ARK ENERGY

PROPOSED WIND FARM
ST. PATRICKS PLAINS, CENTRAL HIGHLANDS TASMANIA

HYDROGEOLOGICAL REPORT

December 2022

Cover image

Oblique image looking north over part of the central highlands of Tasmania. The five properties which will host the St Patricks Plains Wind Farm are bordered in yellow. The red areas are the footprints of the towers, access roads and associated infrastructure of the wind farm. The dark areas are lakes: Great Lake and Arthurs Lake are in the central left and right of the image respectively; Lagoon of Islands is the oval area at right, to the south of Arthurs Lake. Bass Strait is in the distance.
Google Earth image date: 1 July 2021

Refer to this report as

Cromer, W. C. (2022). *Hydrogeological report, proposed wind farm, St. Patricks Plains, central highlands Tasmania.* Unpublished report for Ark Energy by William C. Cromer Pty Ltd. 21 December 2022.

Use of this document

SUMMARY

A desk-top study combined with limited field investigation has explored the hydrogeology of the district proposed for the St Patricks Plains wind farm.

A regulatory requirement from the Environment Protection Authority was for the proponent to:

- provide a map showing existing water bores, and
- compile a conceptual hydrogeological model depicting groundwater conditions at regional and local scales.

The proponent of the wind farm extended this Brief to include:

- limited aquifer testing to estimate the radius of influence of one or more groundwater extraction bores which might be employed for water supply for construction purposes, and
- reconnaissance surface water and groundwater sampling, and laboratory analysis.

The aquifer testing and water sampling was done on 18 and 18 October 2022.

The hydrogeology of the district is relatively straightforward:

- Dolerite bedrock (with minor basalt and sedimentary rocks) forms a single unconfined aquifer, containing low-salinity, slightly acidic groundwater which moves very slowly in varying directions at different depths:
  - at local scales in hundreds of sub-subcatchments each up to a few hundred hectares in size, near-surface groundwater moves in all direction towards neighboring marshes, lagoons and watercourses;
  - over intermediate scales in several subcatchments each up to tens of square kilometres in size, groundwater moves beneath the local near-surface flow towards the Shannon River and a few of the larger creeks (Ripple Creek, Wihareja Creek), and
  - at a regional scale in major catchments extending over hundreds of square kilometres, groundwater moves beneath the shallower groundwater towards the Ouse River
- the groundwater is slightly acidic and of very low salinity, and
- aquifer testing of the only two operating domestic water bores in the district shows that a production bore for a wind farm water supply will most likely affect only local groundwater conditions and groundwater dependent ecosystems, representing much less than 1% of the footprint of the aquifer.

1 INTRODUCTION

1.1 Background

Ark Energy proposes a wind farm of approximately 46 towers at and in the vicinity of St. Patricks Plains in Tasmania's central highlands. The towers would be located on five agricultural properties which extend over approximately 90km^2 (cover image and Figures 1 and 2).

In Guidelines[1] for the project's Environmental Impact Statement (EIS), the Tasmanian Environment Protection Authority (EPA) requested (Section 6.7):

- a map showing the location of any groundwater bores, and
- a conceptual groundwater model for regional and local aquifer flows.

ERA Planning (ERA) is facilitating the EIS preparation on behalf of Ark Energy. In September 2022 William C Cromer Pty Ltd (WCCPL) was commissioned by ERA to provide the hydrogeological input requested by EPA, and also to:

- conduct aquifer testing of an available groundwater bore to permit estimation of radii of influence of the pumped bore (and other bores in similar situations)[2],
- sample groundwater for chemical analysis, and
- sample selected surface waters for chemical analyses.

Parts of the area are mapped as potentially subject to inland acid sulphate soils. Accordingly, ERA also requested a reconnaissance soil survey of acid sulphate potential at selected locations where the proposed infrastructure would disturb soils. This work is reported[3] separately.

1.2 Methodology, personnel and dates

1.2.1 Methodology and personnel

The methodology for this report included desk-top studies and field work by:

- Bill Cromer (BC; groundwater geologist and Principal of WCCPL),
- Mark Hocking (MH; groundwater geologist and Principal of *Hydro Geo Environmental Consulting*, HGEC), and
- Laurie Veska (LV: geologist and Principal of *Laurie Veska Geological Services*)

[1] EPA (2019). *Project Specific Guidelines for Preparing an Environmental Impact Statement for Epuron Projects Pty Ltd St Patricks Plains Wind Farm.* Environment Protection Authority, Tasmania. October 2019.

[2] Tower construction may require groundwater extraction for concrete production.

[3] Cromer, W. C. (2022). *Reconnaissance acid soil report for a proposed wind farm, St. Patricks Plains, central highlands Tasmania.* Unpublished report for Ark Energy by William C. Cromer Pty. Ltd. 23 December 2022.

1.2.1.1 Desk-top studies

Desk-top studies included:

- a review (BC) of publicly-available, mostly-online geological, topographical and groundwater maps,
- the production (LV) of several LiDAR-based topographic cross sections at regional scale through the district,
- the generation of conceptual hydrogeological models using the cross sections (BC),
- analysis and reporting (MH) of pump test data from water bores, and
- comment (BC) on groundwater and surface water analyses

1.2.1.2 Field work

Field work included:

- site inspections and photography (BC, MH),
- discussions with property owners (BC, MH),
- pump testing of two groundwater bores (MH), and
- the sampling of two groundwaters (MH, BC) and four surface waters (BC).

1.2.2 Dates

Field work was conducted on 17 and 18 October 2022.

Figure 1. St Patricks wind farm proposed infrastructure (black lines) on St Patricks Plains.

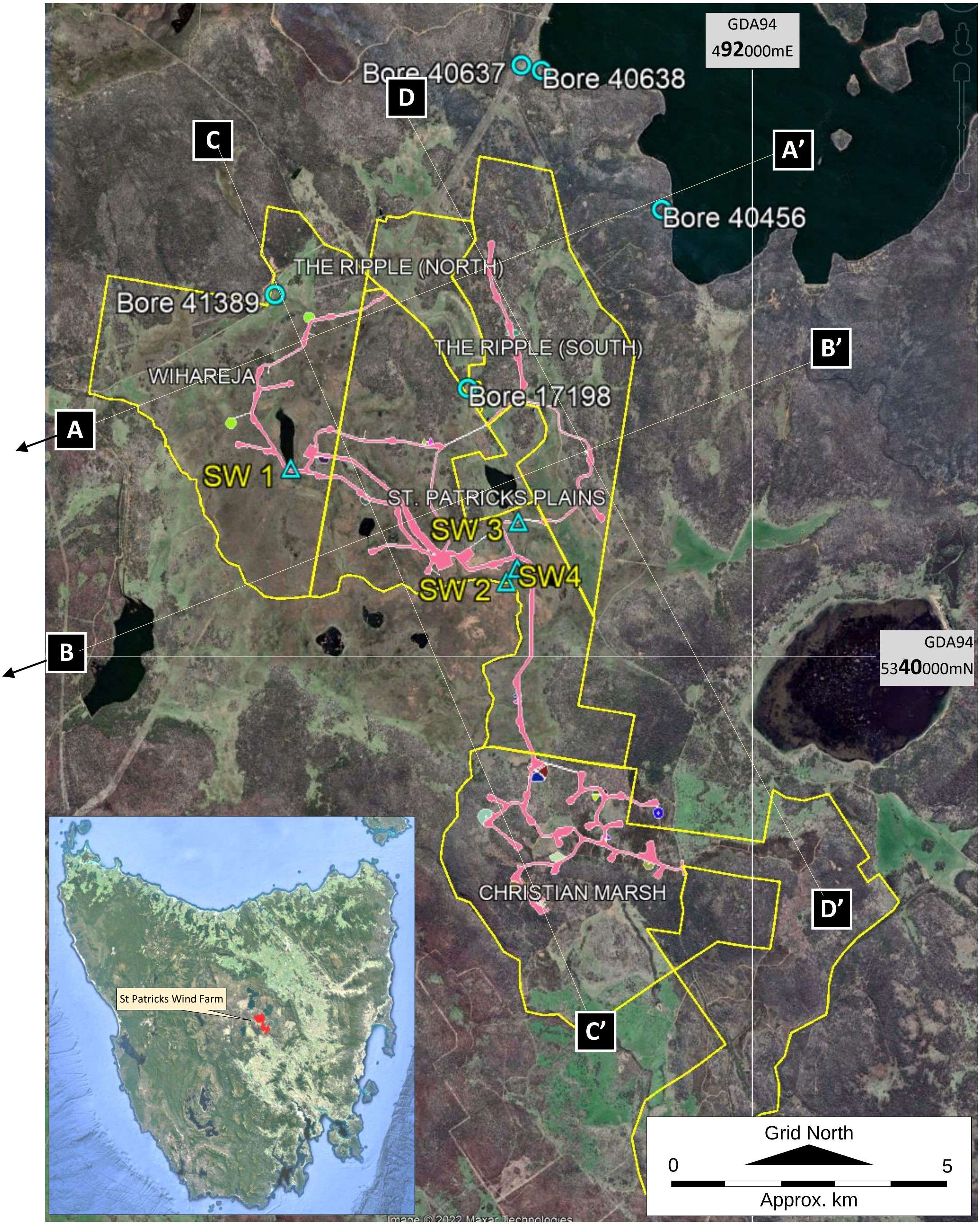


Figure 2. St Patricks wind farm infrastructure (pink lines) on St Patricks Plains. Yellow lines are property boundaries. Also shown are hydrogeological cross section lines A – A'.....D – D'. Recorded groundwater bores (Bores 41389 and 17198) were pump tested and sampled for this report, and surface water locations SW1, SW2, SW3, SW4 were sampled for this report) Source of base image: Google Earth; image date 28 October 2019.

2 RESULTS

2.1 Topography and surface drainage

2.1.1 Topography

St Patrick Plains and the general area of the proposed wind farm is of subdued relief (850 – 900m ASL; Figure 3), with more elevated land (Sheepyard, Norths and Shepherds Hills, and Diamond Tier) rising some 50m or so along the eastern side. To the west, the valley of the Ouse River cuts through the plateau to depths of 100m or so.

In a west-to-east direction the plateau is essentially flat, but in a north-to-south direction it falls about 100m in altitude over a distance of 15km (ie 1:150, or 0.4^0).

2.1.2 Surface drainage

2.1.2.1 Hierarchy of drainage systems

As with all surface drainage systems, the hierarchy of drainage areas in the district is:

- major river catchments
- river and creek subcatchments, and
- creek sub-subcatchments (“CFEV River section subcatchments” on www.thelist.tas.gov.au),

The hierarchy of surface water catchments also corresponds to the hierarchy of unconfined groundwater systems (Section 2.3).

2.1.2.2 Major river catchment

The proposed wind farm is wholly contained within the 1,500km^2 Ouse Catchment, within which is the deeply incised Ouse River (Figure 3 and Map 1.2 in Attachment 1) flowing south along the western side of St Patricks Plains.

2.1.2.3 River and creek subcatchments

The proposed wind farm is wholly contained within the 212km^2 Upper Shannon Subcatchment, and the Shannon River flows south along its western side (Figure 3 and Map 1.2 in (Map 1.2 in Attachment 1). Major creeks in the subcatchment draining to the Shannon River include Ripple Creek and its tributary Noels Creek to the east, and Wihareja Creek to the west.

2.1.2.4 Creek sub-subcatchments

Within the Upper Shannon Subcatchment, smaller defined sub-subcatchments, often only a few hectares in size, include individual minor and mostly intermittent watercourses and wetlands, marshes and lagoons. These are bordered by the hundreds of faint black lines in Map 1.2 in Attachment 1.

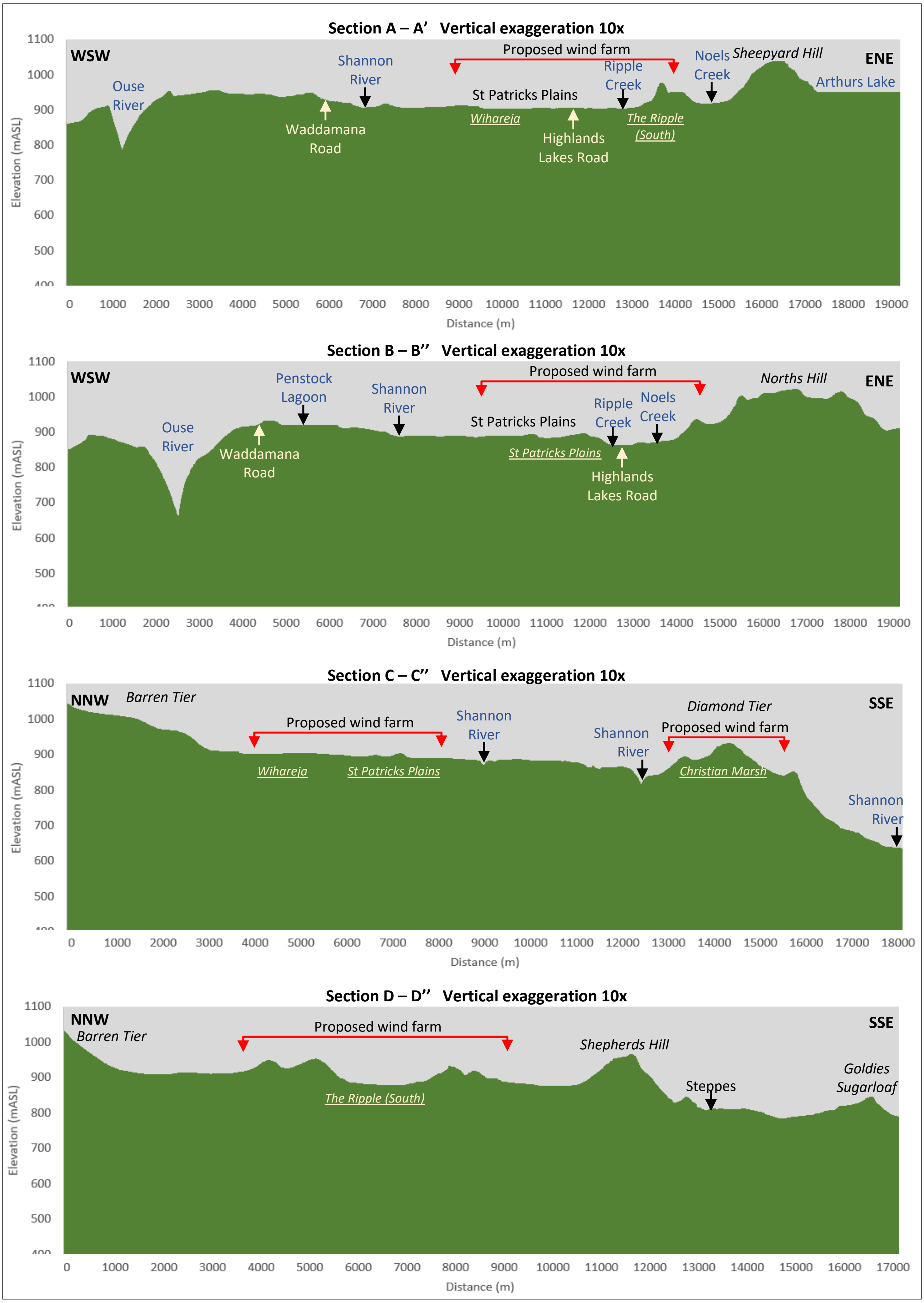


Figure 3. Topographic profiles (vertically exaggerated 10 times) along section lines A – A' to D – D' depicted in Figure 2.

2.2 Published geology

2.2.1 Regional setting

The geology of the district is characterised by Jurassic-age dolerite, which as sills and associated dykes has intruded flat-lying or gently-dipping Permian-age and Triassic-age sedimentary rocks. Together with contemporaneous and later faulting, the rocks have been lifted almost a kilometre vertically above surrounding terrains to form Tasmania's central highlands.

2.2.2 Geology of the St Patrick Plains area

The geology of the St Patrick Plains and adjacent areas is dominated by Jurassic-age dolerite (Map 1.3 in Attachment 1).

Small areas of Permian-age sedimentary rocks occur to the south on the property *Christian Marshes*.

