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# Guideline for estimating groundwater drawdown impacts under water plans

**Great Artesian Basin and Other Regional Aquifers, Condamine and Balonne and Border Rivers and Moonie water plans**

**WM/2026/7450**

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**Acknowledgement of Country**

The Department of Local Government, Water and Volunteers respectfully acknowledges the Traditional Custodians of Country. We recognise the ongoing spiritual and cultural connection Aboriginal Peoples and Torres Strait Islander Peoples have with land, water, sea and sky. We pay our deep respects to their Elders past and present, support future leaders and acknowledge First Nations People's right to self-determination.

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| | |
|---|---|
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# 1. Introduction

## 1.1 Why groundwater drawdown is a problem

Groundwater drawdown caused by pumping from a new water bore in an aquifer reduces the groundwater levels in an area around the bore (known as drawdown). This drawdown increases and expands away from the new bore as pumping from the bore continues. Drawdown also recovers when pumping stops, and the area impacted by the drawdown contracts back towards the bore.

Drawdown can reduce the flow of groundwater to springs and other Groundwater Dependent Ecosystems (GDEs) and can divert groundwater flow away from other existing water bores in the aquifer. This can potentially result in those existing bores having reduced discharges, meaning those bore owners might need to invest in additional pumping infrastructure to maintain their authorised groundwater extraction. They might need to lower their pumps, deepen their bore, or replace their pump with one that is capable of pumping from greater depth. In situations where drawdown is not managed, it can potentially remove access to groundwater completely, for some bore owners.

Groundwater drawdown impacts are generally a more significant issue in confined aquifers (such as the Great Artesian Basin (GAB) or deeper Border Rivers Alluvium) than in unconfined aquifers. They are also an issue in unconfined aquifers where there is potential for new bores to be drilled close to existing bores (such as in the Condamine Alluvium).

A feature of many groundwater management arrangements established in water plans, is to limit or prevent these types of drawdown problems, while also allowing for new bores in an aquifer. This is a key element of water trading in some aquifers.

## 1.2 Guideline purpose

This guideline explains the role of groundwater drawdown impact estimates in supporting the Great Artesian Basin and Other Aquifers (GABORA), and the Condamine and Balonne, and Border Rivers and Moonie water plans of the Queensland Murray Darling Basin (QMDB) (Figure 1). These water plans limit the amount of drawdown impact that some entitlement dealings, such as groundwater trades, can cause on other water bores or GDEs. The plans do this to provide water security to water users and to protect valuable ecosystems.

