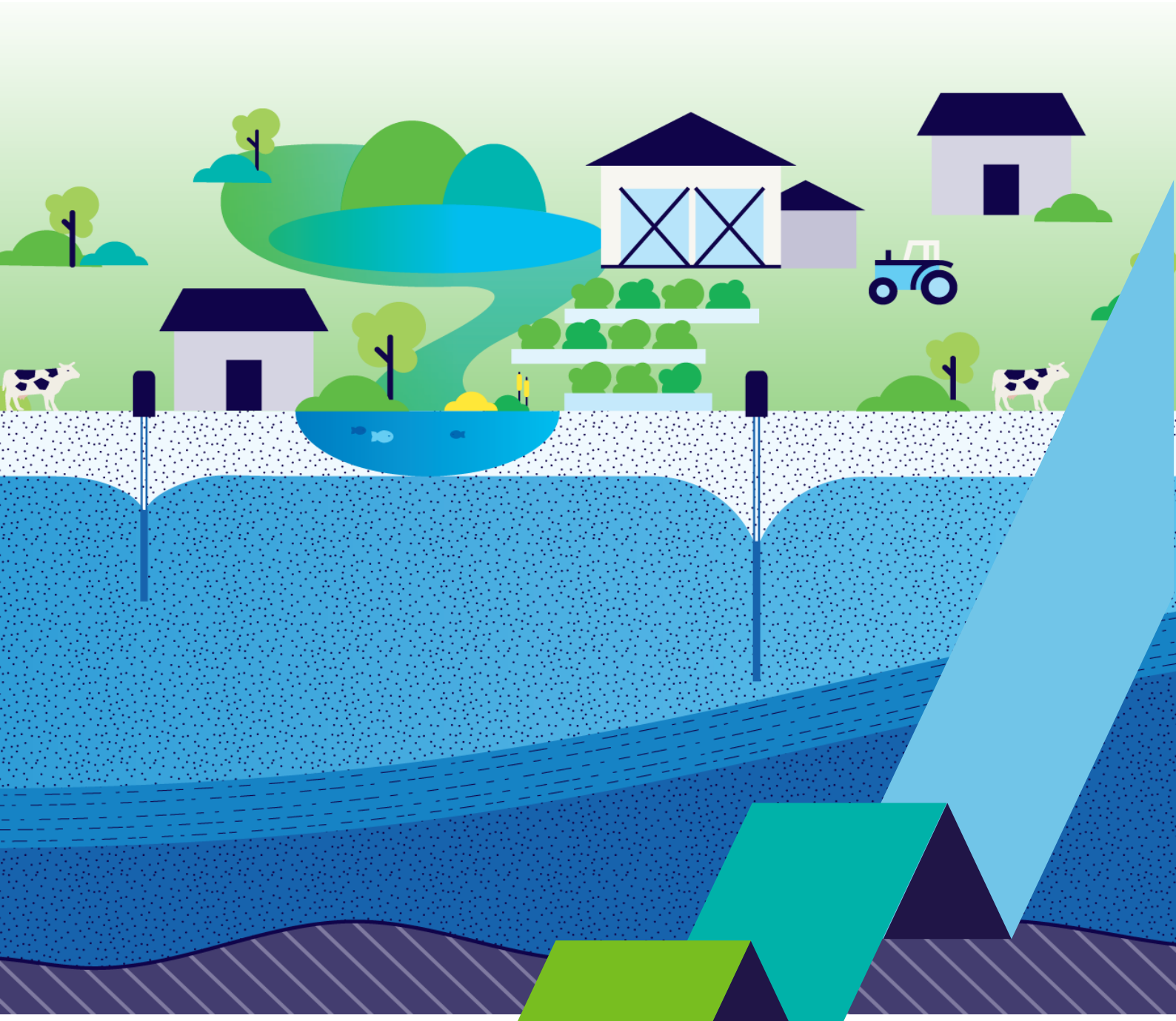
GROUNDWATER SUSTAINABLE YIELD ASSESSMENT: METHODOLOGY REPORT

Part 6 Sustainable Yield Synthesis paper – Confined Aquifers Mapping Approach (DEECA)



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A technical advisory panel provided specialist advice in the development of the assessment method. The panel comprised specialists from Deakin University (Prof. Wendy Timms), Jacobs (Dr Richard Evans) and HydroGeoLogic (Mr Hugh Middlemis).

The assessment was completed with contributions from external industry specialists, who developed the technical details of the methodology and carried out assessments of groundwater resources. These included Jacobs Pty Ltd, GHD Pty Ltd, CDM Smith Pty Ltd, HARC Pty Ltd and Monash University (Dr Tim Peterson).

Authors

Groundwater Assessment and Modelling team, Water Resources Strategy, Department of Energy, Environment and Climate Action. 8 Nicolson Street, East Melbourne 3002.

Editor

Scientel Pty Ltd, 8 Latrobe Street, Melbourne 3000

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it.

We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

DEECA is committed to genuinely partnering with Victorian Traditional Owners and Victoria's Aboriginal community to progress their aspirations.

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About this report

This report outlines the technical approach and methodology of the Sustainable Yield (SY) project. The Victorian Department of Energy, Environment, and Climate Action (DEECA) developed the methodology in partnership with:

- Contractors Jacobs, GHD Pty Ltd and CDM Smith, who were responsible for developing the technical aspects of the methodology and conducting assessments of groundwater resources.
- Representatives from Southern Rural Water Corporation, Goulburn-Murray Rural Water Corporation, Grampians Wimmera Mallee Rural Water Corporation, and the DEECA Environmental Waterways and Water Licensing Policy teams, who possessed extensive experience and expertise in water and groundwater resource management and policy, and offered advice on technical, management and policy aspects of the project.
- A technical review panel, consisting of 3 subject matter experts in groundwater assessment and modelling, who provided expert peer review of the methodologies.