Fairly extensive areas of volcanic rocks (basalt) occur over St Patricks Plains. The volcanics are probably relatively thin, although more than twenty deeper volcanic eruptive centres are inferred to be present[4].

Superficial deposits of unconsolidated Quaternary-age alluvium occupy many of the drainage lines in the district.

2.3 Groundwater

2.3.1 Groundwater fundamentals

Based on general hydrogeological principles, at all scales the dolerite, volcanics rocks and alluvium of the area are regarded as a single unconfined aquifer[5].

In such an environment, Figure 4 illustrates different components of the land-based part of the hydrological cycle[6] at the scale of a single catchment or smaller. Effective rain (precipitation less evapotranspiration) flows overland to surface streams, or infiltrates (at a rate determined by soil and rock permeability) through the unsaturated zone to the water table.

Groundwater moves from recharge areas to discharge areas, forced by gravity.

An important aspect of Figure 4 is the interconnectivity between surface water and groundwater.

[4] Sutherland, FL and Hale, GEA 1970. Cainozoic volcanism in and around Great Lake, Central Tasmania. *Papers and Proceedings of the Royal Society of Tasmania*, vol. 104 , pp. 17-36

[5] In unconfined aquifers, the top of the saturated zone – the water table – is at atmospheric pressure and open to the air. Localised confined conditions may exist where water in fractures is not in hydraulic continuity with adjacent groundwater with a water table under atmospheric conditions, but within the local – intermediate – regional systems these are regarded as of very minor importance.

[6] The *hydrological cycle* is the circulation of water in various phases through the atmosphere, over and under the earth, to the oceans, and back to the atmosphere. The cycle is solar-powered. Because water is a solvent it dissolves elements, and geochemistry is a fundamental part of the cycle, which is a flux for water, energy, and chemicals. Water enters the land-based cycle as precipitation; it leaves as surface streamflow (runoff) or evapotranspiration. The route which groundwater takes from a recharge point to a discharge point is a *flow path.*

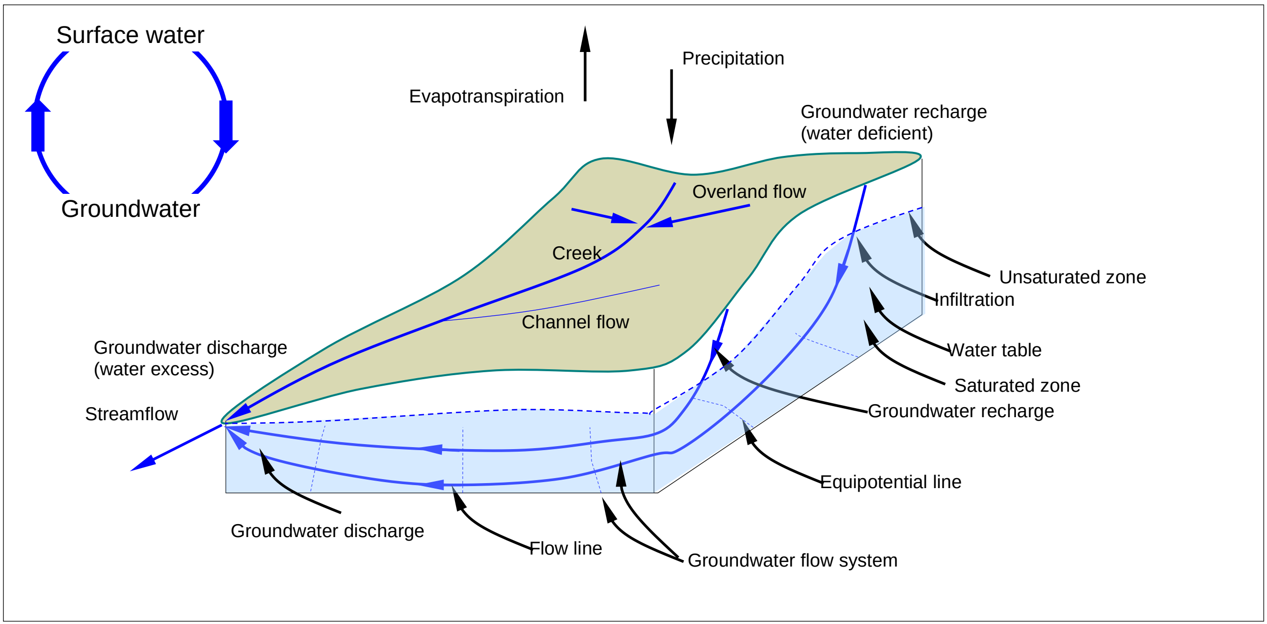


Figure 4. Aspects of the land-based hydrological cycle

The fundamentals of groundwater movement in an unconfined, gravity-driven groundwater flow system (GFS)[7] similar to that in the study area are depicted schematically in Figure 5. Important points are:

- the hydraulic heads in recharge areas are relatively high and decrease with depth. In discharge areas, the energy and flow conditions are reversed; heads are low and increase with depth. In between, the throughflow is almost horizontal as shown by the steeply dipping equipotential lines.

- the concept of a groundwater flow system (GFS[8]) is fundamental to understanding groundwater conditions in the study area (and elsewhere). Given the low to locally moderate relief of the area, it can be expected that the near-surface dominant groundwater flows to depths of a few tens of metres or so will be as local systems, with recharge on more elevated areas discharging to un-named minor streams. Some of the recharge will penetrate to depths of perhaps 50 – 100m or more, bypassing beneath minor streams and travelling to larger creeks of the district. This scale of groundwater movement is regarded as intermediate. Still deeper groundwater infiltration results in regional systems discharging to major rivers or the coast.

These observations indicate that groundwater at different depths may (and often does) travel in different directions.

[7] GFSs are identified in the field based on geology and geomorphology.
[8] Sophocleous (2004) cited in Figure 5 defines a GFS as "a set of groundwater flow paths with common recharge and discharge areas. Flow systems are dependent on the hydrogeologic properties of the soil/rock material, and landscape position. Areas of steep or undulating relief tend to have dominant local *flow systems* (discharging to nearby topographic lows such as ponds and streams). Areas of gently sloping or nearly flat relief tend to have dominant *regional flow systems* (discharging at much greater distances than local systems in major topographic lows or oceans)." A three-dimensional closed groundwater flow system that contains all the flow paths is called the *groundwater basin*.

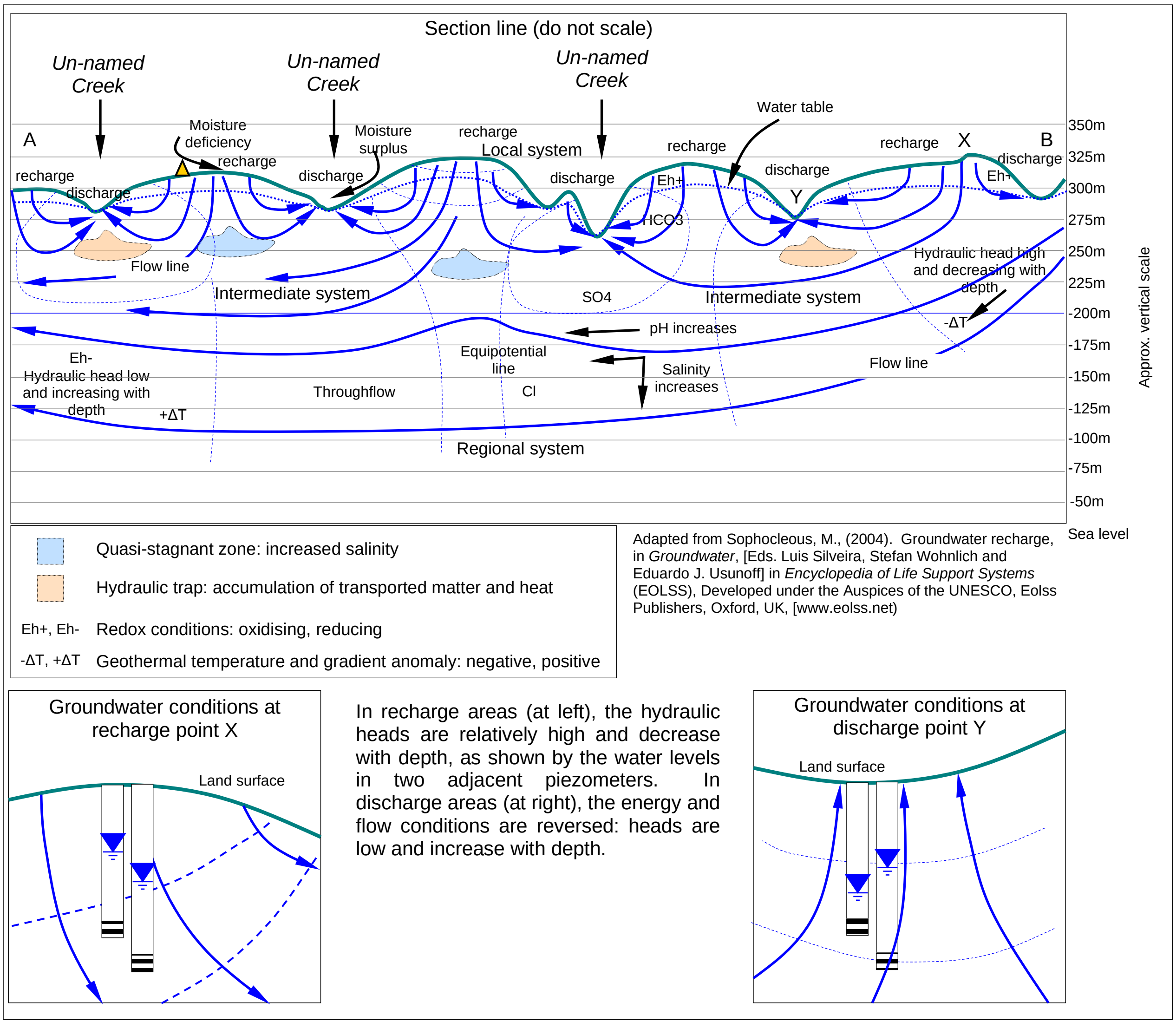


Figure 5. Fundamentals of groundwater hydrology in a gravity-driven groundwater system like that in the study area. Vertical exaggeration for the top section is about 5.

2.3.2 Local, intermediate, and regional groundwater flow systems

2.3.2.1 Scale of groundwater flow systems

Various studies [eg Latinovic *et.al* (2003) and Hocking *et al* (2005)] have reported on local- and intermediate-scale GFS's in Tasmania. The latter's generalised scale of GFSs is shown in Figure 6, together with adopted response times (travel times) for groundwater flow through each system.

The scale of GFSs depends on topography and geology, with local, intermediate and regional systems defined by the sizes of sub-subcatchments, subcatchments and catchments respectively of surface drainage systems[9].

Accordingly, in the study area, the scale of local systems is reduced to nominally less than a kilometre or so, intermediate systems to 1 – 10km, and regional systems to >10km. The response times (travel times) are similarly reduced in proportion, but these are only conceptual since they depend on groundwater gradients, and bulk rock permeability which may change over orders of magnitude at all scales.

[9] Sub-subcatchments ("CFEV River Section Catchments"), subcatchments and catchments are shown as overlays on www.thelist.tas.gov.au.

Table 1 The geographical extent and response time of local, intermediate and regional scale GFSs

Category	Length of flow (km)	Response time (yr)
Local	<1km <5	<30
Intermediate	1 – 10km 5-50	30-100
Regional	>10km >50	>100

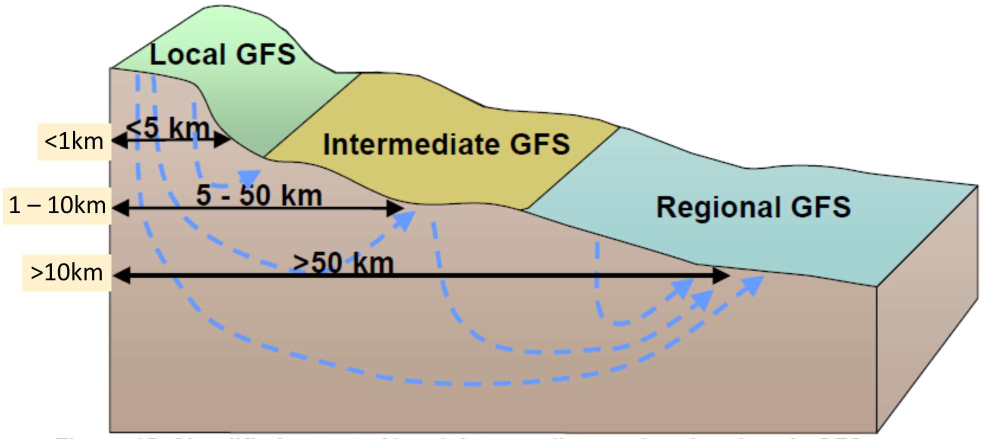


Figure 15 Simplified extent of local, intermediate and regional scale GFSs

Figure 6. The conceptual sizes of, and travel times for groundwater through, local-. Intermediate- and regional-scale GFS's. The sizes of each GFS for the study area are shown at left, and the travel times in the left centre of the table.

Conceptual or not, the travel times for groundwater to move through a small local system may be measured in years to decades[10]; in intermediate systems, decades to centuries; and in regional systems, centuries to millennia.

2.3.2.2 Groundwater flow systems in the study area

Figure 7 depicts GFS's in the vicinity of St Patricks Plains at all scales, and it is an important map. In a conceptual way, it shows:

- regional flow (thick, open red-bordered arrows), which underlies local and intermediate flows, and is west-southwest from the central highlands to and beneath the Ouse River (regional flow moves beneath surface subcatchments within major catchments and at right angles to their boundaries);
- intermediate flow (thick, solid red arrows) is shallower than regional flow, and within the St Patricks Plains area and areas to the south, flow directions are towards the Shannon River within the Upper Shannon subcatchment (and at right angles to surface subcatchment boundaries);
- local flow (thin red arrows), moving in all directions in small sub-subcatchments and at right angles to their boundaries (only some of these directions are shown: there are hundreds more on this map).

[10] For example, using the Dolphin Sands aquifer as a local system, and assuming a permeability of $2m^3/day/m^2$, a water table gradient of 0.01 and an effective porosity of 0.25, the rate of flow through the sand would by Darcy's Law be 2 x 0.01 ⁄ 0.25 = 0.08m/day (ie 8cm/day, or 30m/year, or one kilometre in 33 years).