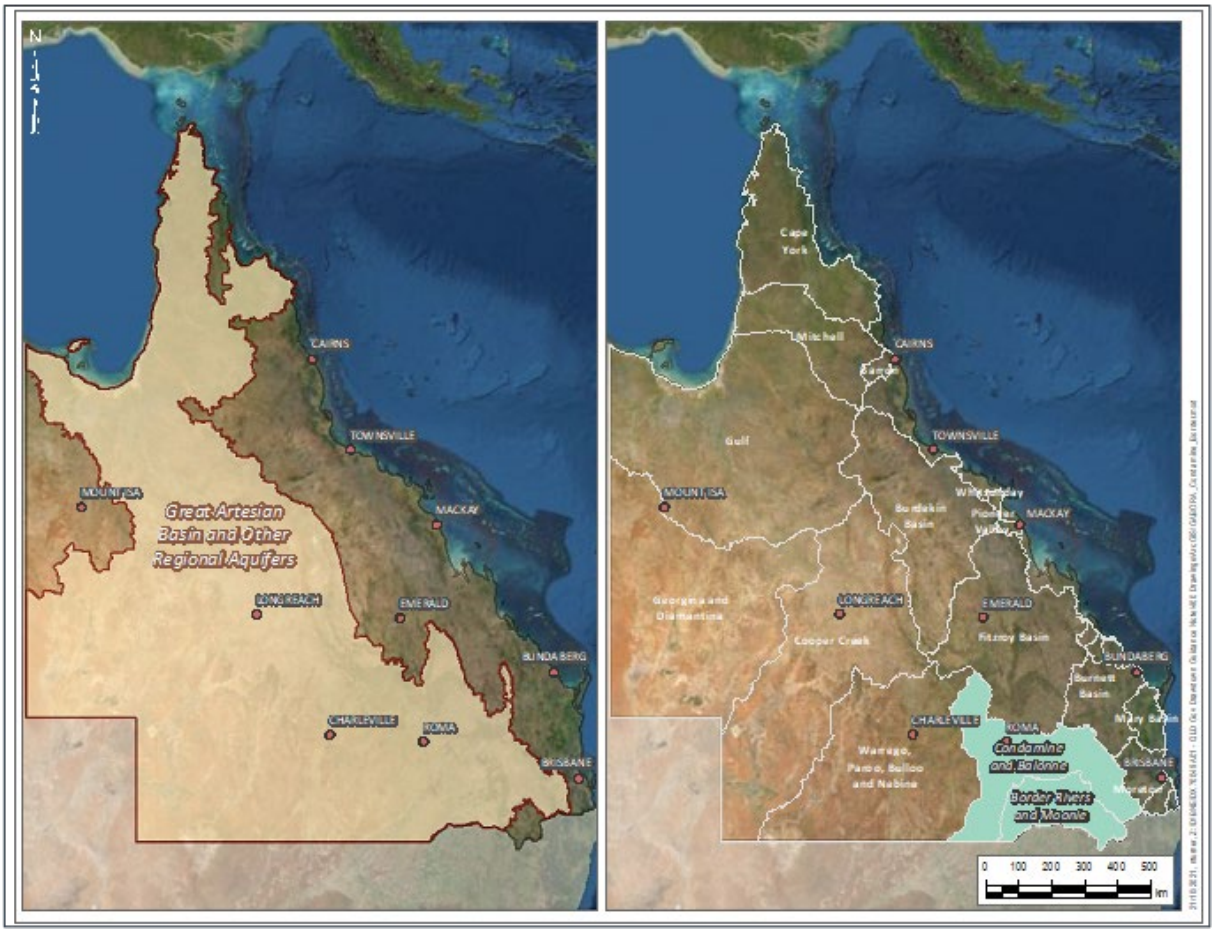
Groundwater drawdown impacts need to be estimated in support of potential water trades and some entitlement dealings that are made under these water plans, and these estimates need to be below defined limits before the dealings are allowed to occur.

This guideline is intended to assist all parties involved in potential water trades or entitlement dealings for the QMDB and GABORA water plans, by explaining why drawdown estimates are important, and the types of assessment needed to support applications for water trades or entitlement dealings.

This guideline explains and clarifies the processes used for estimating groundwater drawdown impacts under these water plans, when they are needed, who needs to apply them, how appropriate estimation methods should be chosen, and how the values for any relevant parameters needed for such methods should be established.

This is a guide only and does not replace the regulatory requirements of water plans and water management protocols. This guideline needs to be read in conjunction with these regulatory documents.

**Figure 1:** **Location of the GABORA (left) and QMDB (right) water plan areas**




## 1.3 Structure of this guideline

Section 2 describes how water plans and water management protocols work together to establish the water planning framework in Queensland. It also provides an overview of the type of drawdown impact estimates that need to be made for the QMDB and GABORA water plans.

Section 3 explains the methods available for estimating groundwater drawdown impacts, due to pumping from a water bore.

Section 4 explains the processes that the Department of Local Government, Water and Volunteers (the department) uses for estimating drawdown impacts for groundwater trades under the QMDB water plans.

Section 5 explains the processes that the department uses for estimating drawdown impacts in most situations for the GABORA water plan.

Section 6 explains an alternative assessment process that can be used by applicants for water licence dealings and trades under the GABORA water plan.

Section 7 summarises this guideline.

Appendix A explains some common terms used in water planning documents, such as entitlements, allocations, and licences.

Appendix B explains the Theis equation, which is used for estimating drawdown.

Appendix C explains how to access GABORA related data online.

Appendices D, E, and F explain the aquifer transmissivities that were used to develop the GABORA water management protocol default drawdown estimation methods (see section 5 of this guideline).

Appendix G contains a blank decision pathway (see section 6 of this guideline) for choosing an appropriate drawdown estimation method for alternative assessments under the GABORA water plan.