The methodology was developed in stages so that assessments could be undertaken in parallel with the methodology refinement. This enabled DEECA to meet the project completion date of June 2024. The methodology is described and reported in 8 parts:

- Part 1: Methodology overview
- Part 2: Confined aquifers – throughflow method (report by (Jacobs, 2024))
- Part 3: Confined aquifers – drawdown-use method (report by (GHD Pty Ltd, 2024))
- Part 4: Unconfined aquifers – recharge estimation and drawdown-use methods (report by (CDM Smith, 2025))
- Part 5: Sustainable Yield synthesis paper – confined aquifers synthesis approach (DEECA)
- Part 6: Sustainable Yield synthesis paper – semi-confined aquifers mapping approach (DEECA) (this report)
- Part 7: Sustainable Yield synthesis paper – semi-confined aquifers synthesis approach (DEECA)
- Part 8: Sustainable Yield synthesis paper – Mapping, Boundaries, and Naming Conventions for Confined Aquifer UAs (DEECA)

Part 1, the methodology overview, provides context for the project by discussing its drivers, current resources and understanding, expected outcomes, objectives, outputs, scope, and principles for the proposed approach to the methodology.

Parts 2 to 8 of the methodology provide additional details of the methods. Parts 2 to 4 were developed and reported on by the contractors, and parts 5 to 8 were developed by DEECA.

This paper presents Part 6 of the Methodology Report.

1. Purpose

This paper discusses mapping semi-confined aquifers and the conditions that are necessary for mapping these aquifers. The basis of this paper is GHD's work in 2014 (GHD Pty Ltd, 2014) that assessed semi-confining behaviour across the state.

2. Background

DEECA undertook a statewide assessment of groundwater sustainable yield. There are some areas in Victoria where the aquifer of interest may be semi-confined. Mapping semi-confined aquifers is the first step in estimating the sustainable yield for these aquifers as the technical methods used in unconfined and confined aquifers may not be appropriate for these areas. The following sections explain how to map these aquifers across the State.

3. Approach for mapping semi-confined aquifers

3.1 Method to identify semi-confined aquifers

This paper is based on GHD's 2014 study (GHD Pty Ltd, 2014), which assessed semi-confining behaviour across the state. GHD (2014) study used hydrograph analysis at nested bore sites and statistical correlation of hydrographs to identify potential relationships between aquifers. A total of 589 nested bores were compared across the state, of which 99 bores showed similar trends and fluctuations. **Figure 1** shows the location of all bores assessed by GHD indicating the potential areas with semi-confined conditions across the state. Appendix 1 provides a tabular summary of the connected areas for each groundwater basin. The suite hydrographs for the interpreted aquifers in these areas are shown in Appendix 2.