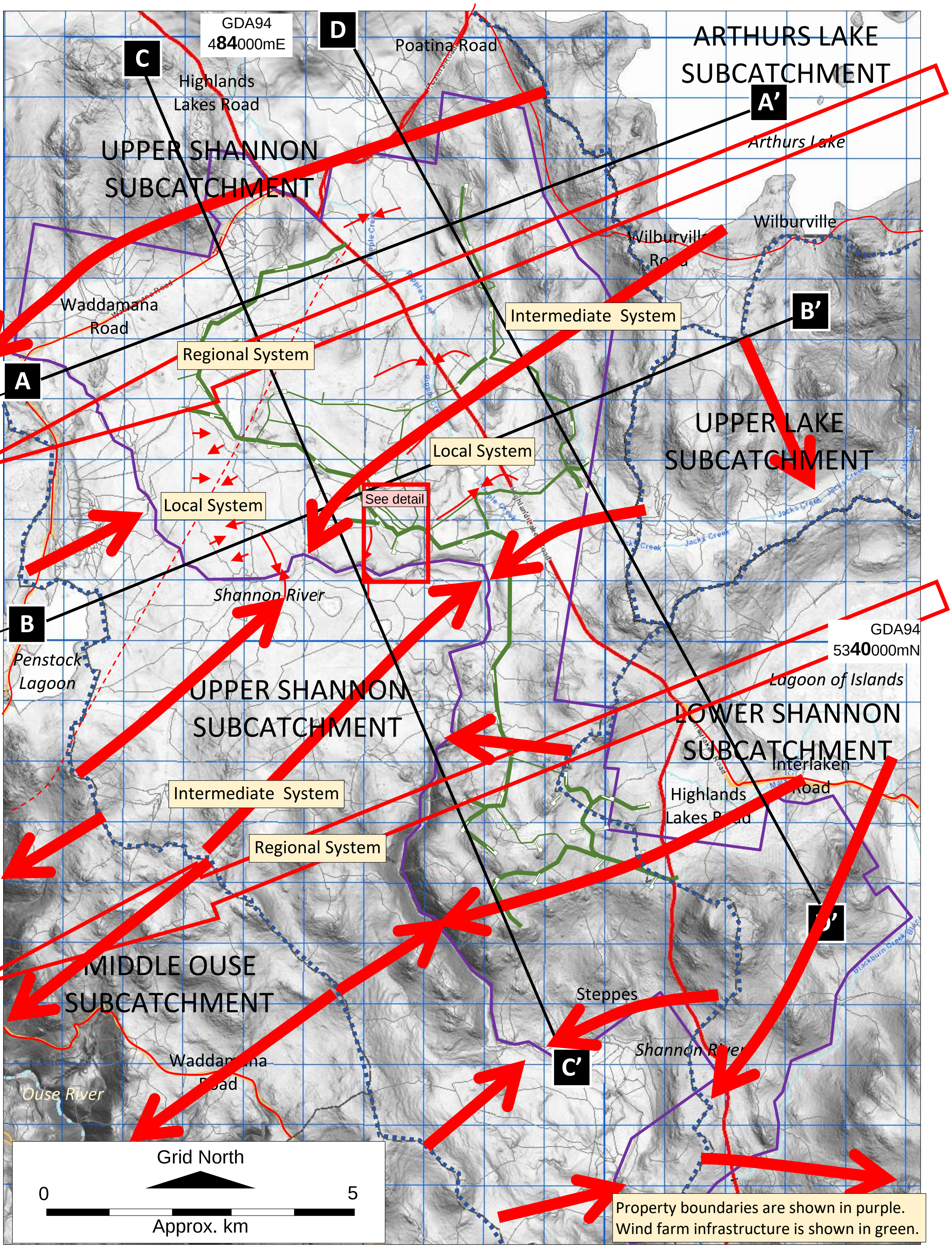


Figure 7. Inferred groundwater flow systems (GFSs) in the vicinity of the proposed St Patricks Wind Farm. Open arrows are regional GFSs; solid red arrows are intermediate GFSs; thin red arrows are local GFSs. Hillshade image: www.thelist.tas.gov.au

The three scales of GFSs do not represent separate aquifers. Rather, there is hydraulic connectivity between each: groundwater moves very slowly within a three-dimensional network of fractures separated by dry rock[11].

2.3.3 Aquifer types

The hard dolerite and sedimentary rocks are classed as a fractured hard rock aquifer.

Groundwater is stored in, and moves between, fractures in the rock. The intervening solid rock between the fractures is dry[12].

The unconsolidated Quaternary alluvium in scattered occurrences along drainage lines is classed as a porous or intergranular aquifer. Groundwater is stored in, and moves slowly through, the pores between the mineral grains[13].

In both aquifer types in the study area, the groundwater is unconfined. Because the groundwater is continuously present in both, all the rocks and unconsolidated materials in the study area constitute a single aquifer.

2.3.4 Prospectivity of the aquifer in the study area

Groundwater **p**rospectivity of an aquifer describes the chance of obtaining useful quantities of groundwater from a water bore drilled into it. Prospectivity can be measured by the proportion of successful bores compared to unsuccessful[14] ones.

Groundwater prospectivity in the vicinity of the proposed wind farm is depicted in Figure 8. Compare the distribution of the prospectivity with the published geology (Map 1.3 I Attachment 1:

- the prospectivity of the intergranular aquifer (the unconsolidated alluvium) ranges from LOW – MODERATE, and
- the prospectivity of the fractured hard rock aquifer (ie the dolerite) is MODERATE – HIGH.

Figures 2 and 8 show the locations of the five recorded water bores in the district. The three bores bordering Arthurs Lake are located in moderate – high prospectivity dolerite. The remaining two are shown as located on Quaternary alluvium (of low to moderate prospectivity), but the published logs of the holes show they were drilled in dolerite, of moderate – high prospectivity..

[11] A useful way to visualize such an interconnected groundwater system is to imagine groundwater movement in a deep water bore several hundred metres deep, fitted with slotted casing so that groundwater is free to move through the bore in all directions. At the top of the water column near the water table, water particles move with the local flow. This may be in any direction: horizontally, downwards in a recharge (groundwater independent) area, or upwards in a discharge (groundwater dependent) area; further down the bore, the flow directions imperceptively change and align with intermediate flow; still deeper, flow directions again slowly change to align with regional flow directions.

[12] Fractures in a hard rock might be (say) 2% of the total volume. So a cubic metre of such rock below the water table would store 20L of groundwater.

[13] Pores between mineral grains in an unconsolidated sand might be (say) 30% of the total volume. So a cubic metre of such sand below the water table would store 300L of groundwater.

[14] A water bore may be deemed unsuccessful for various reasons: no water at all is encountered; water is encountered by the yield is too low to be useful, and/or water is encountered but its quality is not usable.

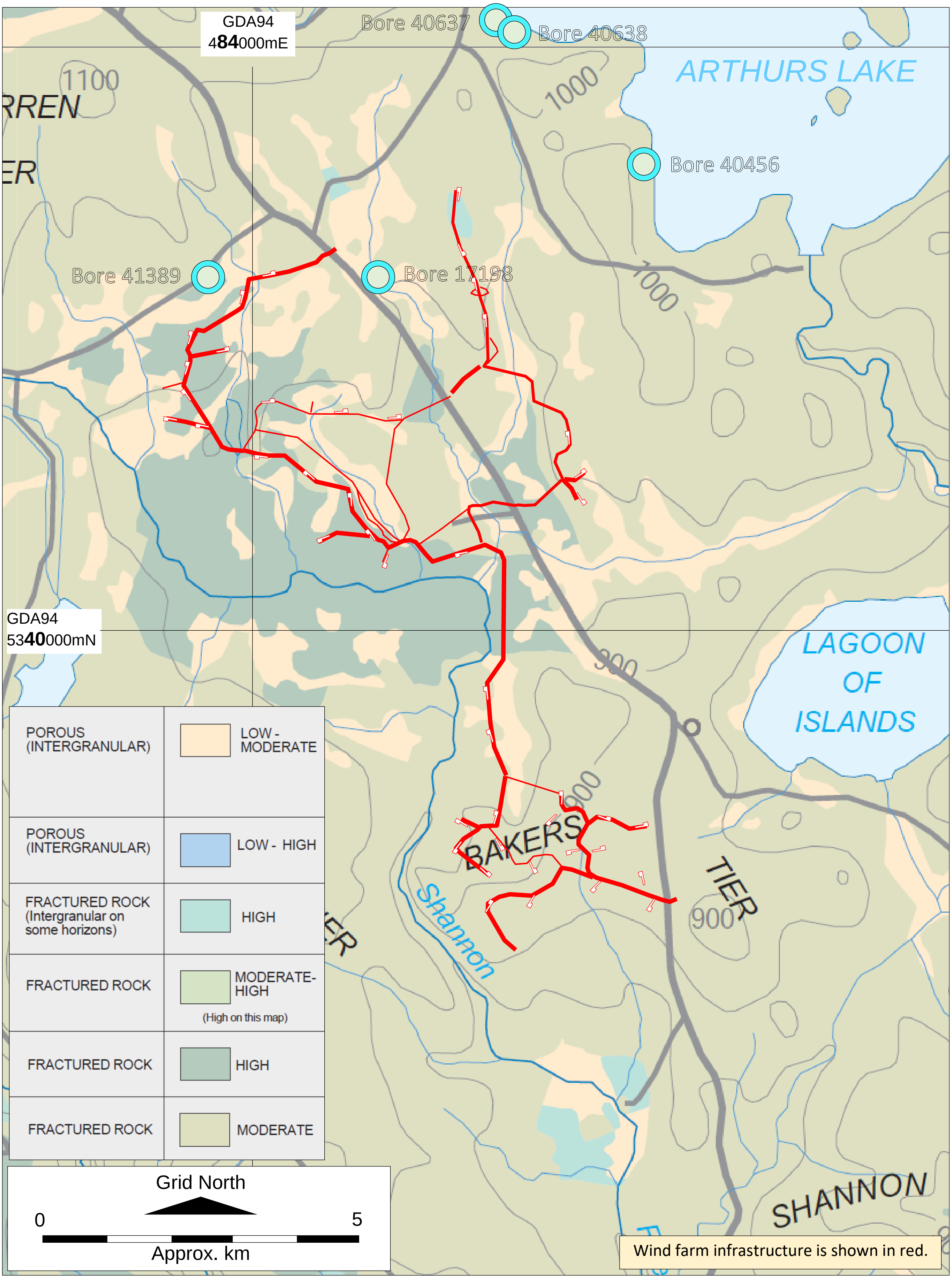


Figure 8. Published prospectivity of the fractured rocks and unconsolidated alluvium in the vicinity of the proposed St Patricks wind farm.
Source: Matthews, W. L. and Latinovic, M. (2006). *Southeast Tasmania Groundwater Quality Map.* 1:250,000 scale. Mineral Resources Tasmania.

2.3.5 Results of drilling for groundwater in the area

Of the five known water bores in the district, two (Nos. 17198 and 41389) were retained as operating at the time of drilling in 1990 and 2012 respectively (Table 1). Their status is unchanged today, and both have been pump-tested (and their groundwater sampled) for the current report. Other observations from Table 1 are:

- the depth range of the bores is 18 – 90m (average 40m),
- yield on drilling was reported from two of the bores (0.44 and 3L/s) but of the others with unreported yields, No. 17198 (at least) yielded useful quantities of water,
- only one water quality (115mg/L of total dissolved solids) was reported, and
- the water table on drilling was shallow (in the range 0 – 3m for three of the bores).

Table 1. Results of drilling for water in the St Patrick Plains district.
Source: Adapted from DPIPWE Groundwater Information Access Portal

	GDA94								
Bore ID	**Easting**	**Northing**	**Year drilled**	**Depth (m) drilled)**	**Initial yield (L/s)**	**Water table depth (m)**	**Salinity (mg/L)**	**Aquifer**	**Status at drilling**
17198	487135	5344812	1990	18		3.1		Jurassic dolerite	Functioning
40456	490666	5348052	2009	90				Jurassic dolerite	Abandoned
40637	488096	5350672	2009	39	0.44	0	115	Jurassic dolerite	Capped
40638	488465	5350580	2009	27				Jurassic dolerite	Abandoned
41389	483600	5346503	2012	24	3.3	3		Jurassic dolerite	Functioning

2.3.6 Aquifer pump testing

Groundwater bores 17198 and 41389 were pump tested to determine the hydraulic parameters of the fractured, unconfined dolerite at both locations, and thereby estimate the likely maximum radius of water level drawdown if long-term groundwater pumping was to occur.

2.3.6.1 Pump testing bore 17198

Bore 17198 was constructed in 1990 to a depth of 18 metres in Jurassic dolerite (Table 1). On 17 October 2022 it was pump-tested at a constant rate of 50L/min for approximately 30 minutes using the existing domestic bore pump.

Time-series groundwater level and temperature were recorded at one second intervals during the pumping and 133-minute recovery periods. The groundwater drawdown was 0.65 metres after 30 minutes of constant pumping (Figure 9). Groundwater temperature decreased by 4^0C when pumping began and then stabilised at 10^0C for the remainder of the time.

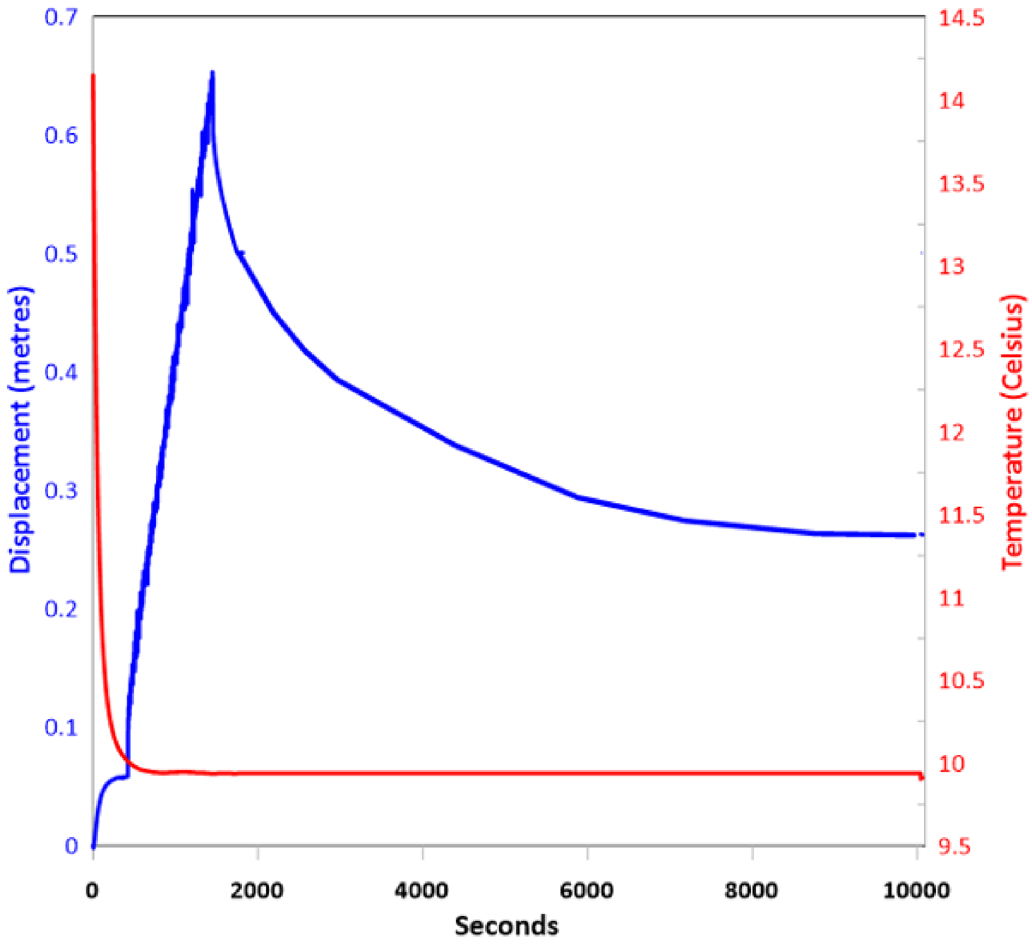


Figure 9. Time series water level and temperature data for the pump test of bore 17198.

To analyse the data, time versus displacement plots were initially considered[15]. However, the initial pumping time series water level data of the bore was removed as the pump needed to gain prime for 1-2 minutes before the pump worked to its full capacity, thereby appearing as a two-stage pumping test (Figure 10). Then analysis of the water level data during the pumping test shows the groundwater level was not yet stable after 30 minutes of pumping (10). Accordingly, the Huntush[16] solution was used. (Although the groundwater flow is via secondary, not primary porosity, the Huntush solution is the nearest approximation.)

Curve fitting suggests the aquifer has a transmissivity of 4.5m^2/day. Assuming the dolerite fracture zone is 50 metres deep, the hydraulic conductivity is 0.1 m/day (Table 2).

[15] using Neuman (1974) curve fitting: Neuman, .P., 1974. Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response, Water Resources Research, vol. 10, no. 2, pp. 303-312.

[16] Hantush, M.S., 1964. Hydraulics of wells, in: Advances in Hydroscience, V.T. Chow (editor), Academic Press, New York, pp. 281-442. Hantush derived a solution for unsteady flow to a fully penetrating well in a homogeneous and isotropic leaky confined aquifer.

