelihood of groundwater dependence. When coupled with the significant distance (more than 10 km) between the potential development footprint and the river, these results demonstrate that groundwater pumping from the regional aquifer would not detrimentally impact the river and its permanent pools.

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Appendix A. Site Photos from 13 November 2019.

Site 1

Site 2

Site 3

Site 4

Site 5

Site 6

Site 7

Site 8

Site 9

Site 10

Site 11

Site 12

Site 13

Appendix E

Predicted drawdown contours for the P10 and P90 model realizations (based on maximum predicted drawdown for all times at Ngooderoodyne Spring) at 1 year, 10 years and 30 years.

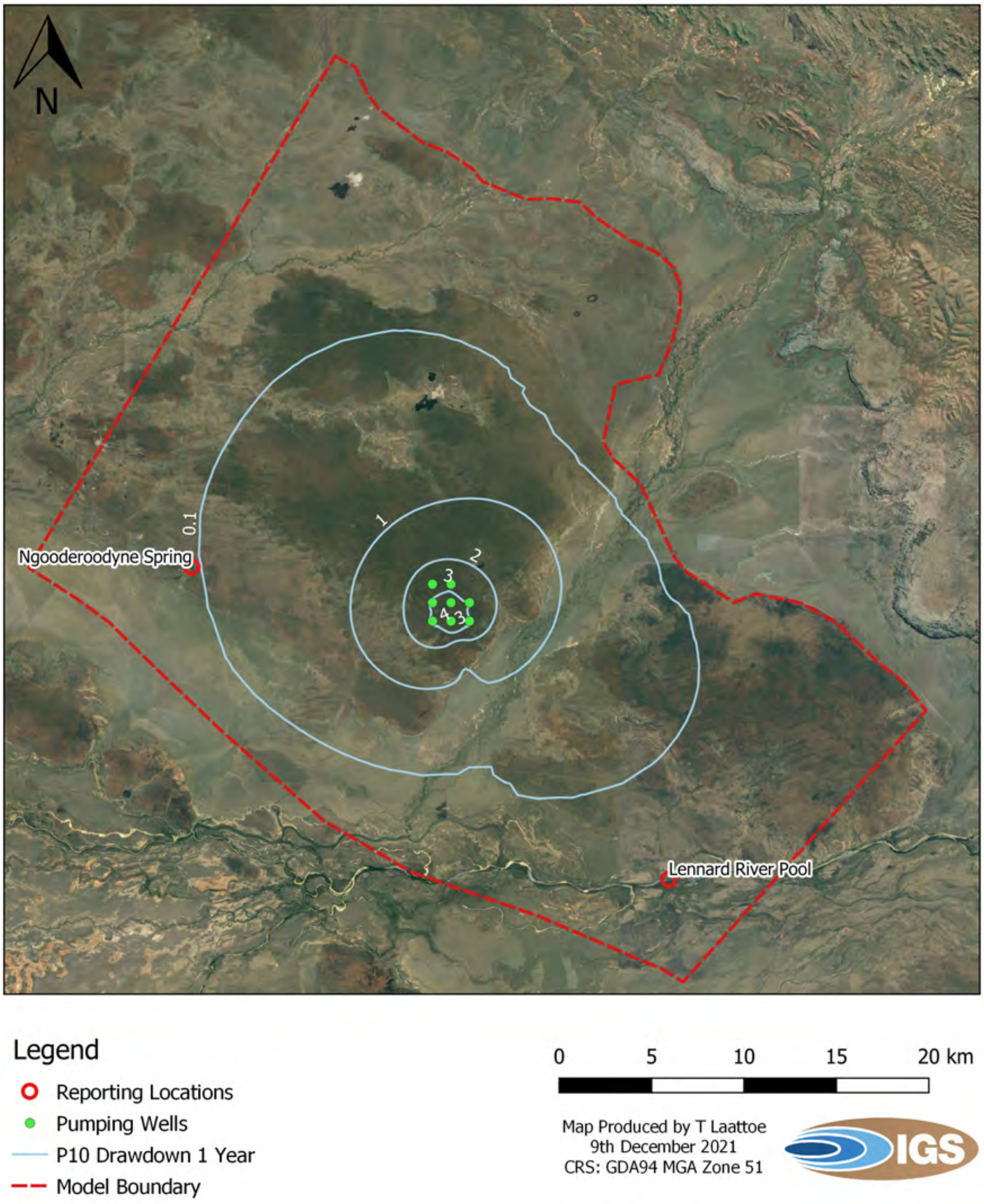

Figure E1. Predicted drawdown contours at 1 year for the model realization representing the 10th percentile of the maximum drawdown at Ngooderoodyne Spring.