# 2. Queensland water plans and water management protocols

Water plans are developed under the *Water Act 2000* to sustainably manage and allocate water resources in Queensland. A water plan may apply to:

- rivers, lakes, and springs.
- overland flow.
- underground water.

Water plans are tailored for each plan area to balance the needs of water users (e.g., towns, agriculture, and other industries), and the environment. Bore set back rules are in place to protect groundwater supplies that support existing businesses, investment, and regional production, and urban and domestic water supplies. In some cases, rules also protect the flow of groundwater to important GDEs, such as the culturally valued GAB springs, that also provide a home for valued rare and threatened species.

Water plans are implemented through a range of documents, developed in consultation with water users. The table below explains the roles of water plans and water management protocols.

| | |
|---|---|
| **Water plans** | Water covered by the plan<br>Desired outcomes, measures and strategies for achieving the outcomes<br>Performance indicators<br>Amounts of water available for consumptive use and future use<br>Specifications of water management areas and trading zones<br>Criteria for deciding water licences |
| **Water management protocols** | Water dealing/trading rules<br>Water sharing rules for unsupplemented water<br>Seasonal water assignment rules<br>Any volumes of unallocated water reserved for particular purposes or stated locations |

Water management protocols implement important aspects of each of the water plans. Importantly, in terms of this guideline, they establish rules about the assessments that are needed to support water trades or other entitlement dealings.

Appendix A contains explanations of common terminology used in relation to water plans, water management protocols, water licences, and water allocations.

*Water Act 2000* documents relevant to this guideline are:

- For the GABORA Water Plan:
  - GABORA Water Plan 2017.
  - GABORA Water Management Protocol 2017 (Amended 2019), Revision 1.
- For the QMDB:
  - Border Rivers and Moonie Water Plan 2019.
  - Border Rivers and Moonie Water Management Protocol February 2019 (Amended March 2019), Revision 1.
  - Condamine and Balonne Water Plan 2019.
  - Condamine and Balonne Water Management Protocol 2019.

Part 1, section 3, of the GABORA Water Plan establishes its purpose as:

a. to define the availability of water in the plan area; and

b. to provide a framework for sustainably managing water and the taking of water in the plan area; and

c. to identify priorities and mechanisms for dealing with future water requirements; and

d. to provide a framework for reversing, if practicable, the degradation of groundwater-dependent ecosystems.

The purposes of the Condamine and Balonne and the Border Rivers and Moonie water plans are outlined in part 1, section 2 of those plans, as to:

a. define the availability of water to which the plans apply; and

b. provide a framework for sustainably managing water to which the plans apply; and

c. identify priorities and mechanisms for dealing with the future water requirements in the plan areas; and

d. provide a framework for managing water allocations; and

e. provide a framework for reversing, where practicable, the degradation of natural ecosystems caused by the taking of, or interference with, water to which the plans apply.

## 2.1 Groundwater trading – QMDB and GABORA

Groundwater trades can only occur under the QMDB and GABORA water plans if rules related to limiting drawdown impacts on other entitlement holders, and/or GDEs, are adhered to. In most cases the drawdown impact assessments for a water trade are done by the department, according to rules established in the relevant water plans and water management protocols. Sections 4 and 5 of this guideline explain the processes used by the department in making these drawdown impact estimates.

Water users wanting to trade groundwater under the GABORA water plan are also allowed to make their own drawdown impact estimates or engage a professional hydrogeologist to do so. Section 6 of this guideline explains the process that the GABORA water plan and the department require for such alternative assessments to occur.

## 2.2 GABORA unallocated groundwater

Before applying this guideline, applicants for entitlements from GABORA unallocated water reserves should consider the terms of release of the unallocated water (for example, the tender or auction conditions), and whether these terms of release allow for alternative methods of estimating drawdown– considering the location, the volumetric amount, the purpose, and any other relevant conditions that might apply.

In many releases of general reserve water, the department estimates drawdown for each bid made under the tender or auction, using the default process established in the water management protocol (see Section 5 of this guideline) and the applicant or bidder is not able to do such an assessment themselves.