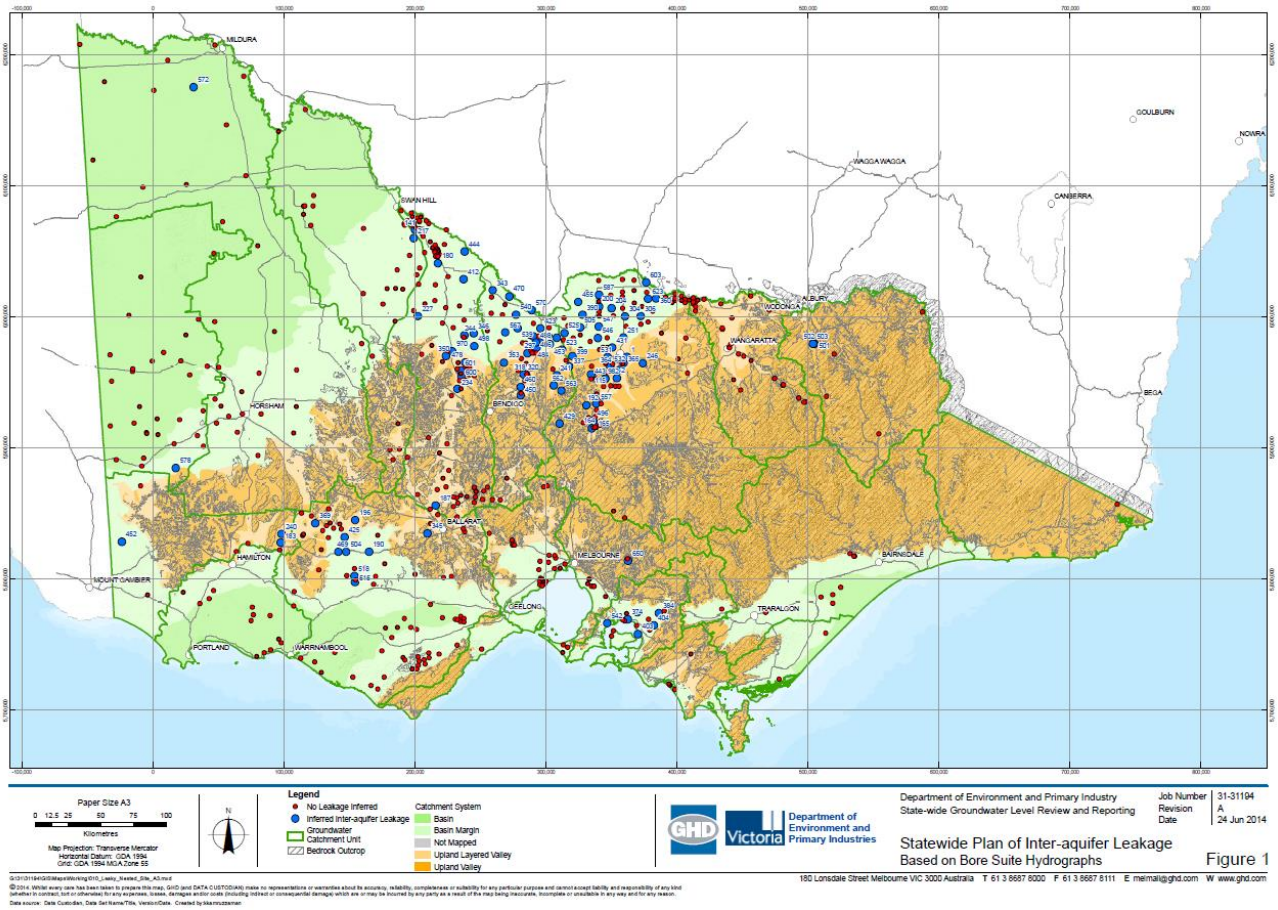

Figure 1. Statewide inter-aquifer leakage areas (GHD, 2014)

3.2 GIS procedure for mapping semi-confined aquifers

The following steps were taken in GIS for mapping semi-confined aquifers.

3.2.1 Plot bores with semi-confined behaviour identified by GHD

Figure 2 shows the distribution of the bores with semi-confined behaviour identified by GHD across the state.

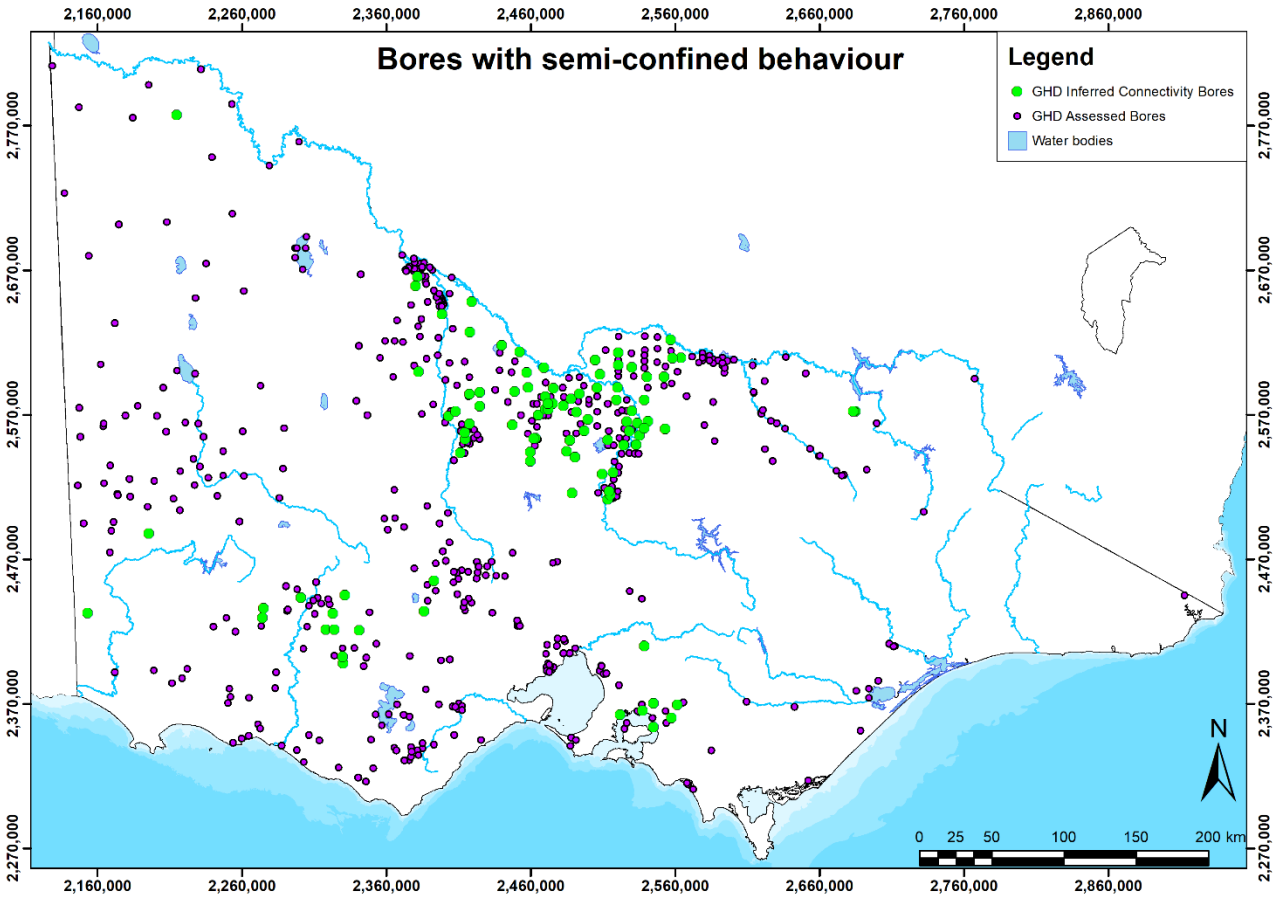

Figure 2. Statewide leaky bores identified by GHD (GHD, 2014)

Mapping semi-confined aquifers across the State

Most bores in semi-confined aquifers are located in the Murray Basin – Northeast, the upper Otway Basin, and areas around Western Port in the Central Basin. Most of these bores fall outside the extents of the Victorian Aquifer Framework (VAF) aquitard layers (**Table 1**), suggesting that other VAF layers likely function as semi-confining layers. In the northern part of the state, the UTQA is the most probable semi-confining layer, while in the upper Otway Basin, it is likely the UTB (DSE, 2012; GMW, 2014). However, in some regions with bores with semi-confined behaviour, no VAF layer has been identified as providing semi-confining properties. The following sections examine the areas where UTB and UTQA act as semi-confining layers, as well as regions with bores with semi-confined behaviour but lacking identified semi-confining layers.