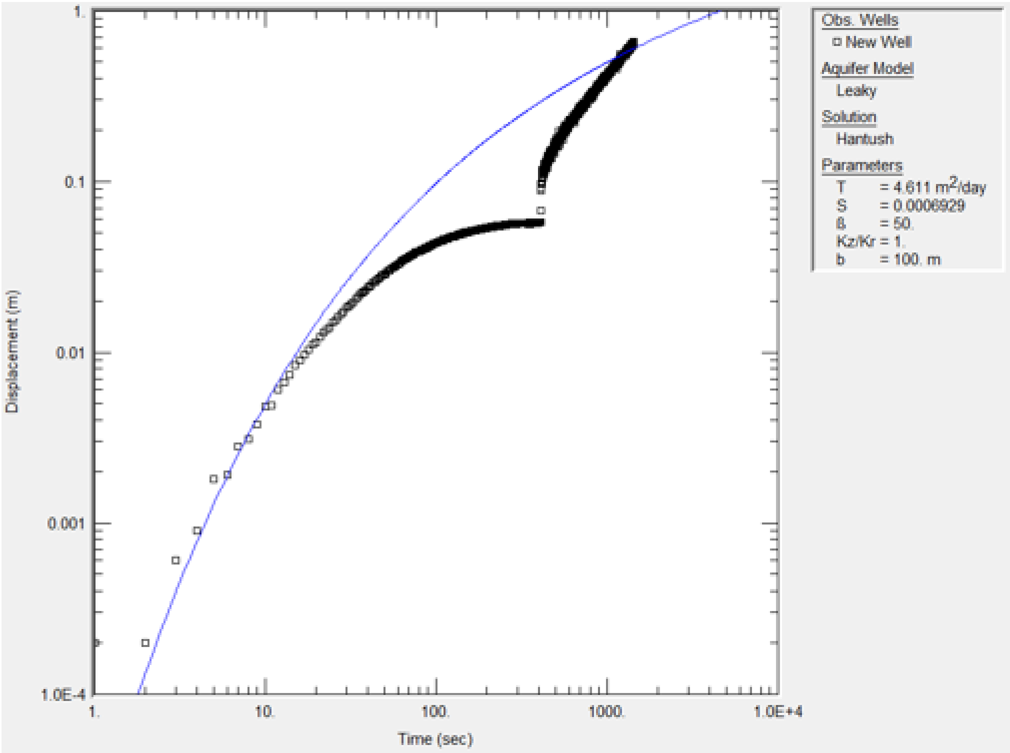


Figure 10. Time series displacement pumping of bore 17198.

2.3.6.2 Pump testing bore 41389

Bore 41389 was constructed in 2012 to a depth of 24 metres in Jurassic dolerite (Table 1). On 17 October 2022 it was pump-tested at a constant rate of 50L/min for approximately 20 minutes using the existing domestic bore pump at the farmhouse.

Time-series groundwater level and temperature were recorded at one second intervals during both the pumping and 113-minute recovery phase (Figure 11). Drawdown was almost 3 metres after 20 minutes of constant pumping and the water level was fully recovered approximately 10 minutes afterward pumping stopped. The groundwater temperature decreased initially after pumping began when bore casing water was drawn into the pump and then increased after pumping stopped when the casing water mixed with the slightly cooler aquifer water.

Hydraulic assessment of the groundwater data level data was undertaken assuming the aquifer was unconfined, and partially penetrating the dolerite aquifer. This assumption allowed the application of the Newman (1974) method of pumping curve analysis to determine the properties of the aquifer. Figure 12 showing the curve fitting of displacement water level versus time at the bore suggests the aquifer has a transmissivity of 14 m^2/day. Assuming the dolerite fracture zone is 50 metres deep, the hydraulic conductivity is 0.28 m/day (Table 2).

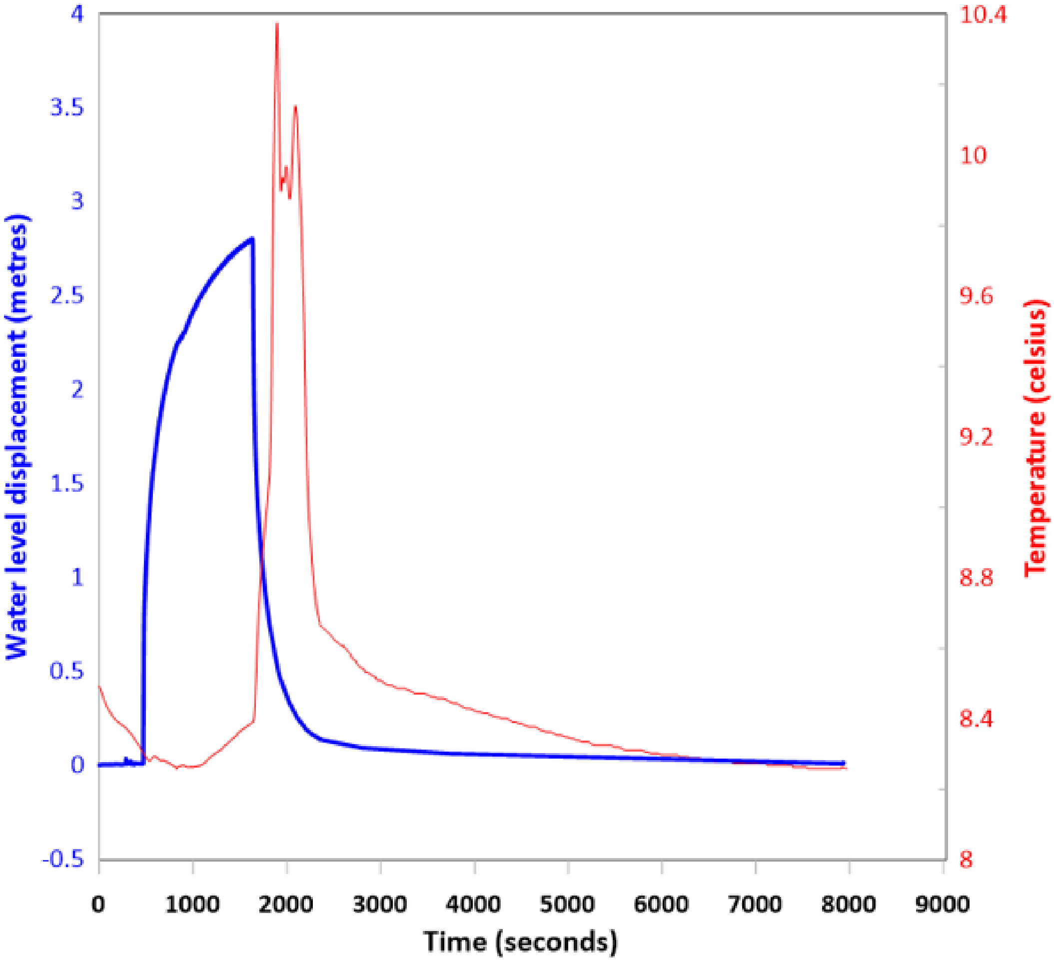


Figure 11. Time series water level and temperature data for the pump test of bore 17198.

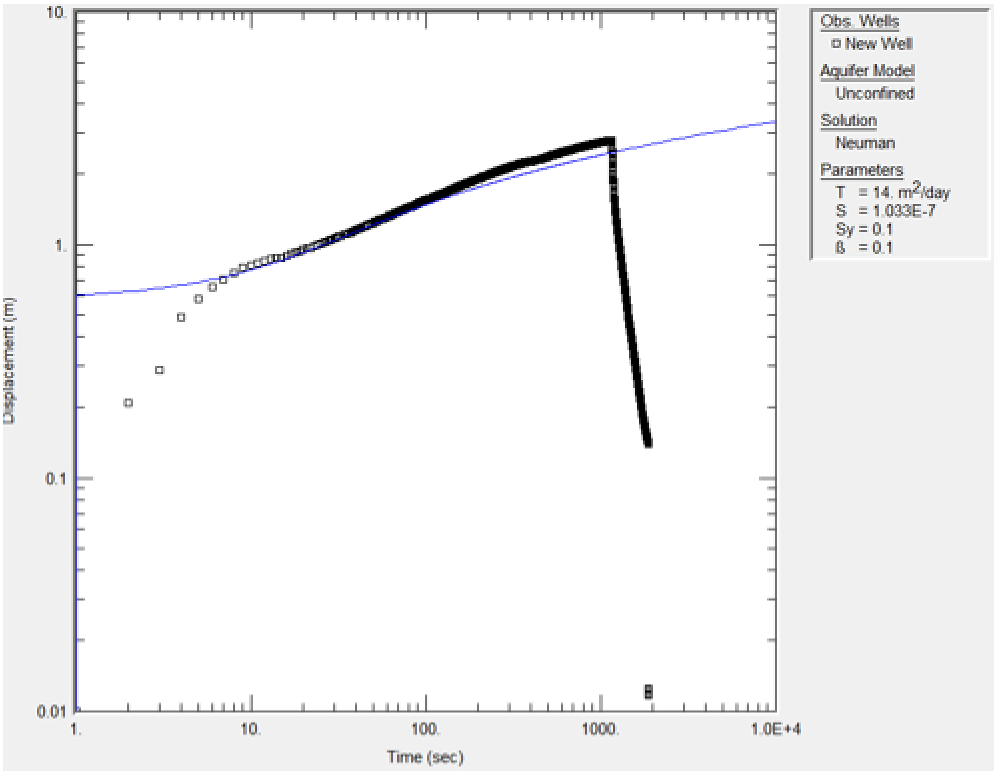


Figure 12. Time series displacement pumping of bore 41389.

2.3.6.3 Aquifer properties

The results of pump testing both bores are summarised in Table 2.

Table 2. Aquifer properties derived from the pump testing of bores 17198 and 41389

	GDA94							
Bore ID	**Easting**	**Northing**	**Year drilled**	**Depth (m) drilled)**	**Water table depth (mbg) 17 Oct 2022**	**Transmissivity (m2/day)**	**Hydraulic conductivity (m/day)**	**Specific yield**
17198	487135	5344812	1990	18	0.97	4.6	0.1	ND
41389	483600	5346503	2012	24	1.1	14	0.3	0.1

Notes

mbg = metres below ground
Specific yield = 'drainable porosity'; "a ratio, less than or equal to the effective porosity, indicating the volumetric fraction of the bulk aquifer volume that a given aquifer will yield when all the water is allowed to drain out of it under the forces of gravity" (Wikipedia)

2.3.6.4 Radii of influence of a pumped bore in dolerite

Information calculated from the pumping drawdown curves has been used to determine the maximum radius of drawdown from pumping at steady state[17] (assumed to be 1 year). Pumping rates of 2 or more litres per second were found to be too high and unsustainable, so drawdown curves were considered at a rate of 1L/s only.

Figure 13 presents the likely drawdown radius if the aquifer was pumped constantly to equilibrium (ie. steady state) for a range of hydraulic conductivity values between 0.1 to 0.5 m/day (the latter was the maximum likely value based on the pumping analysis). The graph shows:

- if bore 17198 were pumped for long periods of time (eg one year) at a constant rate of 1L/s, its effect on the water table would extend to a radius of approximately 200m from it,
- pumping bore 17198 for lesser periods of time, and/or at lower pump rates, would produce a radius of influence less than 200m,
- if bore 41389 were pumped for long periods of time (eg one year) at a constant rate of 1L/s, its effect on the water table would extend to a radius of approximately 360m from it, and
- pumping bore 41389 for lesser periods of time, and/or at lower pump rates, would produce a radius of influence less than 360m.

[17] Steady state means that the pumped water level in the bore, and the radius of influence of the pumping, remain constant. The radius of influence is the horizontal distance from the bore beyond which the water table is unaffected by pumping. It depends on aquifer hydraulic conductivity, pump rate and pumping time.

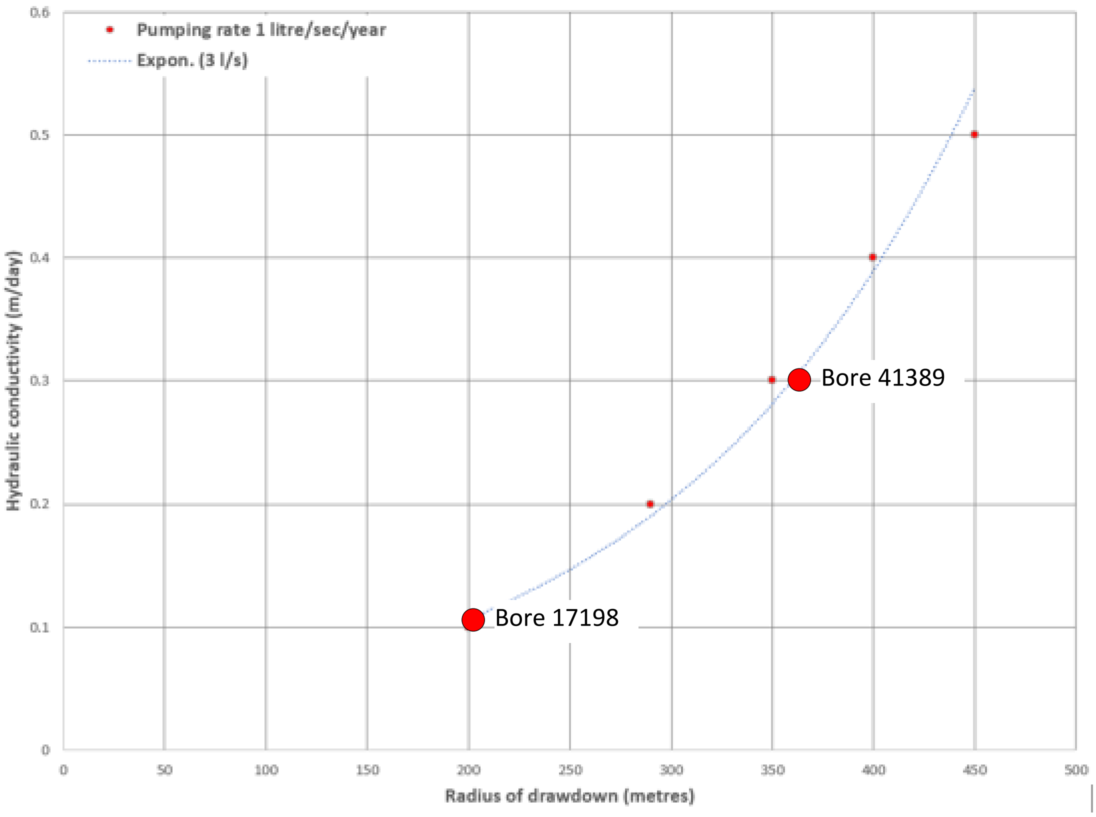


Figure 13. Maximum radii of influence for different hydraulic conductivities in the unconfined dolerite aquifer in the vicinity of the proposed St Patricks Plains wind farm. This graph is based on pump testing the only two operating bores in the district. Different hydraulic conductivities are very likely to be obtained from bores drilled in other locations in the same dolerite aquifer, so the graph should be regarded as indicative only.

2.3.7 Surface and groundwater quality

2.3.7.1 Sampling

As a preliminary and opportunistic background survey[18], on 17 October 2022:

- surface water samples were collected from four locations (SW1 – SW4), on the properties *Wihareja* and *St Patrick Plains*:
  - SW1 (Plate 1) was the outfall from Wihareja Lagoon (ie from Wihareja Creek)
  - SW2 (Plate 2) was from the Shannon River upstream from its confluence with Ripple Creek,
  - SW3 was from Ripple Creek flowing at an estimated 1 – 1.5 cumecs, and
  - SW4 (Plate 3) was from a spring flowing at an estimated 2 – 3L/s, and
- groundwater samples were collected from bores 17198 and 41389 (Plates 4 – 7).

Sample locations are shown in Figure 14.

All samples were submitted to Australian Laboratory Services (ALS) in Melbourne for analysis.

[18] All surface streams were in flood following recent heavy rains.