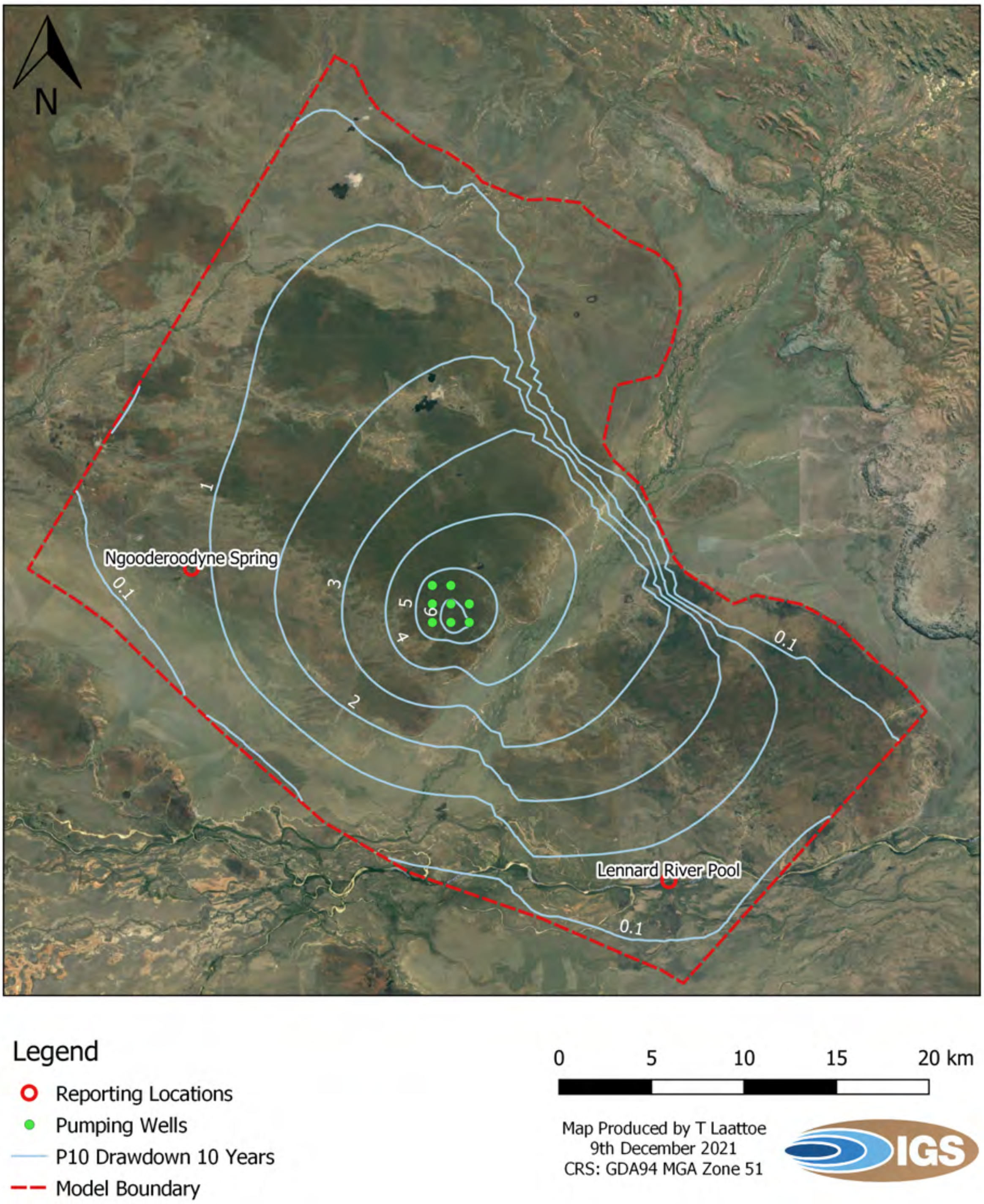

Figure E2. Predicted drawdown contours at 10 years for the model realization representing the 10th percentile of the maximum drawdown at Ngooderoodyne Spring.