Table 1. Statewide aquitard availability across the major sedimentary basins

Aquitard	Otway Basin	Central Coast Basin	Gippsland Basin	Murray Basin - NW	Murray Basin - NE
Upper Tertiary/Quaternary (UTQD)	Absent	Absent	UTQD	UTQD	Absent
Upper Tertiary (UTD)	Absent	Absent	UTD	UTD	Absent
Upper-Mid Tertiary (UMTD)	UMTD	UMTD	UMTD	UMTD	Absent
Lower-Mid Tertiary (LMTD)	LMTD	LMTD	LMTD	LMTD	Absent

Mapping of semi-confined bores based on UTB and UTQA VAF extent

The bores with semi-confined behaviour were mapped based on the UTB and UTQA VAF layers, resulting in the identification of potential semi-confining Groundwater Management Units (GMU) / Unincorporated Areas (UA) across the State based on these two VAF layers (**Figure 3**).

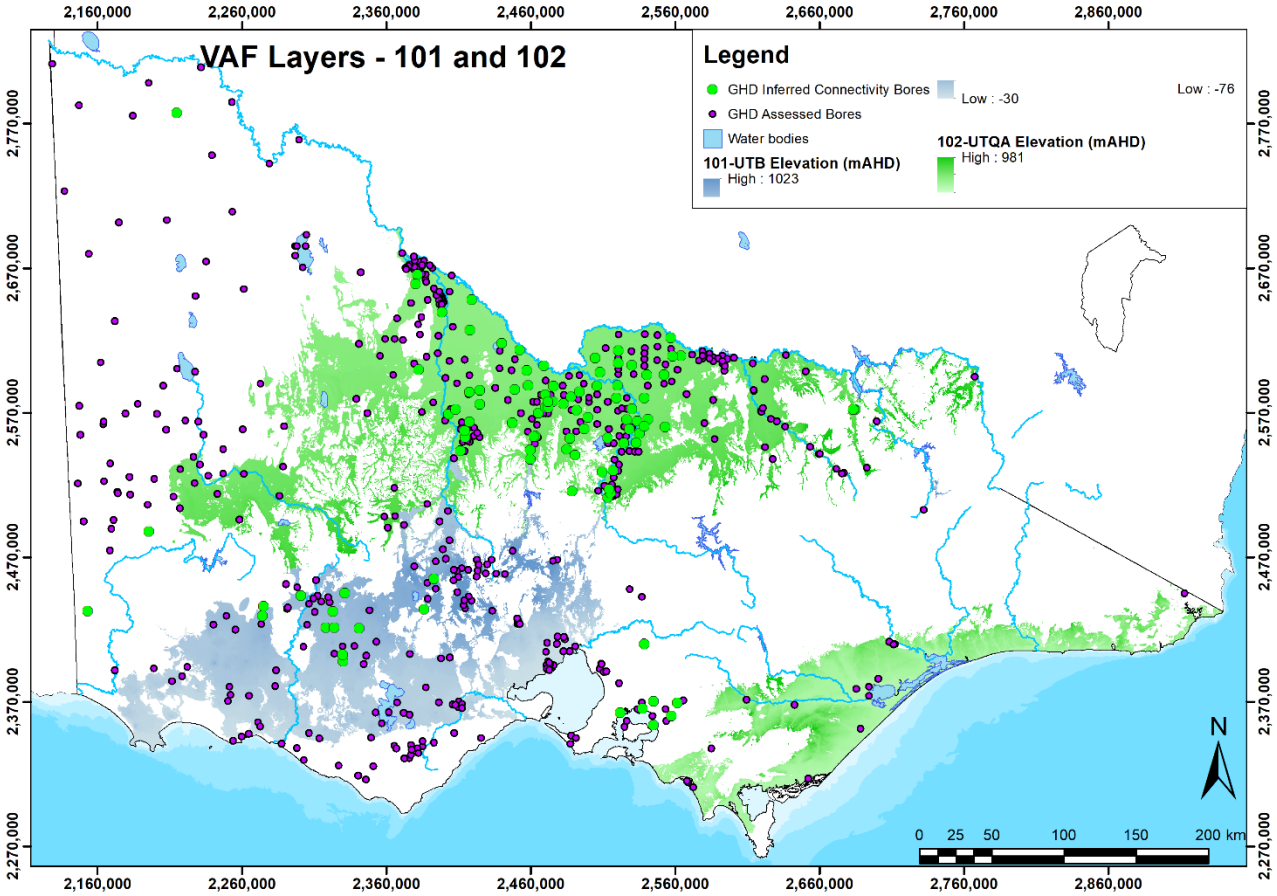

Figure 3. Mapping bores in semi-confined aquifers identified by GHD on UTB and UTQA VAF layers

The extent of the UTB and UTQA VAF layers was overlaid with the extent of the different VAF layers (Northeast: 105, Southwest: 104, 105, 107) to achieve the “extent of potential semi-confined layers” (**Figure 4**) (**Table 2**).