In other releases, such as for state reserve water, the applicant may be requested by the department to do such an assessment. Section 6 of this guideline explains alternative assessments for the GABORA water plan.

## 2.3 Other licence dealings for GABORA

In the GABORA Water Plan, drawdown estimates are required for some licence dealings that are not related to either water trading or unallocated water. These can include:

New stock or domestic (S&D) water licences located within 5km of a GDE or within 300 metres of another water authorisation.

Water licence relocations that are unrelated to water trading. A water licence holder might want to relocate their entitlement, or part of their entitlement, to a different location. This can include situations where the entitlement is relocated to facilitate a make-good agreement with a resource tenure holder such as a coal seam gas (CSG) company.

Sections 5 and 6 of this guideline explain the assessments needed for the GABORA water plan.

## 2.4 Underground water impact reports and OGIA

Underground Water Impact Reports (UWIRs) provide estimates of impacts on groundwater from resource tenure operations such as CSG fields and coal mines. Although UWIRs are involved with predicting groundwater drawdown impacts, they serve a different purpose to water plans or water management protocols, so are irrelevant to water trades or water entitlement dealings.

Data sets created through the development of UWIRs, and model outputs (particularly from the Office of Groundwater Impact Assessment (OGIA) predictive modelling of the Surat CMA), may however be useful and applied when using alternative methods for estimating groundwater drawdown impacts under the GABORA Water Plan (see Section 6 of this guideline).

# 3. Drawdown impact estimation

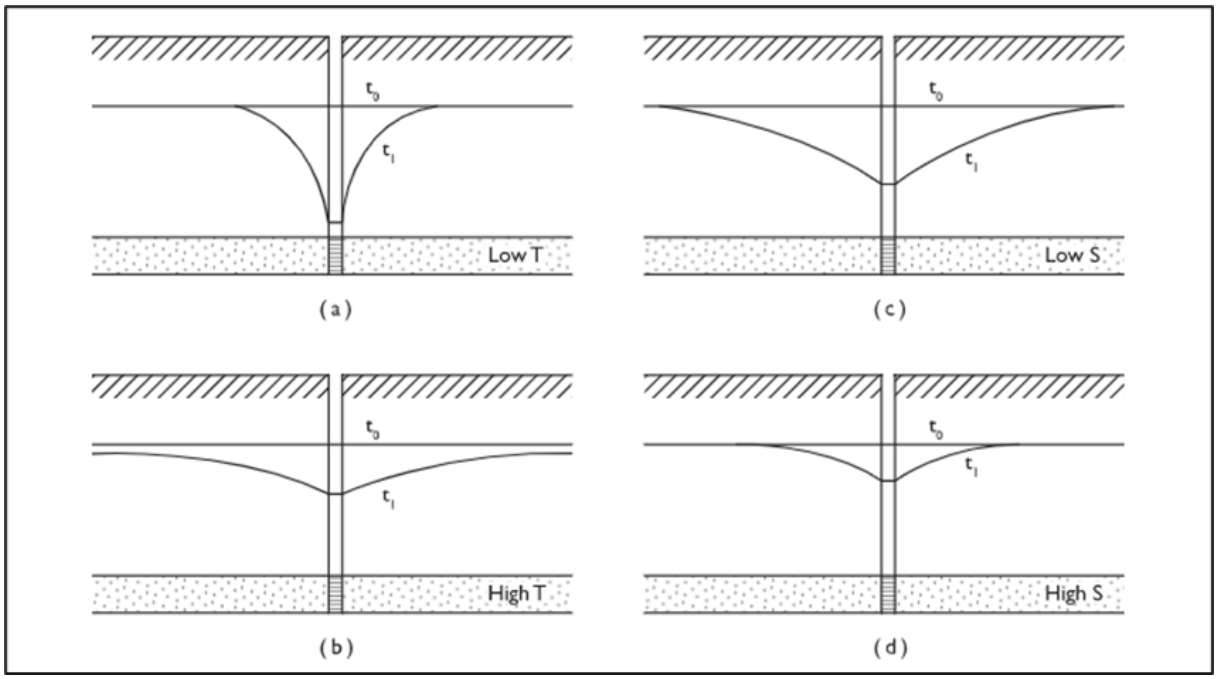
There are many techniques, of varying complexity, available for estimating groundwater drawdown and predicting impacts on other groundwater users, caused by pumping from a bore.