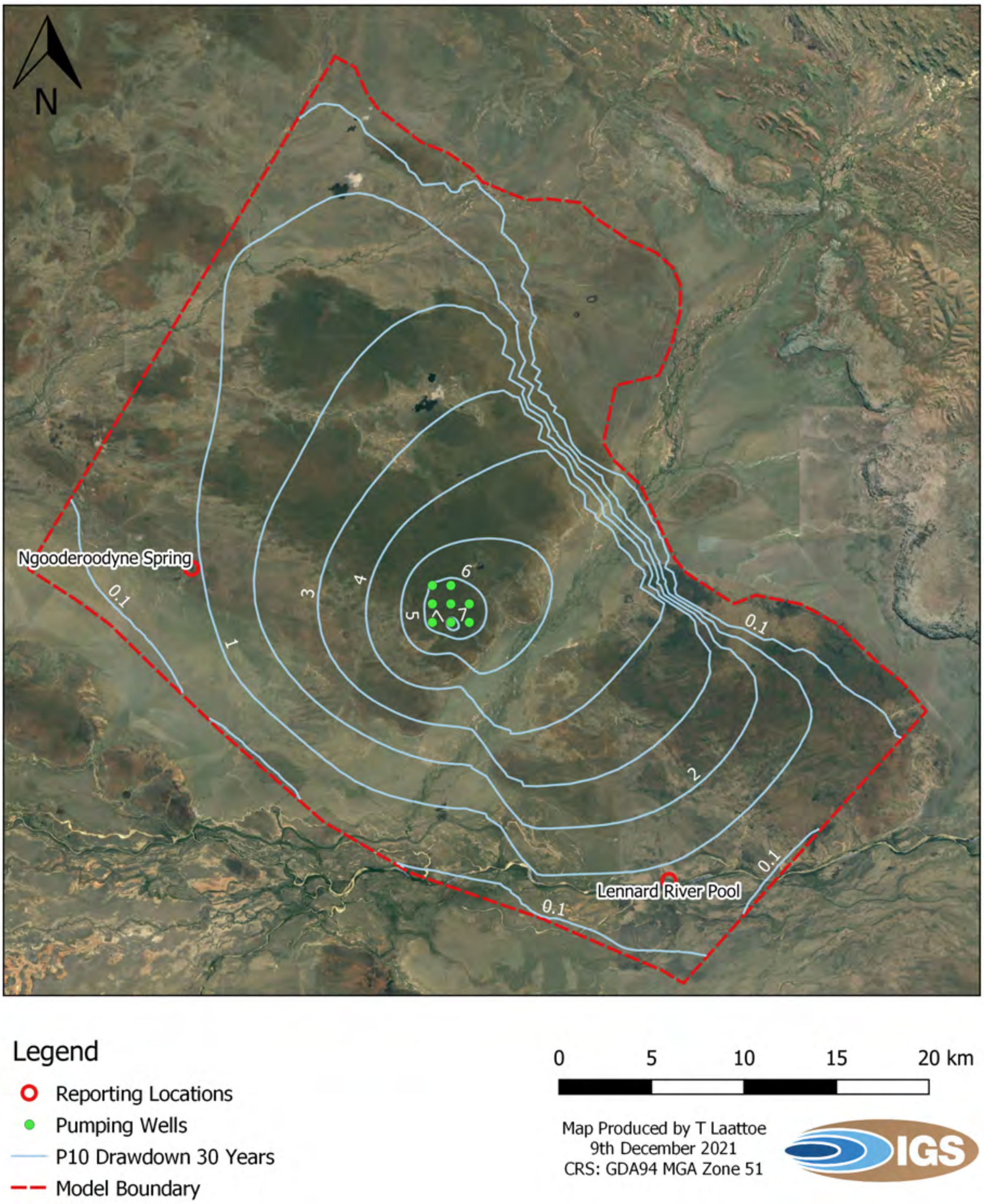

Figure E3. Predicted drawdown contours at 30 years for the model realization representing the 10th percentile of the maximum drawdown at Ngooderoodyne Spring.