Table 2. Potential semi-confining layer

Aquifers	Potential semi-confining layers
105 (Northeast)	102 (UTQA)
104, 105, 107 (Southwest)	101 (UTB)

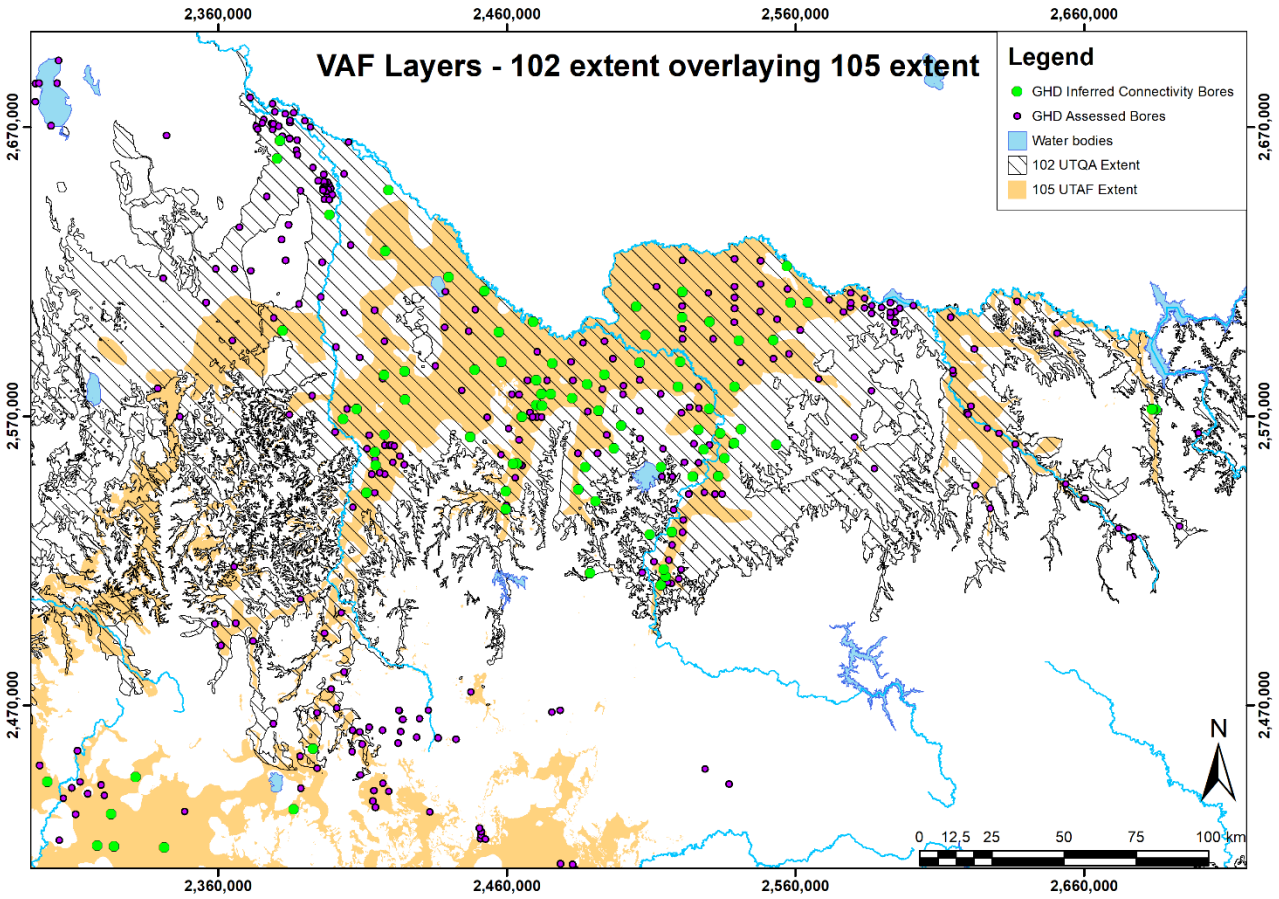

Figure 4. VAF layer 102 as a semi-confining layer overlaid on VAF layer 105

The "potentially semi-confined extent" layer was trimmed to demarcate what semi-confined areas are in GMUs and what are in UAs. In detail:

- Northeast (VAF layer 102)
  - VAF layer 105 is covered by Mid Loddon, Mid Goulburn 1070, Mid Goulburn 1071, West Goulburn, Lower Campaspe valley, Katunga, Lower Ovens, Kiewa and Broken GMUs.
- Southwest (VAF layer 101)
  - VAF layer 104 is partly covered by the Warrion GMA
  - VAF layer 105 is partly covered by Cardigan, Bungaree, Deutgam and Cut Paw Paw GMUs
  - VAF layer 107 is partly covered by the Heywood and Hawkesdale GMUs (South West Limestone does not apply since it has no PCV).
  - Portland and Condah GMUs don’t apply since their depth range does not include the relevant aquifers (104, 105, 107).
- Any remaining "potentially semi-confined extent" that is not covered by GMUs is referred to as "potentially semi-confined UAs".

Figure 5 shows semi-confined GMUs and UAs for the Northeast (VAF layer 102).