Analytical techniques often apply the Theis equation (see Appendix B for details), which uses parameter values related to the aquifer (transmissivity (T) and storativity (S)), the pumping rate (Q), and duration of proposed pumping (t), to calculate either drawdown (s) at a specified distance (r) from the pumping bore, drawdown at a certain time, or the time and distance at which a certain drawdown will be reached in an aquifer, as the drawdown effects propagate away from the pumping bore.

This approach is possible, and effective, because saturated groundwater flow is assumed to conform to the principle of non-equilibrium (or non-steady state) flow. Non equilibrium flow is the constant expansion of drawdown from a pumping bore at an ever-diminishing rate – and, for as long as there continues to be a measurable change in drawdown over time, the flow remains classed as non-equilibrium or non-steady (Hazel, 1973).

The concept of non-equilibrium flow and the effect of variations in the two aquifer attributes of transmissivity and storativity, are shown schematically in Figure 2. The higher the aquifer transmissivity (T), the more distant the drawdown effects extend, but the smaller they are. Storativity (S) is the volume of water released from storage in an aquifer during pumping, from a unit volume of the aquifer material (i.e., rock or sand or gravel). The higher the storativity, the lower the drawdown for a given pumping rate. Variability in these two aquifer attributes, and the pumping rate assigned, result in a near infinite range of drawdown possibilities.

**Figure 2:** **Comparison of drawdown cones at a given time for aquifers of (a) low transmissivity, (b) high transmissivity, (c) low storativity, and (d) high storativity (Freeze & Cherry, 1979)**




Typical values for storativity are usually between 0.01 and 0.3 in unconfined aquifers, and between 0.00005 and 0.005 in confined aquifers; a difference of 10 to 10,000 times. Hence, drawdown tends to be greater in confined aquifers than in unconfined. This also helps explain why drawdown impacts tend to be more significant in aquifers that are confined than in those that are unconfined.

As shown in Figure 2, the 'shape' of the drawdown cone around a pumping bore varies with the aquifer parameters of transmissivity and storativity. For a low transmissivity aquifer, the cone is 'deep and tight', and sites close to a pumping bore can have drawdown much higher than in aquifers with higher transmissivity. This can be significant when considering drawdown at existing nearby water bores. For a high transmissivity aquifer, the drawdown at the pumping bore can be very small, but it can extend a very significant distance away. This means that drawdown estimations at GDEs may need to cover much greater distances in high transmissivity aquifers than in low, because relatively small drawdowns at GDEs can have significant impacts.

The Theis equation is useful across a range of different aquifer types and is a standard tool for most hydrogeologists. While it was originally developed for use in confined aquifers only, its simplicity and ease of use have also made it a useful tool in most unconfined aquifers. Appendix B explains this aspect further.

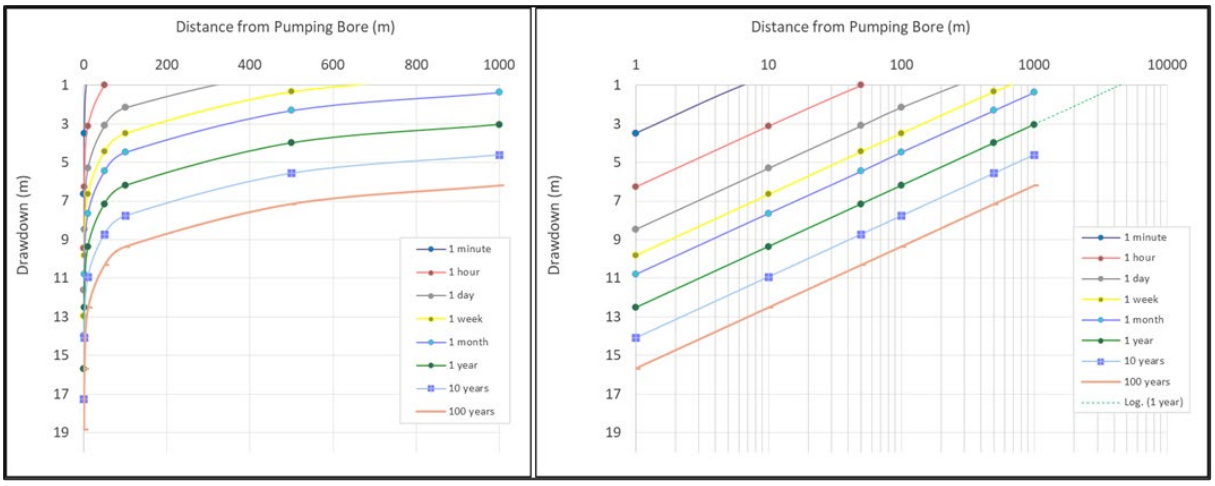
Figure 3 shows how drawdown varies and expands in an aquifer over time, with a constant pumping rate from a bore in an aquifer with uniform properties[1] and infinite extent (that is, no boundaries). The same Theis equation derived drawdowns are plotted in each figure: on the left, using a linear distance scale, and on the right, using a logarithmic distance scale. The plot on the left shows the physical shape of each of the predicted drawdown curves after different periods of pumping. The plot on the right shows the distance-drawdown relationship is a straight line when plotted on a logarithmic scale.