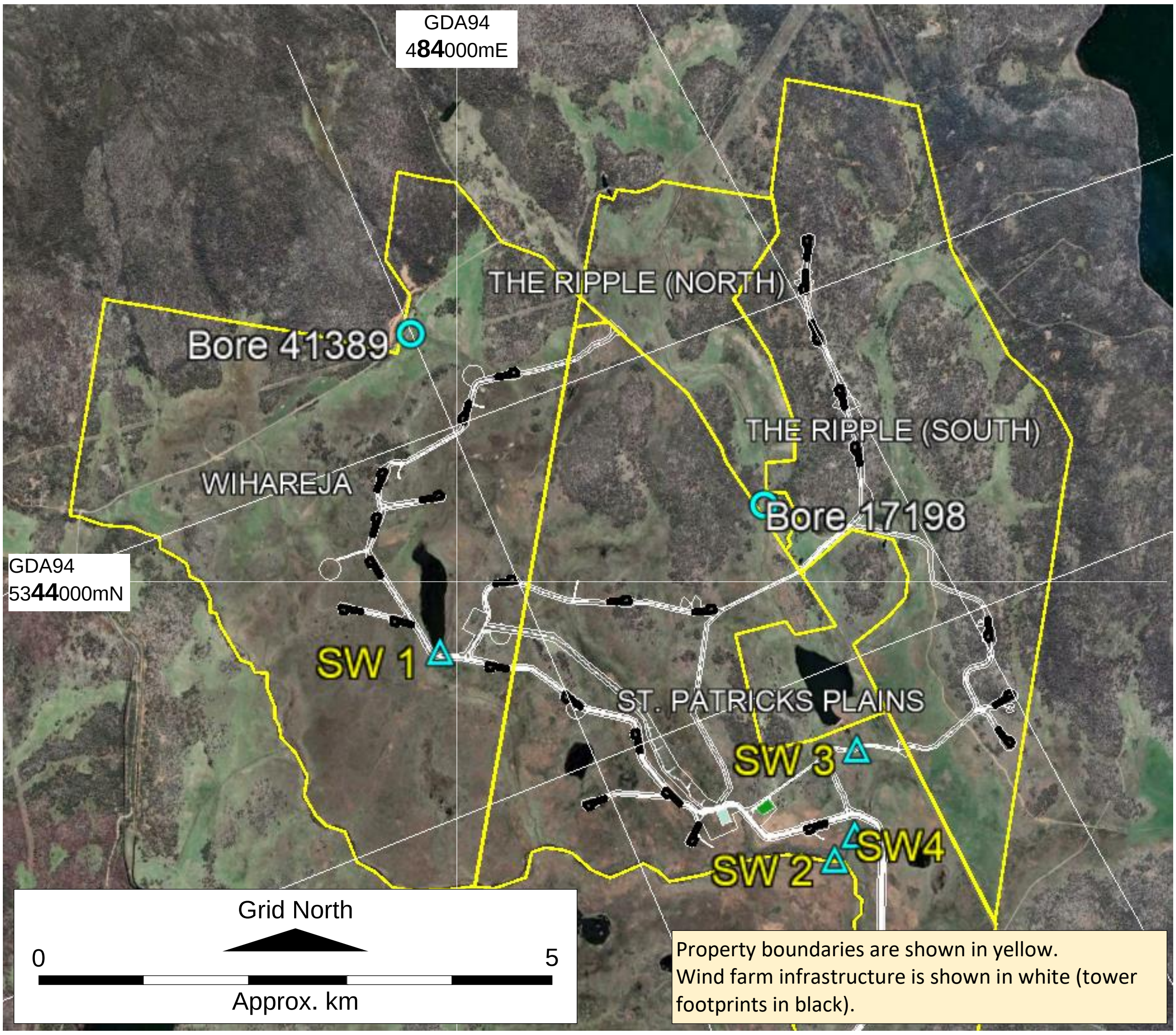


Figure 14. Water bores 17198 and 41389, and surface water locations SW1 – SW4, sampled on 17 October 2022. The six samples were submitted to ALS for analysis.

2.3.7.2 Surface water quality

Field parameters and laboratory analyses of surface waters SW1 – SW4 (and groundwaters) are summarised in Table 3. The laboratory report is presented in Attachment 3[19]. Some observations from Table 3 are:

- all surface waters are slightly acidic, very low electrical conductivity, sodium chloride – calcium chloride/sulphate types,
- except for traces of aluminium, iron, manganese and copper, metals were undetected,
- nitrate is present in SW1 and SW3, but undetected in SW2 and SW4,
- the spring water SW4 is almost identical in quality to SW1, SW2 and SW3.

[19] Pages 3, 4 and 5 of the ALS report are purposely omitted. They relate to soil samples tested for acid sulphate potential and are discussed in Cromer, W. C. (2022). *Reconnaissance survey of potential acid sulphate soils for a proposed wind farm at St. Patricks Plains, central highlands Tasmania.* Unpublished report for Ark Energy by William C. Cromer Pty. Ltd. 23 December 2022.

Plate 1 (above). Sample location SW1 on *Wihareja*, on the outfall of Wihareja Lagoon [483897mE, 5343353mN]. 17 October 2022.

Plate 2 (left). Sample location SW2 on *St Patricks Plains*, on the Shannon River (487857mE, 5341288mN]. 17 October 2022.

Plate 3 (below). Spring (SW4) on *St Patricks Plains* at [488053mE, 5341536mN. 17 October 2022.

Thee is no photo of SW3 on Ripple Creek.

Plates 4 and 5 (left and below). Bore 17198 on *The Ripple (South)*, at [487135mE, 5344812mN]. 17 October 2022.

Plates 6 and 7 (above and right). Bore 43189 on *Wihareja* at [483600mE, 5346503mN]. 17 October 2022.

Table 3. Summary of surface water and groundwater quality, 17 October 2022, in the vicinity of the proposed St Patricks Plains wind farm.

	Units	Limit or reporting	SW1	SW2	SW3	SW4	BORE 17918	BORE 41389	QA/QC 1 (Field Blank)	QA/QC 2 (Trip Blank)
	Field parameters									
pH*	pH Unit		5.45	5	5.2	4.3	6.2	5.5		
Electrical conductivity	uS/cm		49	43	43	58	235	200		
Dissolverd oxygen	mg/L		7.7	8.4	9.7	3.2	4	5.5		
Dissolverd oxygen	%		68	70	86	28	38	47		
Redox	mV		427	435	441	374	364	439		
Turbidity	NTU		8	7	8	3	2	3		
Temperature	^0C		10.2	7.8	10.0	9.3	11.0	9.2		
	Laboratory results									
pH	pH Unit	0.01	6.52	6.44	7	6.47	7.25	6.38	7.66	----
Total Dissolved Solids @180Â°C	mg/L	10	122	65	62	47	171	181	<10	----
Hydroxide Alkalinity as CaCO3	mg/L	1	<1	<1	<1	<1	<1	<1	<1	----
Carbonate Alkalinity as CaCO3	mg/L	1	<1	<1	<1	<1	<1	<1	<1	----
Bicarbonate Alkalinity as CaCO3	mg/L	1	7	6	13	16	90	31	4	----
Total Alkalinity as CaCO3	mg/L	1	7	6	13	16	90	31	4	----
Sulfate as SO4	mg/L	1	3	5	1	2	2	2	<1	----
Fluoride	mg/L	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	----
Major ions										
Chloride	mg/L	1	6	6	5	7	8	10	<1	----
Calcium	mg/L	1	4	3	3	3	21	21	<1	----
Magnesium	mg/L	1	1	1	1	2	10	6	<1	----
Sodium	mg/L	1	4	4	3	4	10	8	<1	----
Potassium	mg/L	1	<1	<1	<1	<1	<1	<1	<1	----
Sodium Adsorption Ratio		0.01	0.46	0.51	0.38	0.44	0.45	0.4	0.12	----
Total metals										
Aluminium	mg/L	0.01	0.46	0.72	1.25	0.34	<0.01	0.16	<0.01	----
Arsenic	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	----
Beryllium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	----
Boron	mg/L	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	----
Cadmium	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	----
Chromium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	----
Cobalt	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	----
Copper	mg/L	0.001	0.003	0.001	0.005	<0.001	<0.001	0.003	<0.001	----
Iron	mg/L	0.05	0.34	0.46	0.68	0.2	<0.05	0.13	<0.05	----
Lead	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	----
Lithium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	----
Manganese	mg/L	0.001	0.012	0.011	0.016	0.001	<0.001	0.004	<0.001	----
Mercury	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	----
Molybdenum	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	----
Nickel	mg/L	0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.001	<0.001	----
Selenium	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	----
Uranium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	----
Vanadium	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	----
Zinc	mg/L	0.005	0.021	<0.005	0.01	<0.005	0.01	0.012	<0.005	----
Nutrients										
Nitrite as N	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	----
Nitrate as N	mg/L	0.01	4.57	<0.01	0.94	<0.01	7.23	16.2	<0.01	----
Nitrite + Nitrate as N	mg/L	0.01	4.57	<0.01	0.94	<0.01	7.23	16.2	<0.01	----
EN055: Ionic Balance										
Total Anions	meq/L	0.01	0.37	0.39	0.42	0.56	2.06	2.1	0.08	----
Total Cations	meq/L	0.01	0.46	0.4	0.36	0.49	2.3	1.89	<0.01	----
Total Petroleum Hydrocarbons										
C6 - C9 Fraction	Äµg/L	20	----	----	----	----	----	----	----	<20
Total Recoverable Hydrocarbons										
C6 - C10 Fraction	Äµg/L	20	----	----	----	----	----	----	----	<20
C6 - C10 Fraction minus BTEX (F1)	Äµg/L	20	----	----	----	----	----	----	----	<20
BTEXN										
Benzene	Äµg/L	1	----	----	----	----	----	----	----	<1
Toluene	Äµg/L	2	----	----	----	----	----	----	----	<2
Ethylbenzene	Äµg/L	2	----	----	----	----	----	----	----	<2
meta- & para-Xylene	Äµg/L	2	----	----	----	----	----	----	----	<2
ortho-Xylene	Äµg/L	2	----	----	----	----	----	----	----	<2
Total Xylenes	Äµg/L	2	----	----	----	----	----	----	----	<2
Sum of BTEX	Äµg/L	1	----	----	----	----	----	----	----	<1
Naphthalene	Äµg/L	5	----	----	----	----	----	----	----	<5

*field pH probably under-reading (problems with meter calibration)

2.3.7.3 Groundwater quality

Field parameters and laboratory analyses of groundwaters from bores 17198 and 43189 are summarised in Table 3. The laboratory report is presented in Attachment 3. Some observations from Table 3 are:

- the groundwaters are of similar quality to surface waters, but with higher electrical conductivities and nitrate levels,
- except for traces of iron and zinc, metals were undetected.

3 Discussion

3.1 Conceptual hydrogeological models

Attachment 2 presents two conceptual hydrogeological models along sections lines A – A' and C – C' on the maps in Attachment 1. These models are attempts at describing the directions of groundwater movement at any location in the general vicinity of the proposed wind farm.

Observations from the conceptual models are:

- all rock types in the district are a single unconfined hard-rock (and minor unconfined intergranular) aquifer,
- groundwater moves through secondary openings (mainly joints) between otherwise dry bulk rock in hard rock, and between mineral grains in intergranular (unconsolidated) materials,
- groundwater at local-scale comprises recharge and discharge areas between neighbouring sub-subcatchments and un-named minor creeks (the creeks and marshes scattered over the area are discharge zones),
- groundwater at intermediate-scale comprises recharge and discharge areas between neighbouring subcatchments and major creeks and rivulets (discharge zones),
- groundwater at regional-scale comprises recharge and discharge areas between neighbouring catchments and rivers (discharge zones), and
- groundwater flow rates everywhere are judged to be very low (perhaps of the order of a few cm/day) and travel times are relatively long (from years – decades in local-scale systems, to centuries –millennia in regional-scale systems).

3.2 Groundater independent ecosystems (GIE's)

Rain falls on an unconfined aquifer across its full areal extent.

On this aquifer, on relatively higher ground (interfluves; eg Sheepyard Hills, Barren Tier, Norths Hill), between adjacent watercourses, infiltrating rain moves vertically down through the soil profile towards the water table and downgradient away from the interfluve to join local, intermediate or regional GFS's. The water is entering the systems and "recharging" them.

Flora and fauna inhabiting the land and soil profile in interfluves receive intermittent water from direct and infiltrating rain which evaporates, evapotranspires and leaves the area as groundwater.

Such areas have a groundwater deficit and a relatively deep water table.

The flora and fauna may depend on the rain but do not depend on the groundwater.

Recharge zones are groundwater independent ecosystems (GIE's).

Some but not all GIE's in the study area are depicted in the cross sections in Attachment 2.

3.3 Groundater dependent ecosystems (GDE's)

Groundwater from recharge areas has travelled via gravity through local, intermediate or regional GFS's towards lower-lying areas, and if sufficient head is available the water moves upwards through the soil profile to evaporate and evapotranspire.

Such lower-lying areas have a groundwater excess and a relatively high water table. If the water table rises to or above the land surface, it forms wetlands and marshes, or contributes to creek and river flows.

Wetlands, marshes and lagoons are scattered throughout the generally flattish and poorly-drained area of the proposed wind farm.

Flora and fauna inhabiting the land and soil profile in these areas receive intermittent water from direct and infiltrating rain (the former evapotranspires or flows away, and the latter leaves the area), but also from upwards moving groundwater.

The flora and fauna may depend on the rain, but also depend on the groundwater.

Discharge zones are groundwater dependent ecosystems (GDE's).

Some but not all GDE's in the study area are depicted in the cross sections in Attachment 2.

3.4 Groundwater extraction from possible wind farm water bores

Groundwater from one or more water bores may be considered as a water source for construction activities at the wind farm.

3.4.1 Prospectivity of a water bore

The underlying dolerite is regarded as moderately-highly prospective (Section 2.3.4), and a successful water bore might be capable of sustaining yields of several L/s (Table 1).

However, a successful bore depends on being drilled through sufficient and intersecting water bearing fractures, and their presence or absence are unpredictable (see the models in Attachment 2). More than one attempt at drilling may be required.

Groundwater quality (Table 3; Attachment 3) is expected to be suitable for construction purposes.

3.4.2 Effect of a pumped bore on groundwater conditions

A production water bore for the wind farm will extract water from the local groundwater system, and (although unlikely but depending on bore depth) from the underlying intermediate-scale groundwater system. During pumping, the groundwater flow directions will be altered so that water will flow radially towards the bore. Since any bore will most likely be in a GDE, upward groundwater flow will be disrupted.

The disruption will be limited to the radius of influence of the pumped bore. To illustrate the effect, Figure 15 shows a hypothetical production bore installed at a nominal location at the proposed wind farm, and two radii of influence for two hydraulic conductivities (0.1 and 0.3m/day), assuming a steady state pump rate of 1L/s. In this example, steady state conditions are assumed to occur after one year continuous pumping at the stated rate. In practice, pumping durations are likely to be intermittent and shorter -lived, so the radii of influence will be smaller.