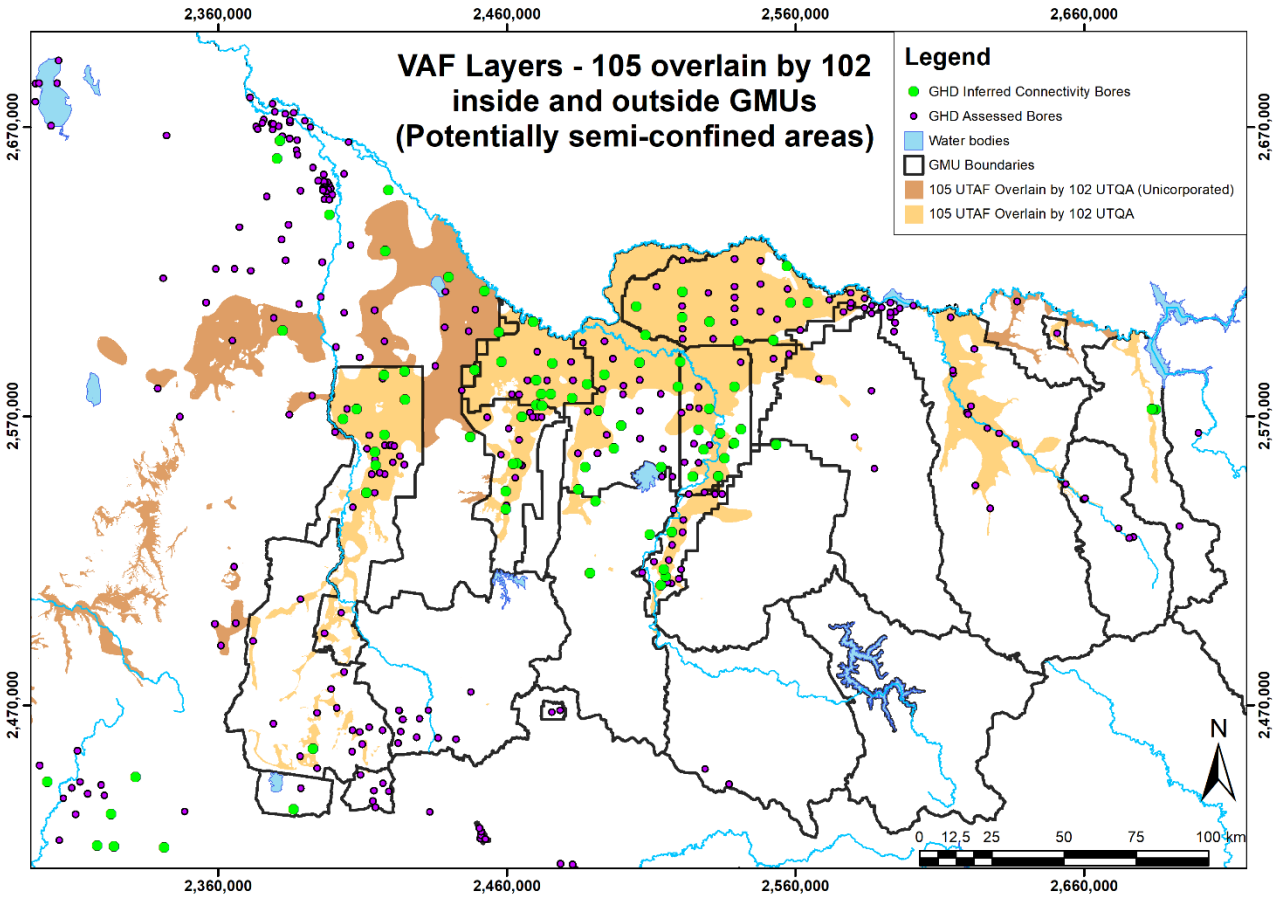

Figure 5. Semi-confined GMUs and UAs based on VAF layer 102

Mapping of semi-confined aquifer bores outside of the UTB and UTQA VAF extents

We also assessed whether the GHD bores exhibit semi-confined behaviour in areas beyond the extents of the UTB and UTQA VAFs. We found that there are a small number of bores to the northwest of the 105 VAF extent that exhibited semi-confined behaviour.

3.2.2 Semi-confined areas across the State

Areas where UTB and UTQA act as semi-confining layers

Figure 6 and **Figure 7** show the identified semi-confined aquifers on the GMU and UA scales in areas UTB and UTQA VAF extents. These GMUs/UAs met either of the following criteria: similar trends in bores with different fluctuations, or the presence of clay lenses in the bores within the GMU/UA. Following is a list of GMUs and UAs with semi-confined conditions:

- Northeast – GMU scale
  - Mid Loddon
  - Mid Goulburn 1070
  - Mid Goulburn 1071
  - West Goulburn North
  - Lower Campaspe Valley
  - Lower Oven
  - Broken
- Northeast – UA scale
  - North of Mid Loddon
  - Between Mid Loddon and Lower Campaspe Valley