This linear relationship on a log scale was important before the advent of modern computers, as the extent of pumping impact and the size of the drawdown at any distance from the pumped bore, could be easily determined with simple mathematics or a graphical technique, provided the aquifer parameters of transmissivity and storativity were known. For example, with 1 year of pumping (the green line), impacts extend to a theoretical zero impact distance (shown as an extension of the green line) to ~4.0-4.5 km, in this case. Similarly, a bore which might be 1,000 metres from the pumping bore at the same time would be expected to show an impact of about 3 metres drawdown.

[1] Uniform aquifer transmissivity 100m$^2$/day, storativity 0.001, and a constant assigned pumping rate of 10L/s (~315ML/annum)

The relative simplicity of the Theis equation continues to be useful today when estimating drawdown, even when we have modern computers.

**Figure 3: Example time-distance-drawdown Theis predictions**




More complex methods of estimating drawdown have been developed since Theis developed his equation in 1935. Many are easily researched online. These newer methods incorporate additional parameters (such as the leakiness of overlying aquitards) or deal with additional aspects of aquifers that weren't dealt with by Theis (such as aquifer boundaries or non-uniform aquifer properties).

These more modern methods, including the use of groundwater flow models, account for aspects of a site's aquifer conditions that can be important for predicting drawdown, such as:

- the natural parameter variability within an aquifer
- the geometric uniqueness of the aquifer – its location, depth, and distribution
- the presence of other aquifers, aquitards, leaky aquitards, and structures such as faults – above and below
- the presence and location of boundary conditions – rivers, lakes, or aquifer edges
- the rate and location of groundwater movement, aquifer recharge and discharge
- the effects of other users, such as other pumping bores, or natural spring discharge
- time variations in all these properties and effects.

A complex numerical groundwater flow model is typically needed to evaluate all these influences. Large models can take months to construct and days to weeks to run. This is significant because most model projects need many model-runs to find a solution. Models are inherently complex, and this can introduce additional technical uncertainty around model predictions, which is sometimes difficult to adequately address.

With this increased complexity also comes an increase in the calculations that need to be made, and more possible sources of predictive uncertainty associated with drawdown estimates. Care is required in choosing appropriate methods, because a method will be more complex the more it attempts to incorporate the realities of a given aquifer situation. Appropriate methods need to be chosen that only incorporate the aspects of a site's aquifer conditions that are important for predicting drawdown – noting the intent is not to model every physical aspect of an aquifer, but to predict drawdown as effectively as possible. Any desire to model all aspects of an aquifer needs to be balanced against the need to minimise the sources of prediction uncertainty that come with added complexity.

But such complexity is not required in most cases, so simpler analytical techniques can frequently be applied, and this reduces the time taken to make predictions and can also increase prediction confidence. The simplest and often most appropriate method to estimate groundwater drawdown impacts caused by pumping, can often be the Theis equation. Most drawdown impact assessments

require drawdown to be estimated in an aquifer at a location distant from a bore that is pumping from that same aquifer. The Theis equation is fit-for-purpose for most of these assessments.