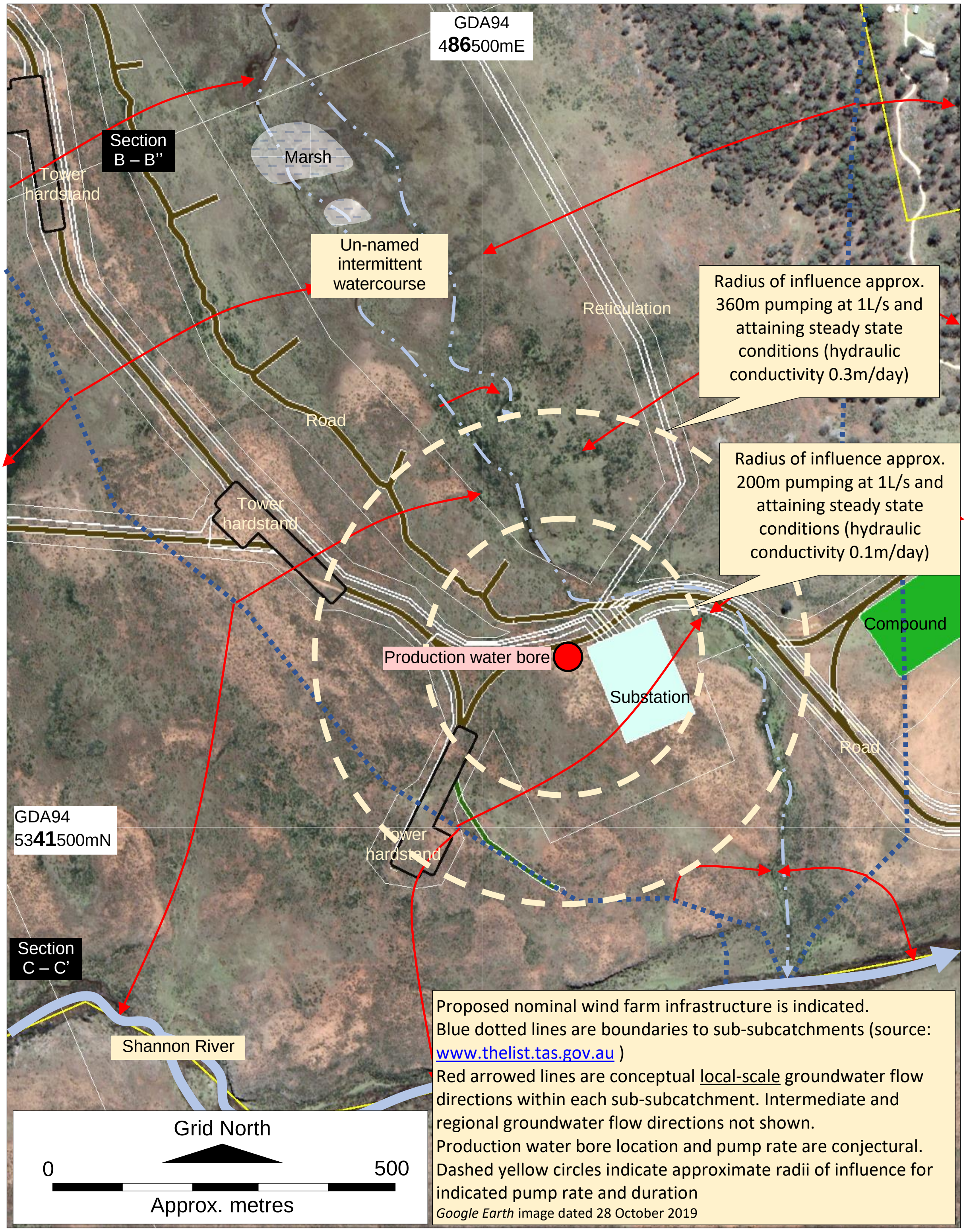


Figure 15. Inferred local-scale flow directions and proposed (nominal) wind farm infrastructure near the Shannon River on St Patricks Plains. Also shown as an example are the radii of influence of a hypothetical production water bore for two different hydraulic conductivities, under steady state conditions and pumping at 1L/s. The thickness of the fractured, unconfined dolerite aquifer is assumed to be 50m.

3.4.3 Effect of a pumped bore on existing domestic bores

Any production bore for the wind farm will not affect existing water bores provided the distance separating them is more than the combined radii of influence of the bores.

3.4.4 Relative scale of groundwater disruption

The footprint of the proposed wind farm infrastructure in the St Patricks Plains district extends over approximately 30km^2, and that of the aquifer at least 100km^2. The groundwater effect of a production bore under the conditions depicted in Figure 15 covers approximately 40ha, or (say) 0.5% of the aquifer. In practice, with intermittent pumping and lesser pumping times, the effect is unlikely to extend over no more than a small fraction of this area.

4 CONCLUSIONS

This hydrogeological report has demonstrated that in relation to the proposed St Patricks Plains wind farm:

- Jurassic-age dolerite is the dominant rock type in the area; it probably extends vertically for hundreds of metres, interspersed with zones of subhorizontal Permian- and Triassic-age sedimentary rocks,
- Tertiary-age basalt is scattered over the land surface, overlying the dolerite mostly as a veneer, but thicker in places where it has filled pre-volcanic river systems,
- the dolerite, basalt and sedimentary rocks are regarded as a single, fractured-rock aquifer; within it, groundwater moves through a three-dimensional network of fractures between dry rock,
- local-, intermediate- and regional-scale groundwater flow systems (GFSs) occur:
  - local-scale groundwater is near-surface flow between adjacent minor watercourses and to wetlands, marshes and lagoons,
  - intermediate-scale groundwater flows beneath the local-scale flow, between neighbouring major creeks and rivers, and
  - regional-scale groundwater bypasses both of the former, flowing beneath to major river systems.
- groundwaters and surface waters are slightly acidic, and of very low salinity
- most of the almost-flat plateau is a groundwater dependent ecosystem (GDE), with upward moving groundwater forming wetlands, lagoons and marshes,
- two water bores extract groundwater from the unconfined aquifer; bore yields are up to about 1L/s, and are probably sustainable at that rate,
- groundwater extraction from a possible wind farm production bore will (depending on pumping rate and duration) affect groundwater conditions for radii of up to several hundred metres; the local GDE will also be affected (put into perspective, the effect would represent less than 1% of the area of the aquifer).

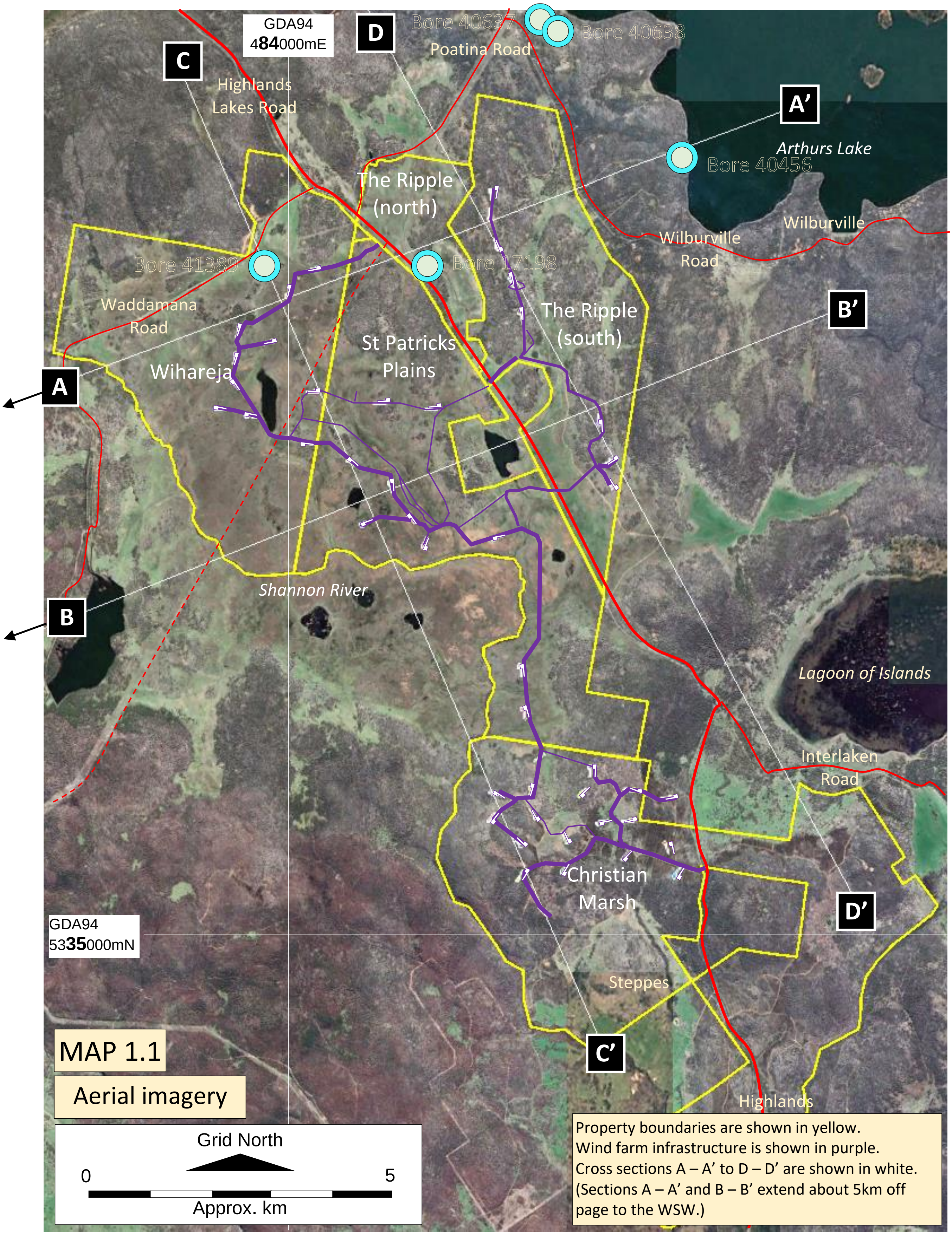
Attachment 1

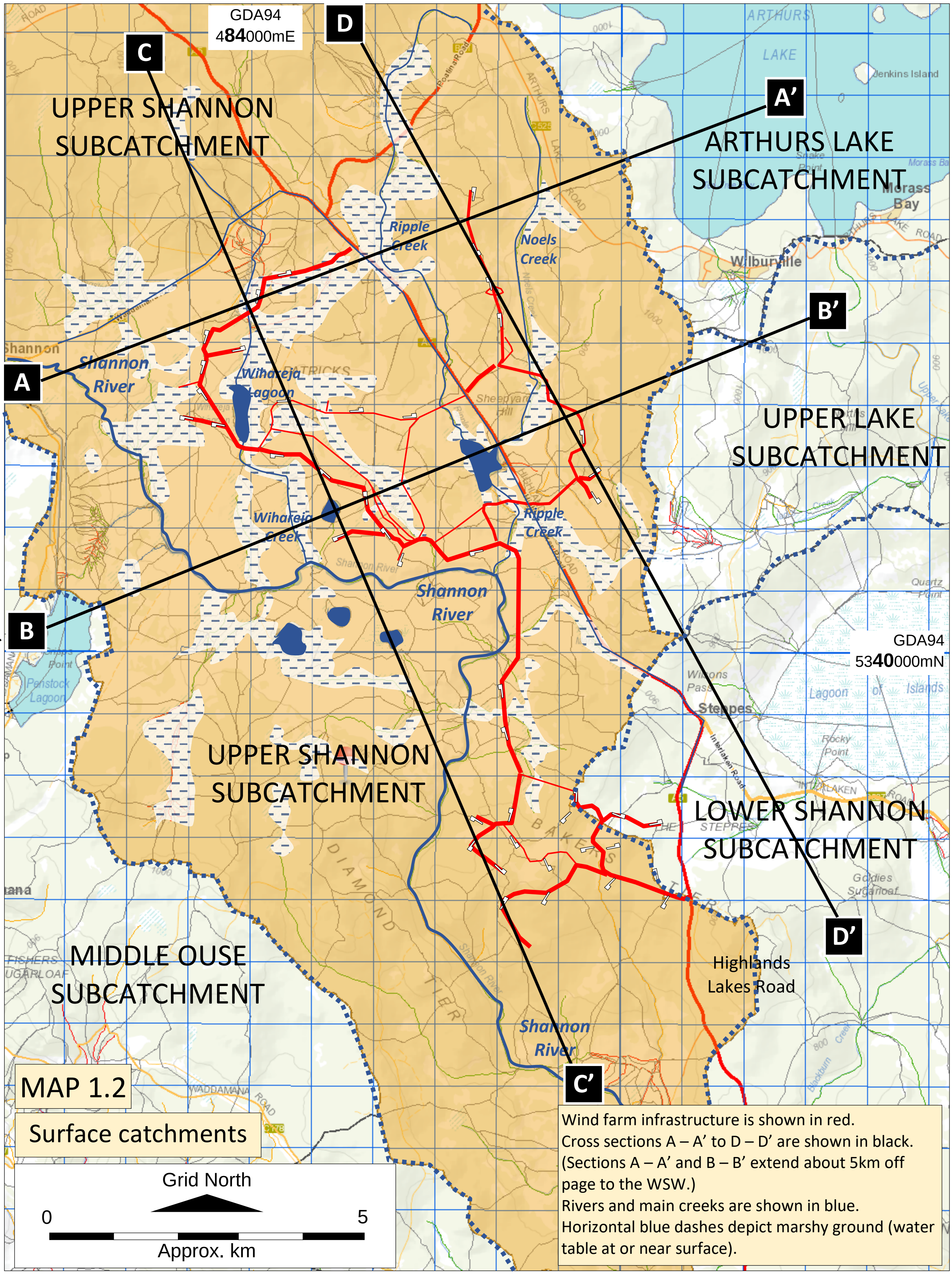
(5 pages including this page)