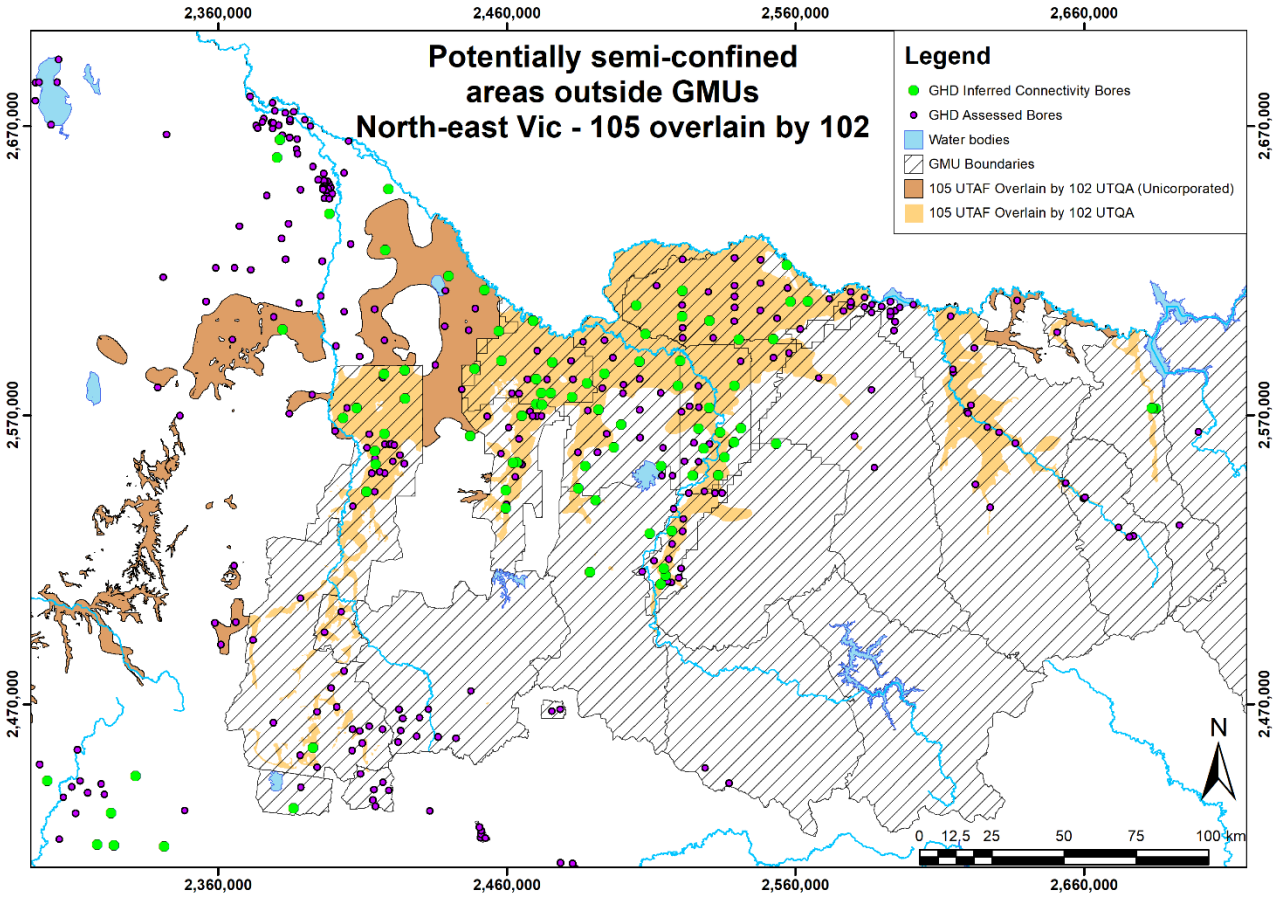

Figure 6. Semi-confined GMUs and UAs based on VAF layer 102 in Northeast

- Southwest – GMU scale
  - None
- Southwest – UA scale
  - Near Dunkeld
  - Around Westmere
  - North Port Philip