In situations where a method other than the Theis equation is being considered for use, that method, whether it be a numerical model or an analytical approach, needs to appropriately deal with the characteristics of the aquifer, the type of drawdown prediction being made, and the prediction uncertainty that inherently comes with increased complexity.

# 4. Estimating drawdown impacts under the QMDB water plans

The rules in the QMDB water plans (the Condamine and Balonne, and Border Rivers and Moonie) relate to protecting existing water entitlements from drawdown impacts due to groundwater trading.

Groundwater drawdown impact assessments have been used for this purpose in the Condamine, Oakey, and Dalrymple Creek alluviums for many years, since before the 2019 water plans. This was to facilitate water trading as well as water recovery by the Commonwealth Government in the Upper Condamine Alluvium.

These older arrangements were carried forward into the 2019 water plans, with some modifications for use with water allocations, and applied to the Border Rivers Alluvium, to comply with the groundwater trading rules of the Australian Government's Basin Plan 2012. Under section 12.24 of the Basin Plan, trading of groundwater is prohibited unless certain conditions can be demonstrated:

1. There is sufficient hydraulic connectivity between the two locations.
2. No resource condition limits specified in the relevant water resource plan will be exceeded (see Basin Plan sections 10.18-10.21). Resource condition limits are:
3. Limits beyond which the taking of groundwater will compromise environmental watering requirements.
4. Limits beyond which the taking of groundwater will compromise the discharge of groundwater into a surface water resource.
5. Limits beyond which the taking of groundwater will cause structural damage to an aquifer or disrupt the hydraulic relationships and properties within and between groundwater systems, and between groundwater and surface water systems.
6. Limits beyond which the taking of groundwater will result in an elevated level of salinity or another type of water quality degradation.
7. Water access rights in the two locations have substantially similar characteristics in terms of timing, reliability and volume, or measures are in place to ensure that the right to be traded maintains its characteristics.
8. Measures are in place to address third party impacts caused by the trade

The locations of existing entitlements are identified by their registered points of take, stated on a water entitlement, as a GPS coordinate from which water may be taken. For the Border Rivers alluvium, part of which is in New South Wales, the assessment also considers registered points of take in that jurisdiction.

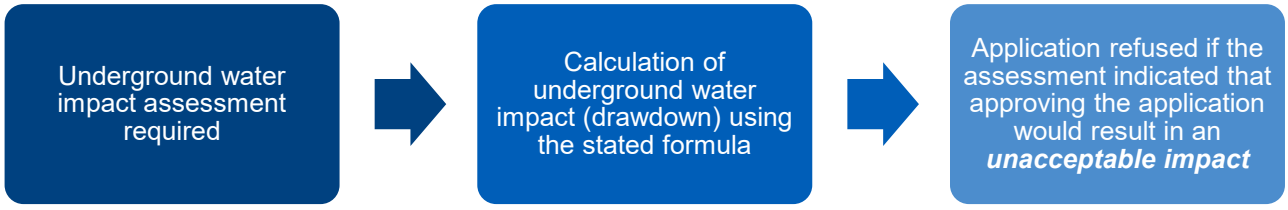
Drawdown impact assessments are not required for new bores used exclusively for taking water for stock or domestic purposes, or for replacement bores located within 10 metres of the bore being replaced. Stock or domestic bores and replaced water bores are also not considered to be points of take for impact assessments done for water trades,

The procedure for evaluating these impacts is prescriptive and specific. This makes groundwater trading simpler and more predictable.

If an assessment results in an unacceptable impact, the application must be refused.

The chief executive must refuse the application if the assessment indicates that approving the application would result in an **unacceptable impact.**

**Figure 4: QMDB water plans decision making and process flow**




In the following sections the Condamine and Balonne water plan is discussed separately from the Border Rivers and Moonie plan because there are some differences in the ways each plan deal with assessing drawdown impacts.

## 4.1 Condamine and Balonne water plan

The Condamine and Balonne Water Plan partitions the groundwater areas into sub-areas, which are divided further into specific units or zones as outlined in sections 10, 11, 12 and 13 of the Condamine and Balonne Water Plan. Specific trading zones are outlined in section 14 as per section 43(1)(e)(i) of the Act.