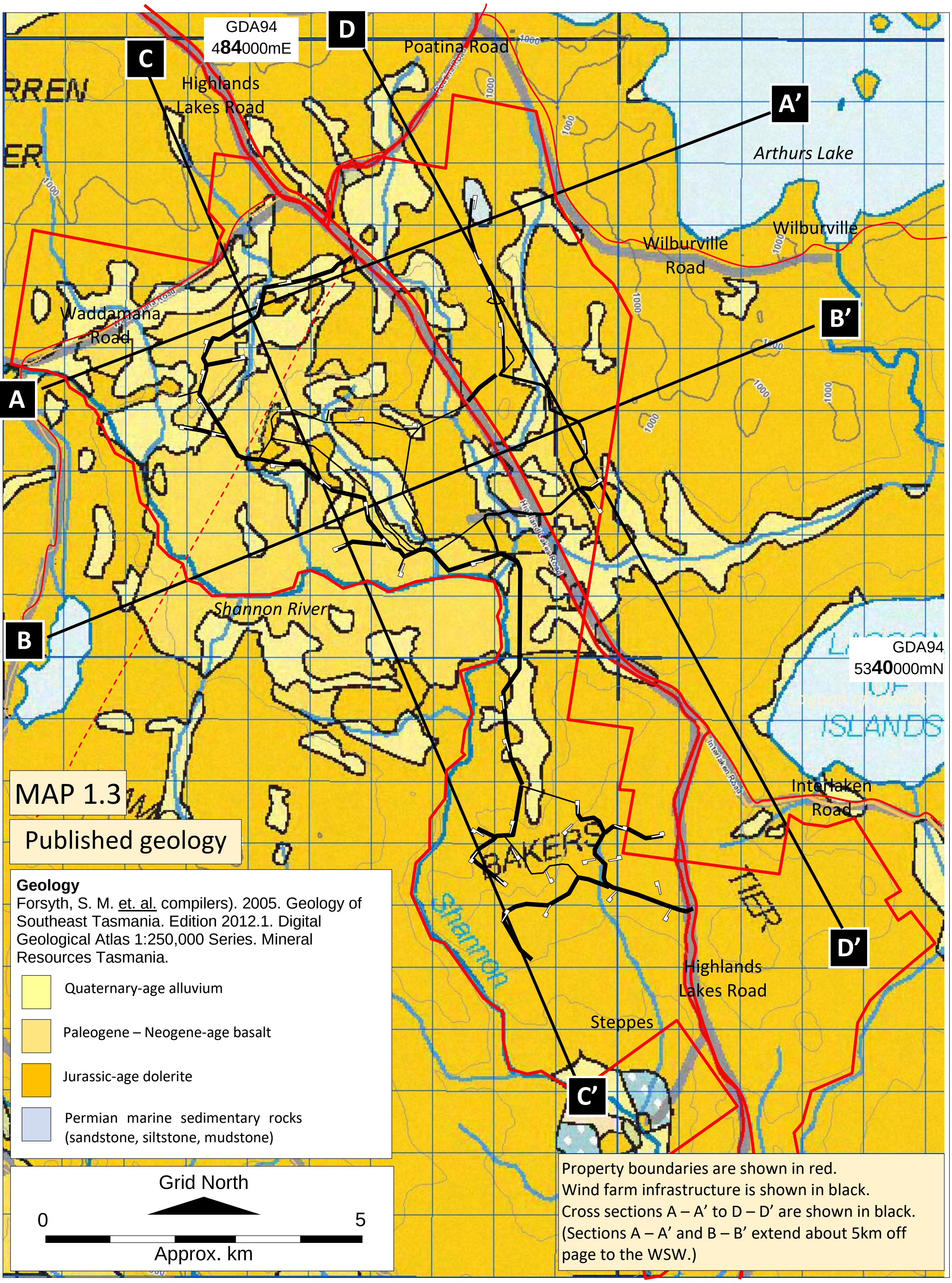
Maps of the study area

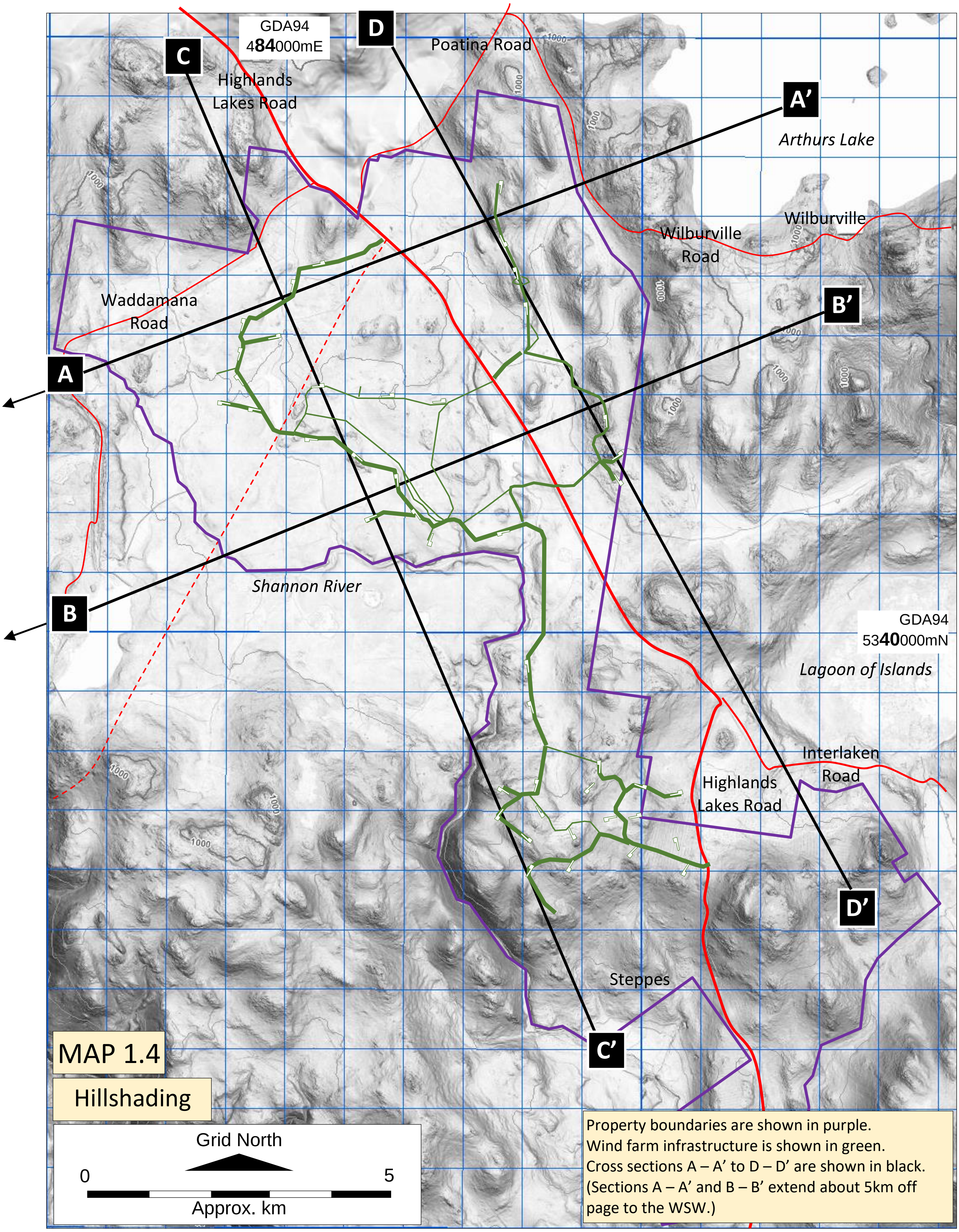
Map 1.1:	Aerial imagery with property boundaries, wind farm infrastructure and existing water bores
Map 1.2:	Surface catchments
Map 1.3:	Published geology
Map 1.4	Hillshading

Superimposed on each map are the four cross sections used to develop the conceptual hydrogeological models in Attachment 2.


GDA94
484000mE
D
C
Bore 40637
Bore 40638
Poatina Road
Highlands
Lakes Road
A'
Arthurs Lake
Bore 40456
The Ripple
(north)
Wilburville
Wilburville
Road
Bore 41389
Bore 17198
Waddamana
Road
The Ripple
(south)
B'
St Patricks
Plains
Wihareja
A
Shannon River
B
Lagoon of Islands
Interlaken
Road
Christian
Marsh
D'
GDA94
5335000mN
Steppes
C'
MAP 1.1
Aerial imagery
Highlands
Grid North
0
5
Approx. km
Property boundaries are shown in yellow.
Wind farm infrastructure is shown in purple.
Cross sections A – A' to D – D' are shown in white.
(Sections A – A' and B – B' extend about 5km off page to the WSW.)


GDA94
484000mE
GDA94
5340000mN
C
D
A
A'
B
B'
C'
D'
UPPER SHANNON SUBCATCHMENT
ARTHURS LAKE SUBCATCHMENT
UPPER LAKE SUBCATCHMENT
UPPER SHANNON SUBCATCHMENT
LOWER SHANNON SUBCATCHMENT
MIDDLE OUSE SUBCATCHMENT
Ripple Creek
Noels Creek
Shannon River
Wihareja Lagoon
Wihareja Creek
Ripple Creek
Shannon River
Shannon River
Highlands Lakes Road
Wilburville
Jenkins Island
Steppes
MAP 1.2
Surface catchments
Grid North
0
5
Approx. km
Wind farm infrastructure is shown in red.
Cross sections A – A' to D – D' are shown in black.
(Sections A – A' and B – B' extend about 5km off page to the WSW.)
Rivers and main creeks are shown in blue.
Horizontal blue dashes depict marshy ground (water table at or near surface).


MAP 1.3
Published geology
GDA94
484000mE
GDA94
5340000mN
A
A'
B
B'
C
C'
D
D'
Highlands Lakes Road
Poatina Road
Arthurs Lake
Wilburville Road
Wilburville
Waddamana Road
Shannon River
Interlaken Road
Steppes
BAKERS
TIER
Shannon
ISLANDS
Geology
Forsyth, S. M. et. al. compilers). 2005. Geology of Southeast Tasmania. Edition 2012.1. Digital Geological Atlas 1:250,000 Series. Mineral Resources Tasmania.
Quaternary-age alluvium
Paleogene – Neogene-age basalt
Jurassic-age dolerite
Permian marine sedimentary rocks (sandstone, siltstone, mudstone)
Grid North
0
5
Approx. km
Property boundaries are shown in red.
Wind farm infrastructure is shown in black.
Cross sections A – A' to D – D' are shown in black.
(Sections A – A' and B – B' extend about 5km off page to the WSW.)


GDA94
484000mE
C
D
Poatina Road
Highlands
Lakes Road
A'
Arthurs Lake
Wilburville
Wilburville
Road
Waddamana
Road
B'
A
B
Shannon River
GDA94
5340000mN
Lagoon of Islands
Interlaken
Road
Highlands
Lakes Road
D'
Steppes
C'
1000
MAP 1.4
Hillshading
Grid North
0
5
Approx. km
Property boundaries are shown in purple.
Wind farm infrastructure is shown in green.
Cross sections A – A' to D – D' are shown in black.
(Sections A – A' and B – B' extend about 5km off page to the WSW.)

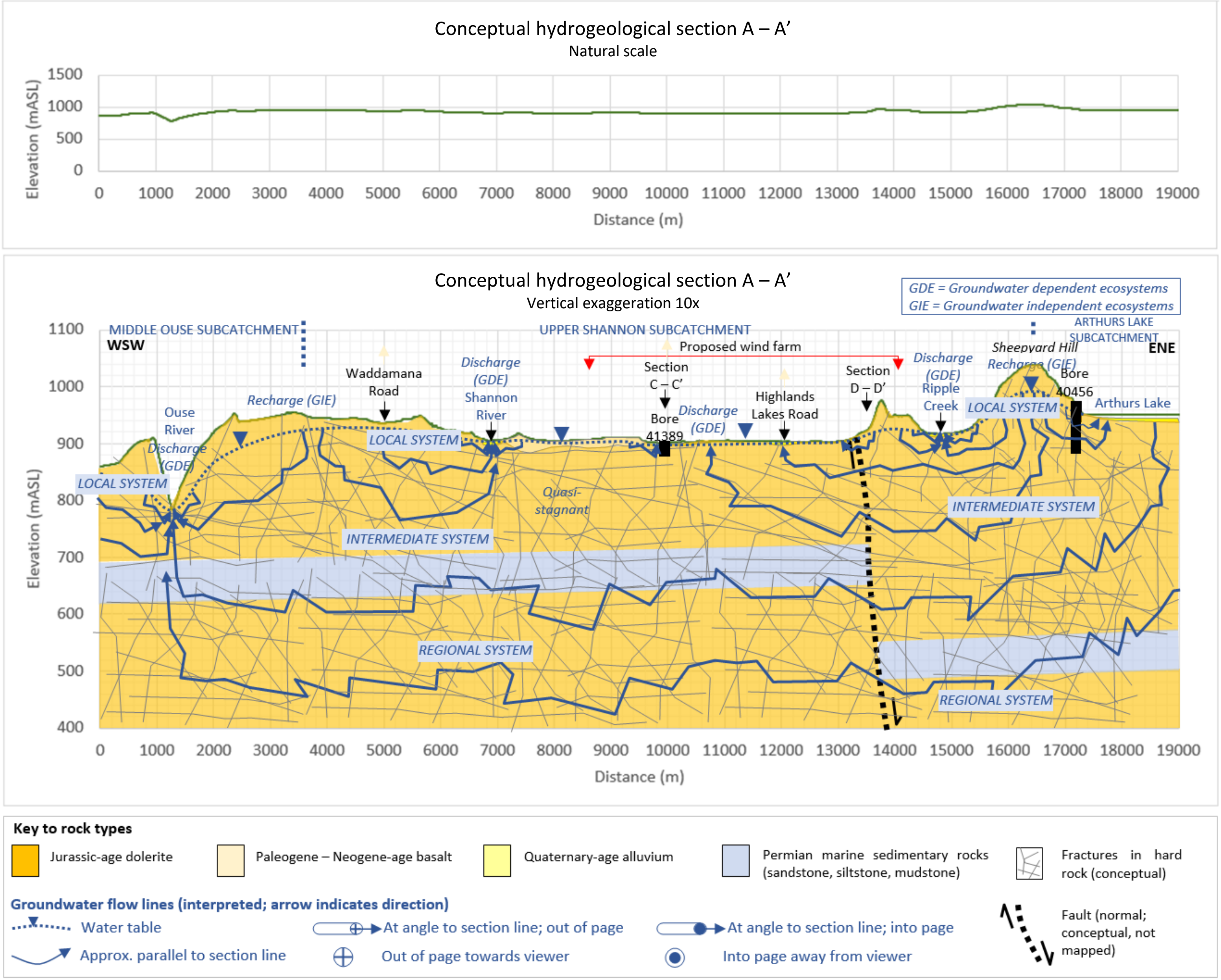
Attachment 2

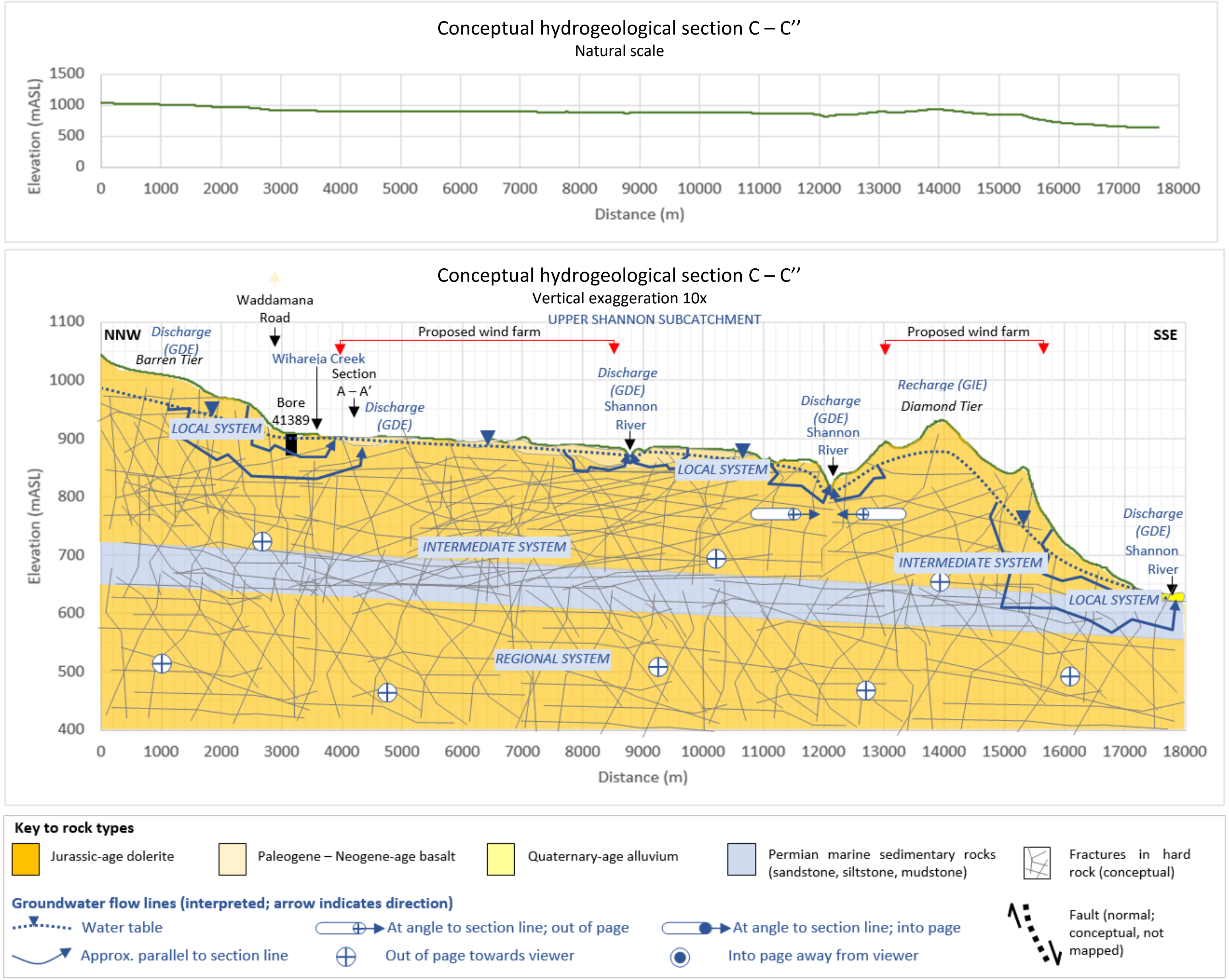
(3 pages including this page)

Conceptual hydrogeological cross sections

The location of each cross section is shown in the maps in Attachment 1.

These cross sections are based on published data, the maps in Attachment 1, and general hydrogeological principles. Like all models, they are likely to be refined by future groundwater information.