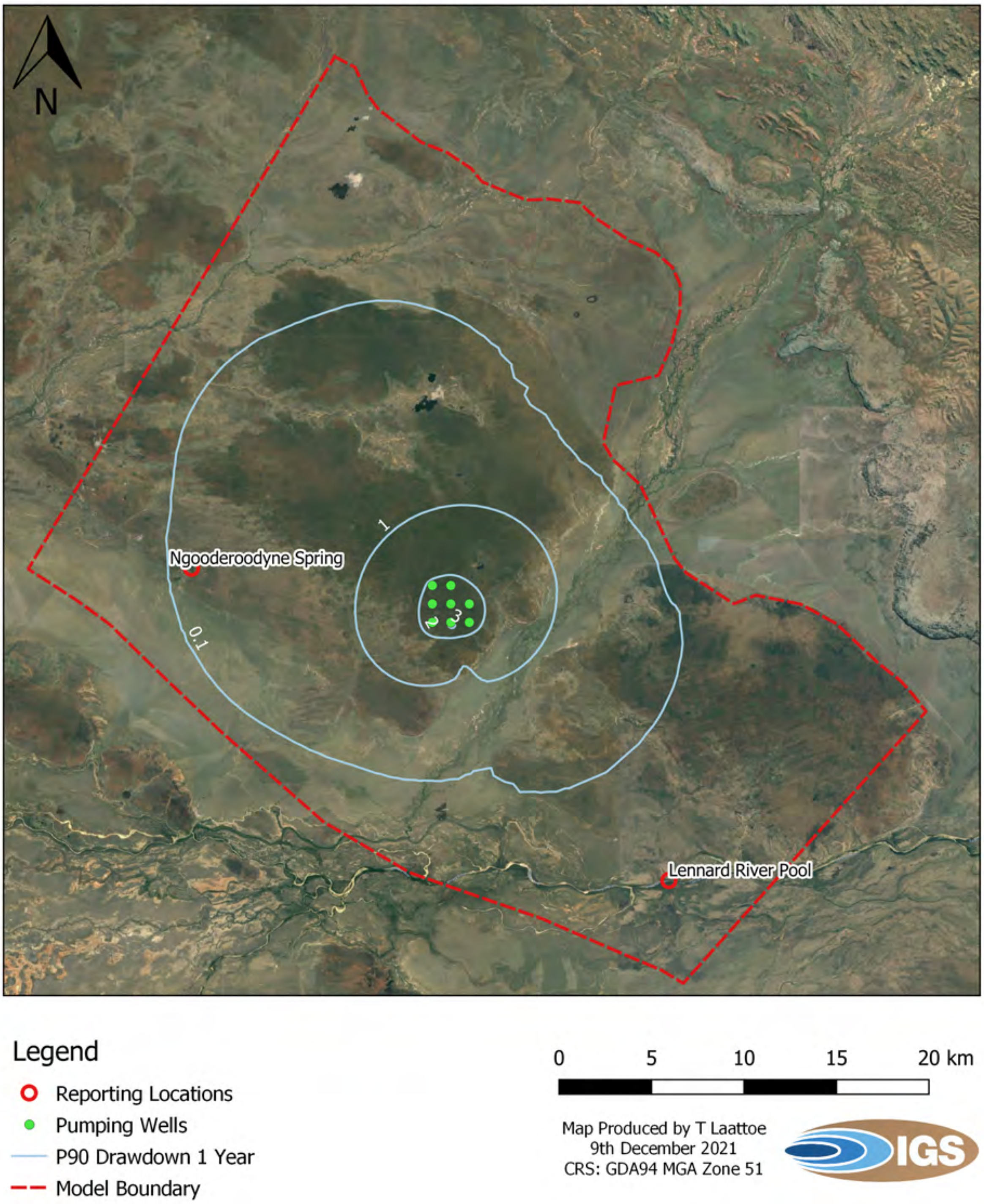

Figure E4. Predicted drawdown contours at 1 year for the model realization representing the 90th percentile of the maximum drawdown at Ngooderoodyne Spring.