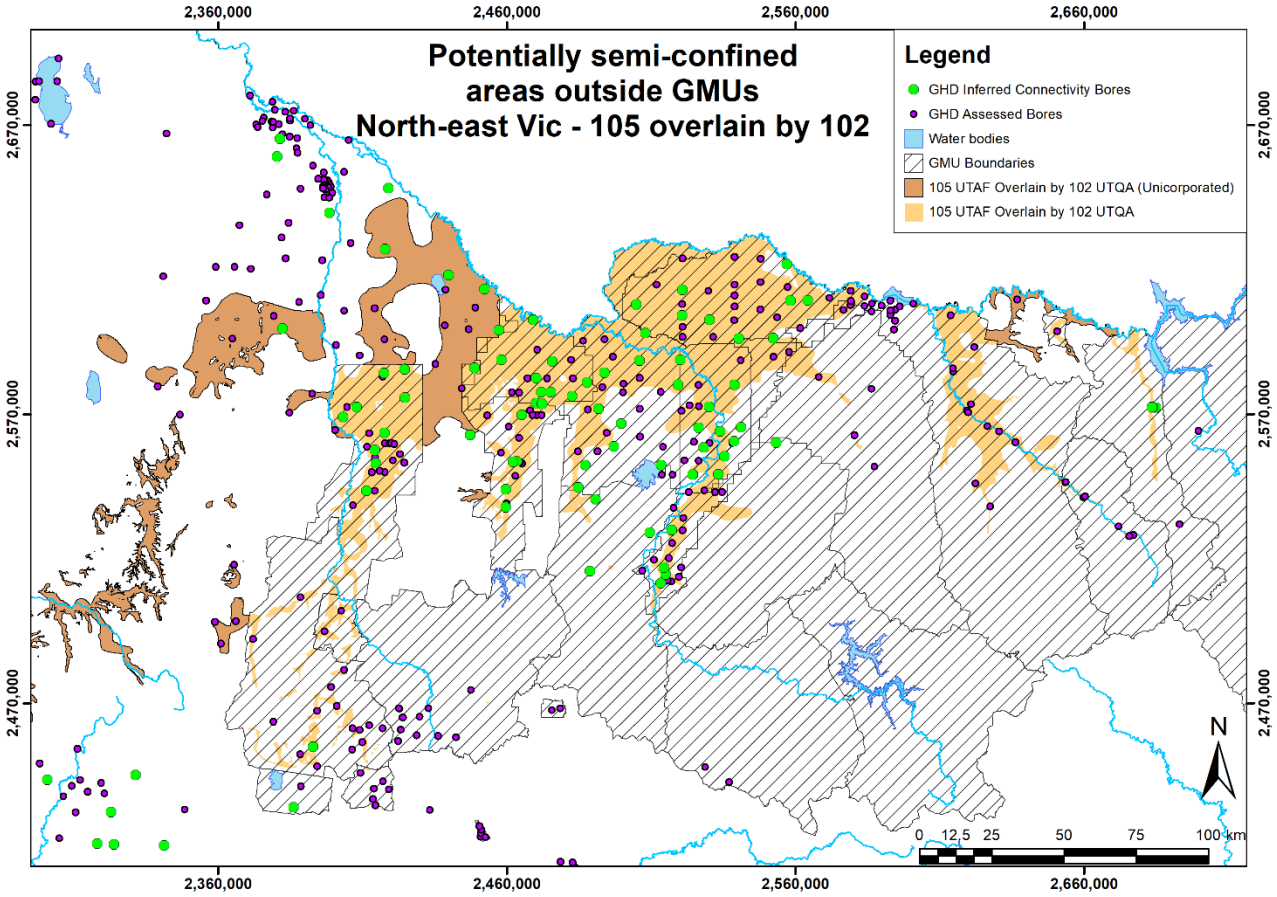

Figure 7. Semi-confined GMUs and UAs based on VAF layer 101 in Southwest

3.2.3 Semi-confined GMUs and UAs

The target VAF and formations of all semi-confined GMUs and UAs are presented in the **Table 3** and **Table 4**.

Table 3. Semi-confined GMUs across the state

GMU	GMU depth range (m)	VAF layers	Target VAF and Formations
Mid Loddon	All formations below surface	Upper Layer (UL): QA, UTB, UTQA Middle Layer (ML): UTAF	UL: UTB (Newer Volcanics – highlands only), UTQA (Shepparton) ML: UTAF (Calivil)
Mid Goulburn 1070 (overlain by Shepparton I.R. GMA)	All formations from 25 metres below ground surface to 50 metres into bedrock or 200 metres from the surface (whichever is the greater depth)	UL: QA (Shepparton I.R. GMA), UTQA (Upper Shepparton - Shepparton I.R. GMA) UTQA (Lower Shepparton - Mid Goulburn 1070 GMA) ML: UTAF	UL: UTQA (Lower Shepperton) ML: UTAF (Calivil)
Mid Goulburn 1071	All formations from ground surface to 50 metres into bedrock or 200 metres from the surface (whichever is the greater depth)	UL: QA, UTQA ML: UTAF	UL: UTQA (Shepperton) ML: UTAF (Calivil)
West Goulburn North (overlain by Shepparton I.R. GMA)	All formations from 25 metres below ground surface	UL: QA (Shepparton I.R. GMA) UTQA (Upper Shepparton - Shepparton I.R. GMA) UTQA (Lower Shepparton - West Goulburn North GMA) ML: UTAF	UL: UTQA (Lower Shepperton) ML: UTAF (Calivil)
Lower Campaspe Valley	All formations below the surface with the exception of all formations from the surface to 25 metres below the surface north of the Waranga West Channel	UL: QA, UTB, UTQA ML: UTAF	UL: UTB (Newer Volcanics – highlands only), UTQA (Shepparton) ML: UTAF (Calivil)
Broken	All formations from ground surface to 50 metres into bedrock or 200 metres from the surface (whichever is the greater depth)	UL: QA, UTQA ML: UTAF	UL: UTQA (Shepparton) ML: UTAF (Calivil)

GMU	GMU depth range (m)	VAF layers	Target VAF and Formations
Lower Ovens	All formations from ground surface to 50 metres into bedrock or 200 metres from the surface (whichever is the greater depth)	UL: QA, UTQA ML: UTAF	UL: UTQA (Shepparton) ML: UTAF (Calivil)
Kiewa	All formations from ground surface to 50 metres into bedrock or 200 metres from the surface (whichever is the greater depth)	UL: QA, UTQA ML: UTAF	UL: UTQA (Shepparton) ML: UTAF (Calivil)

Table 4. Semi-confined UAs across the state

UA	UA depth range (m)	Available VAF layers	Target VAF and Formations
North of Mid Loddon (UTAF-NE2)	All formations below the surface	UP: QA, UTQA ML: UTAM, UTAF	UP: UTQA (Shepparton) ML: UTAM (Parilla Sand), UTAF (Calivil)
West of Mid Loddon (UTAF-NE1)	All formations below the surface	UP: QA, UTQA ML: UTAM, UTAF	UP: UTQA (Shepparton) ML: UTAM (Parilla Sand), UTAF (Calivil)
Northwest Port Philip (UTAF-PP1)	All formations below the surface	UL: QA, UTB ML: UTAF, UMTD	UL: UTB (Newer Volcanics) ML: UTAF (Brighton Group)

4. Limitations and gap analysis

Since this report is based on GHD's 2014 study, we acknowledge and account for any changes that may have occurred in the semi-confining status since then. Also, we acknowledge the gap analysis in the study at that time that some areas of the state lack sufficient bore data to identify the presence of semi-confined aquifers. Moreover, localised semi-confining conditions may occur where overlying aquitards thin or become more permeable, but these variations cannot be evaluated at a state-wide scale.

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