Conceptual hydrogeological section A – A’
Natural scale
Elevation (mASL)
Distance (m)
Conceptual hydrogeological section A – A’
Vertical exaggeration 10x
GDE = Groundwater dependent ecosystems
GIE = Groundwater independent ecosystems
MIDDLE OUSE SUBCATCHMENT
UPPER SHANNON SUBCATCHMENT
ARTHURS LAKE SUBCATCHMENT
WSW
ENE
Proposed wind farm
Ouse River
Discharge (GDE)
LOCAL SYSTEM
Recharge (GIE)
Waddamana Road
Discharge (GDE) Shannon River
Section C – C’
Bore 41389
Discharge (GDE)
Highlands Lakes Road
Section D – D’
Discharge (GDE) Ripple Creek
Sheepyard Hill Recharge (GIE)
Bore 40456
Arthurs Lake
Quasi-stagnant
INTERMEDIATE SYSTEM
REGIONAL SYSTEM
Key to rock types
Jurassic-age dolerite
Paleogene – Neogene-age basalt
Quaternary-age alluvium
Permian marine sedimentary rocks (sandstone, siltstone, mudstone)
Fractures in hard rock (conceptual)
Groundwater flow lines (interpreted; arrow indicates direction)
Water table
Approx. parallel to section line
At angle to section line; out of page
Out of page towards viewer
At angle to section line; into page
Into page away from viewer
Fault (normal; conceptual, not mapped)


Conceptual hydrogeological section C – C''
Natural scale
Elevation (mASL)
Distance (m)
Conceptual hydrogeological section C – C''
Vertical exaggeration 10x
NNW
SSE
Waddamana Road
UPPER SHANNON SUBCATCHMENT
Proposed wind farm
Proposed wind farm
Discharge (GDE)
Barren Tier
Wihareia Creek
Section A – A'
Bore 41389
Discharge (GDE)
Discharge (GDE) Shannon River
Discharge (GDE) Shannon River
Recharge (GIE)
Diamond Tier
Discharge (GDE) Shannon River
LOCAL SYSTEM
LOCAL SYSTEM
LOCAL SYSTEM
INTERMEDIATE SYSTEM
INTERMEDIATE SYSTEM
REGIONAL SYSTEM
Key to rock types
Jurassic-age dolerite
Paleogene – Neogene-age basalt
Quaternary-age alluvium
Permian marine sedimentary rocks (sandstone, siltstone, mudstone)
Fractures in hard rock (conceptual)
Groundwater flow lines (interpreted; arrow indicates direction)
Water table
At angle to section line; out of page
At angle to section line; into page
Approx. parallel to section line
Out of page towards viewer
Into page away from viewer
Fault (normal; conceptual, not mapped)

Attachment 3

(8 pages including this page)

ALS laboratory report EM2220953 for surface and groundwater analyses

(Pages 3, 4 and 5 of the ALS report are purposely omitted. They relate to soil samples tested for acid sulphate potential and are described in a separate report.)

ALS Environmental

CERTIFICATE OF ANALYSIS

Work Order	: **EM2220593**	Page	: 1 of 11
Client	: **WILLIAM C CROMER PTY LTD**	Laboratory	: Environmental Division Melbourne
Contact	: MR BILL CROMER	Contact	: Shirley LeCornu
Address	: 74A CHANNEL HIGHWAY TAROONA TASMANIA 7053	Address	: 4 Westall Rd Springvale VIC Australia 3171
Telephone	: 03 6227 8970	Telephone	: +6138549 9630
Project	: ARK ENERGY	Date Samples Received	: 19-Oct-2022 12:10
Order number	: ARK ENERGY 01 OCT 2022	Date Analysis Commenced	: 20-Oct-2022
C-O-C number	: ----	Issue Date	: 31-Oct-2022 17:54
Sampler	: W.CROMER		
Site	: ----		
Quote number	: EN/222		
No. of samples received	: 22		
No. of samples analysed	: 22		

Accreditation No. 825
Accredited for compliance with ISO/IEC 17025 - Testing

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted, unless the sampling was conducted by ALS. This document shall not be reproduced, except in full.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits

Additional information pertinent to this report will be found in the following separate attachments: Quality Control Report, QA/QC Compliance Assessment to assist with Quality Review and Sample Receipt Notification.

Signatories

This document has been electronically signed by the authorized signatories below. Electronic signing is carried out in compliance with procedures specified in 21 CFR Part 11.

Signatories	*Position*	*Accreditation Category*
Arenie Vijayaratnam	Senior Inorganic Chemist	Melbourne Inorganics, Springvale, VIC
Ben Felgendrejeris	Senior Acid Sulfate Soil Chemist	Brisbane Acid Sulphate Soils, Stafford, QLD
Dilani Fernando	Laboratory Coordinator	Melbourne Inorganics, Springvale, VIC
Xing Lin	Senior Organic Chemist	Melbourne Organics, Springvale, VIC

RIGHT SOLUTIONS | RIGHT PARTNER

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Work Order	: EM2220593
Client	: WILLIAM C CROMER PTY LTD
Project	: ARK ENERGY

General Comments

The analytical procedures used by ALS have been developed from established internationally recognised procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are fully validated and are often at the client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contract for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
ø = ALS is not NATA accredited for these tests.
~ = Indicates an estimated value.

- EP080: Where reported, Total Xylenes is the sum of the reported concentrations of m&p-Xylene and o-Xylene at or above the LOR.
- As per QWI – EN55-3 Data Interpreting Procedures, Ionic balances are typically calculated using Major Anions - Chloride, Alkalinity and Sulfate; and Major Cations - Calcium, Magnesium, Potassium and Sodium. Where applicable and dependent upon sample matrix, the Ionic Balance may also include the additional contribution of Ammonia, Dissolved Metals by ICPMS and H+ to the Cations and Nitrate, SiO_2 and Fluoride to the Anions.
- ED093F : EM2220593 #6 results for dissolved cations have been confirmed by re-preparation and re-analysis.
- EA015H: EM2220593 #1,#4,#6:TDS by method EA-015 may bias high due to the presence of fine particulate matter, which may pass through the prescribed GF/C paper.
- ASS: EA033 (CRS Suite): ANC not required because pH KCl less than 6.5
- Ionic balances were calculated using: major anions - chloride, alkalinity and sulfate; and major cations - calcium, magnesium, potassium and sodium.
- Ionic balances were calculated using: major anions - chloride, alkalinity, sulfate and NO_x; and major cations - calcium, magnesium, potassium and sodium for sample #6.
- ED045G: The presence of Thiocyanate, Thiosulfate and Sulfite can positively contribute to the chloride result, thereby may bias results higher than expected. Results should be scrutinised accordingly.
- ASS: EA033 (CRS Suite): Liming rate is calculated and reported on a dry weight basis assuming use of fine agricultural lime ($CaCO_3$) and using a safety factor of 1.5 to allow for non-homogeneous mixing and poor reactivity of lime. For conversion of Liming Rate from 'kg/t dry weight' to 'kg/m3 in-situ soil', multiply 'reported results' x 'wet bulk density of soil in t/m3'.
- ASS: EA003 (NATA Field and F(ox) screening): pH F(ox) Reaction Rate: 1 - Slight; 2 - Moderate; 3 - Strong; 4 - Extreme
- Sodium Adsorption Ratio (where reported): Where results for Na, Ca or Mg are <LOR, a concentration at half the reported LOR is incorporated into the SAR calculation. This represents a conservative approach for Na relative to the assumption that <LOR = zero concentration and a conservative approach for Ca & Mg relative to the assumption that <LOR is equivalent to the LOR concentration.

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Work Order : EM2220593
Client : WILLIAM C CROMER PTY LTD
Project : ARK ENERGY

Analytical Results

Sub-Matrix: WATER
(Matrix: WATER)

Compound	CAS Number	LOR	Unit	SW1	SW2	SW3	SW4	BORE 17918
			Sampling date / time	17-Oct-2022 11:00	17-Oct-2022 09:15	17-Oct-2022 09:45	17-Oct-2022 09:00	17-Oct-2022 14:32
				EM2220593-001	EM2220593-002	EM2220593-003	EM2220593-004	EM2220593-005
				Result	Result	Result	Result	Result
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	6.52	6.44	7.00	6.47	7.25
EA015: Total Dissolved Solids dried at 180 ± 5 °C								
Total Dissolved Solids @180°C	----	10	mg/L	122	65	62	47	171
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	<1	<1	<1
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	7	6	13	16	90
Total Alkalinity as CaCO3	----	1	mg/L	7	6	13	16	90
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	3	5	1	2	2
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	6	6	5	7	8
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	4	3	3	3	21
Magnesium	7439-95-4	1	mg/L	1	1	1	2	10
Sodium	7440-23-5	1	mg/L	4	4	3	4	10
Potassium	7440-09-7	1	mg/L	<1	<1	<1	<1	<1
ED093F: SAR and Hardness Calculations								
^ Sodium Adsorption Ratio	----	0.01	-	0.46	0.51	0.38	0.44	0.45
EG020T: Total Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	0.46	0.72	1.25	0.34	<0.01
Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Boron	7440-42-8	0.05	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05
Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Uranium	7440-61-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	0.002
Copper	7440-50-8	0.001	mg/L	0.003	0.001	0.005	<0.001	<0.001
Lithium	7439-93-2	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Manganese	7439-96-5	0.001	mg/L	0.012	0.011	0.016	0.001	<0.001
Molybdenum	7439-98-7	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	7440-02-0	0.001	mg/L	<0.001	<0.001	0.002	<0.001	<0.001
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001

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Work Order : EM2220593
Client : WILLIAM C CROMER PTY LTD
Project : ARK ENERGY

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	SW1	SW2	SW3	SW4	BORE 17918
			Sampling date / time	17-Oct-2022 11:00	17-Oct-2022 09:15	17-Oct-2022 09:45	17-Oct-2022 09:00	17-Oct-2022 14:32
Compound	CAS Number	LOR	Unit	EM2220593-001	EM2220593-002	EM2220593-003	EM2220593-004	EM2220593-005
				Result	Result	Result	Result	Result
EG020T: Total Metals by ICP-MS - Continued								
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	7440-66-6	0.005	mg/L	0.021	<0.005	0.010	<0.005	0.010
Iron	7439-89-6	0.05	mg/L	0.34	0.46	0.68	0.20	<0.05
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N	14797-65-0	0.01	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N	14797-55-8	0.01	mg/L	4.57	<0.01	0.94	<0.01	7.23
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	4.57	<0.01	0.94	<0.01	7.23
EN055: Ionic Balance								
ø Total Anions	----	0.01	meq/L	0.37	0.39	0.42	0.56	2.06
ø Total Cations	----	0.01	meq/L	0.46	0.40	0.36	0.49	2.30

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	BORE 41389	QA/QC 1 (Field Blank)	QA/QC 2 (Trip Blank)	----	----
			Sampling date / time	17-Oct-2022 10:12	17-Oct-2022 00:00	17-Oct-2022 00:00	----	----
Compound	CAS Number	LOR	Unit	EM2220593-006	EM2220593-007	EM2220593-008	-------	-------
				Result	Result	Result	----	----
EA005P: pH by PC Titrator								
pH Value	----	0.01	pH Unit	6.38	7.66	----	----	----
EA015: Total Dissolved Solids dried at 180 ± 5 °C								
Total Dissolved Solids @180°C	----	10	mg/L	181	<10	----	----	----
ED037P: Alkalinity by PC Titrator								
Hydroxide Alkalinity as CaCO3	DMO-210-001	1	mg/L	<1	<1	----	----	----
Carbonate Alkalinity as CaCO3	3812-32-6	1	mg/L	<1	<1	----	----	----
Bicarbonate Alkalinity as CaCO3	71-52-3	1	mg/L	31	4	----	----	----
Total Alkalinity as CaCO3	----	1	mg/L	31	4	----	----	----
ED041G: Sulfate (Turbidimetric) as SO4 2- by DA								
Sulfate as SO4 - Turbidimetric	14808-79-8	1	mg/L	2	<1	----	----	----
ED045G: Chloride by Discrete Analyser								
Chloride	16887-00-6	1	mg/L	10	<1	----	----	----
ED093F: Dissolved Major Cations								
Calcium	7440-70-2	1	mg/L	21	<1	----	----	----
Magnesium	7439-95-4	1	mg/L	6	<1	----	----	----
Sodium	7440-23-5	1	mg/L	8	<1	----	----	----
Potassium	7440-09-7	1	mg/L	<1	<1	----	----	----
ED093F: SAR and Hardness Calculations								
^ Sodium Adsorption Ratio	----	0.01	-	0.40	0.12	----	----	----
EG020T: Total Metals by ICP-MS								
Aluminium	7429-90-5	0.01	mg/L	0.16	<0.01	----	----	----
Arsenic	7440-38-2	0.001	mg/L	<0.001	<0.001	----	----	----
Boron	7440-42-8	0.05	mg/L	<0.05	<0.05	----	----	----
Beryllium	7440-41-7	0.001	mg/L	<0.001	<0.001	----	----	----
Cadmium	7440-43-9	0.0001	mg/L	<0.0001	<0.0001	----	----	----
Cobalt	7440-48-4	0.001	mg/L	<0.001	<0.001	----	----	----
Uranium	7440-61-1	0.001	mg/L	<0.001	<0.001	----	----	----
Chromium	7440-47-3	0.001	mg/L	<0.001	<0.001	----	----	----
Copper	7440-50-8	0.001	mg/L	0.003	<0.001	----	----	----
Lithium	7439-93-2	0.001	mg/L	<0.001	<0.001	----	----	----
Manganese	7439-96-5	0.001	mg/L	0.004	<0.001	----	----	----
Molybdenum	7439-98-7	0.001	mg/L	<0.001	<0.001	----	----	----
Nickel	7440-02-0	0.001	mg/L	0.001	<0.001	----	----	----
Lead	7439-92-1	0.001	mg/L	<0.001	<0.001	----	----	----

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Work Order : EM2220593
Client : WILLIAM C CROMER PTY LTD
Project : ARK ENERGY

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	BORE 41389	QA/QC 1 (Field Blank)	QA/QC 2 (Trip Blank)	----	----
			Sampling date / time	17-Oct-2022 10:12	17-Oct-2022 00:00	17-Oct-2022 00:00	----	----
Compound	CAS Number	LOR	Unit	EM2220593-006	EM2220593-007	EM2220593-008	-------	-------
				Result	Result	Result	----	----
EG020T: Total Metals by ICP-MS - Continued								
Selenium	7782-49-2	0.01	mg/L	<0.01	<0.01	----	----	----
Vanadium	7440-62-2	0.01	mg/L	<0.01	<0.01	----	----	----
Zinc	7440-66-6	0.005	mg/L	**0.012**	<0.005	----	----	----
Iron	7439-89-6	0.05	mg/L	**0.13**	<0.05	----	----	----
EG035T: Total Recoverable Mercury by FIMS								
Mercury	7439-97-6	0.0001	mg/L	<0.0001	<0.0001	----	----	----
EK040P: Fluoride by PC Titrator								
Fluoride	16984-48-8	0.1	mg/L	<0.1	<0.1	----	----	----
EK057G: Nitrite as N by Discrete Analyser								
Nitrite as N	14797-65-0	0.01	mg/L	<0.01	<0.01	----	----	----
EK058G: Nitrate as N by Discrete Analyser								
Nitrate as N	14797-55-8	0.01	mg/L	**16.2**	<0.01	----	----	----
EK059G: Nitrite plus Nitrate as N (NOx) by Discrete Analyser								
Nitrite + Nitrate as N	----	0.01	mg/L	**16.2**	<0.01	----	----	----
EN055: Ionic Balance								
ø Total Anions	----	0.01	meq/L	**2.10**	----	----	----	----
ø Total Anions	----	0.01	meq/L	----	**0.08**	----	----	----
ø Total Cations	----	0.01	meq/L	**1.89**	<0.01	----	----	----
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	----	20	µg/L	----	----	<20	----	----
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	20	µg/L	----	----	<20	----	----
^ C6 - C10 Fraction minus BTEX (F1)	C6_C10-BTEX	20	µg/L	----	----	<20	----	----
EP080: BTEXN								
Benzene	71-43-2	1	µg/L	----	----	<1	----	----
Toluene	108-88-3	2	µg/L	----	----	<2	----	----
Ethylbenzene	100-41-4	2	µg/L	----	----	<2	----	----
meta- & para-Xylene	108-38-3 106-42-3	2	µg/L	----	----	<2	----	----
ortho-Xylene	95-47-6	2	µg/L	----	----	<2	----	----
^ Total Xylenes	----	2	µg/L	----	----	<2	----	----
^ Sum of BTEX	----	1	µg/L	----	----	<1	----	----
Naphthalene	91-20-3	5	µg/L	----	----	<5	----	----
EP080S: TPH(V)/BTEX Surrogates								

Analytical Results

Sub-Matrix: WATER (Matrix: WATER)			Sample ID	BORE 41389	QA/QC 1 (Field Blank)	QA/QC 2 (Trip Blank)	----	----
			Sampling date / time	17-Oct-2022 10:12	17-Oct-2022 00:00	17-Oct-2022 00:00	----	----
Compound	CAS Number	LOR	Unit	EM2220593-006	EM2220593-007	EM2220593-008	-------	-------
				Result	Result	Result	----	----
EP080S: TPH(V)/BTEX Surrogates - Continued								
1.2-Dichloroethane-D4	17060-07-0	2	%	----	----	88.3	----	----
Toluene-D8	2037-26-5	2	%	----	----	101	----	----
4-Bromofluorobenzene	460-00-4	2	%	----	----	92.4	----	----