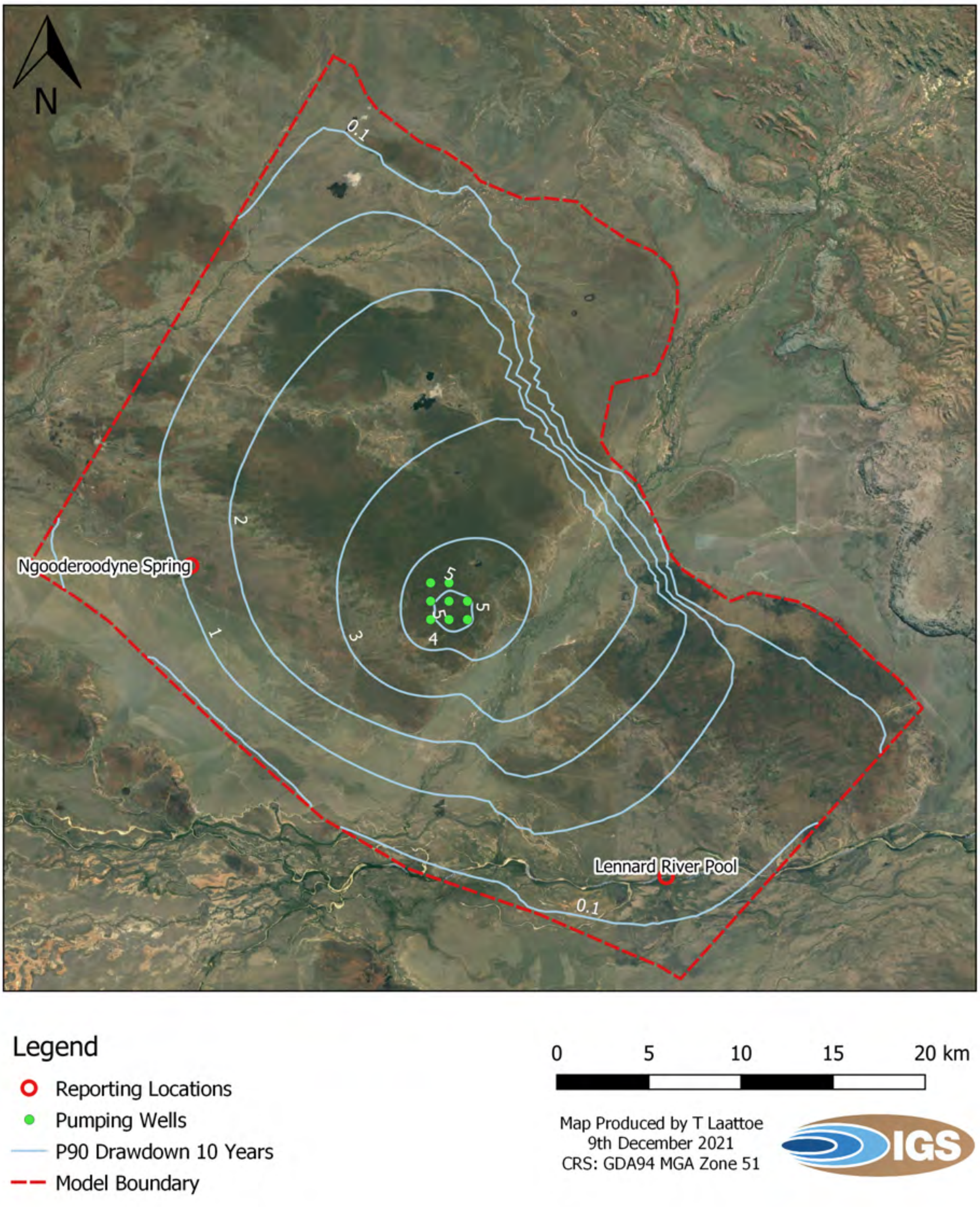

Figure E5. Predicted drawdown contours at 10 years for the model realization representing the 90th percentile of the maximum drawdown at Ngooderoodyne Spring.

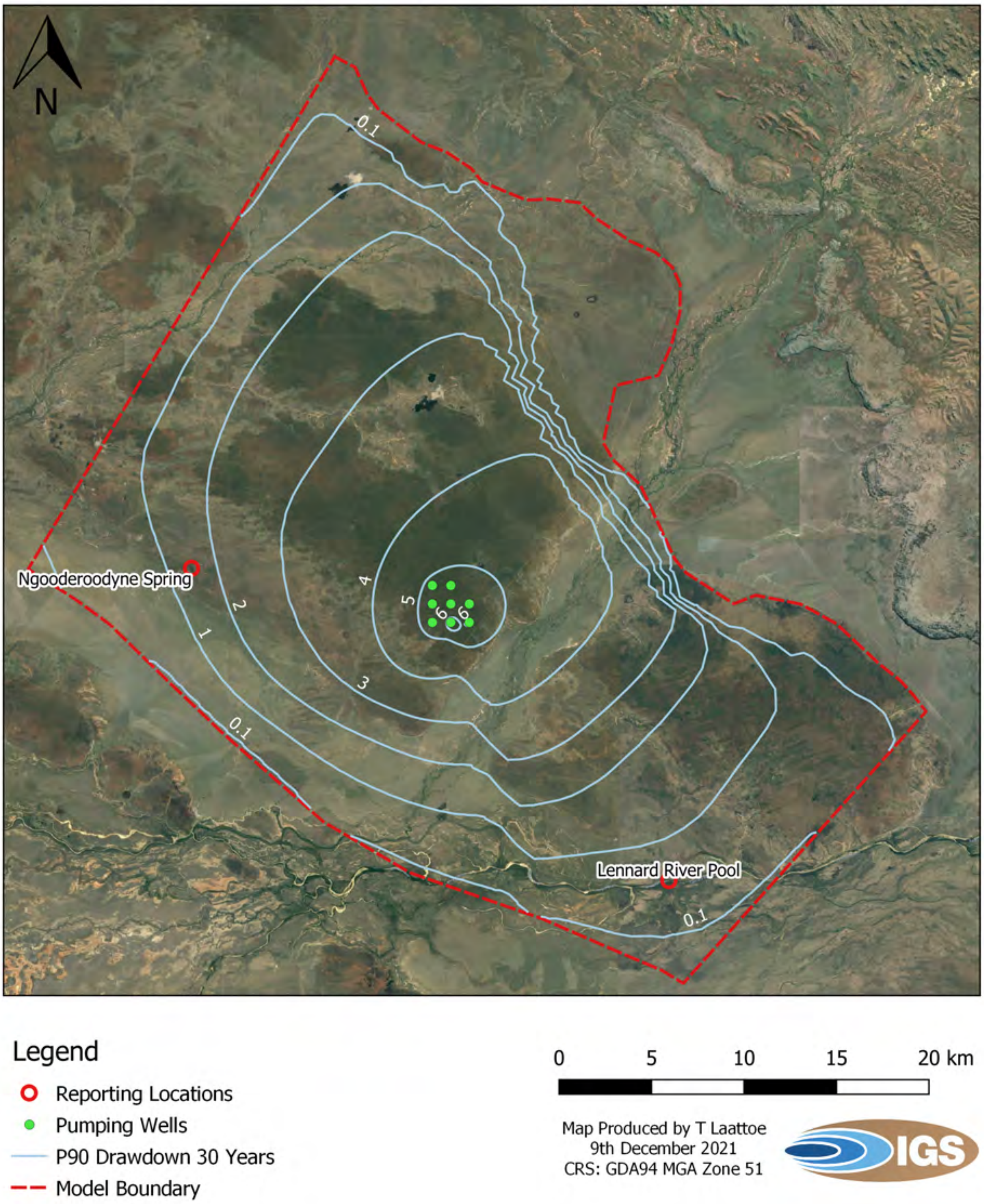

Figure E6. Predicted drawdown contours at 30 years for the model realization representing the 90th percentile of the maximum drawdown at Ngooderoodyne Spring.