The water management protocol addresses groundwater drawdown in chapters 11 and 12 and underground water impact assessment in chapter 13. Chapter 13 establishes an analytical process to use for impact assessment calculation, with the parameter values that need to be used defined in section 228. The department applies this process for any relevant application it receives under this water plan.

This process applies the Theis equation with transmissivity defined for the Oakey Creek and Dalrymple Creek Alluvium sub-areas of 300m$^2$/day, and for the Central Condamine Alluvium and Cunningham Alluvium sub-areas of 500m$^2$/day. A storativity of 0.1 is also defined. Pumping duration is also considered: 365 days for town water supply entitlements, and 100 days for other entitlements.

Should a drawdown impact exceed acceptable impact limits, the application will be rejected (section 229):

If any of the potential drawdown impacts determined in section 228 are greater than **0.5 metres** at any registered point of take, other than the points currently stated on the entitlement being changed, the application would result in an **unacceptable impact.**

## 4.2 Border Rivers and Moonie water plan

The process in the Border Rivers and Moonie Water Plan is very similar to that in the Condamine and Balonne plan, with sections 12, 13, 14 and 15 partitioning groundwater areas into sub-areas with further division into specific units or zones. Section 16 of the water plan respectively outlines specific trading zones.

The water management protocol addresses groundwater drawdown in chapter 10 and underground water impact assessment in chapter 11. Chapter 11 establishes an analytical process to use for impact assessment calculation, with the parameter values that need to be used defined in section 167. The department applies this process for any relevant application it receives under this water plan

This process applies the Theis equation with transmissivity defined for the Border Rivers Alluvium (deep) of 200m$^2$/day. Pumping durations dependent on entitlement purposes are defined for each of ‘urban’ and ‘any’ purposes, and a storativity of 0.001 is defined. Pumping duration is also considered: 365 days for town water supply entitlements, and 180 days for other entitlements.

Should a drawdown impact exceed acceptable impact limits, the application will be rejected (section 168):

The application would result in an **unacceptable impact** if any of the potential drawdown impacts determined in section 167 are greater than either **10% of the available head in the aquifer or 3 metres**, at any registered point of take other than the point(s) currently stated on the entitlement being dealt with.

## 4.3 Calculating drawdown impacts

In the QMDB, underground water impact assessment is calculated using the Theis equation (see Appendix B for more detail) and both water plans (Border Rivers and Moonie, and Condamine and Balonne) set out specific parameter values to be used in this equation.

These parameters and the Theis equation are summarised below in Table 1.

**Table 1: Equation and parameters for calculating potential drawdown impact**

| Parameter/ Equation | Border Rivers and Moonie | Condamine and Balonne |
|---|---|---|
| Theis equation | $$s' = \frac{Q.W(u)}{4\pi T}$$ | |
| W(u) | Theis well function, as follows: $$W(u) = -0.577216 - In(u) + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} + \cdots$$ where: $u = \frac{r^2 S}{4Tt}$ | |
| s’ | Potential drawdown impact in metres | Potential drawdown impact in metres |
| Q | Pumping rate in $m^3$/day for the proposed water entitlement or seasonal water assignment which is determined as follows: $$Q = \frac{Vol^{ML} \times 1000}{t}$$ | Combined pumping rate in $m^3$/day for the proposed and current water entitlement/s or seasonal water assignment/s at a point of take which is determined as follows: $$Q = \frac{Vol^{ML} \times 1000}{t}$$ |
| $Vol^{ML}$ | Volume permitted to be taken in a year in megalitres for a proposed water entitlement or seasonal water assignment which is as follows:<br>for a water allocation with a purpose of ‘urban’ or ‘any’—‘volumetric limit’<br>• for a seasonal water assignment—‘maximum volume to be taken’ | Volume permitted to be taken in a year in megalitres as follows:<br>for a water licence—‘nominal entitlement’;<br>for a water allocation—‘volumetric limit’;<br>for a seasonal water assignment—‘maximum volume to be taken’. |
| T | Transmissivity for the Border Rivers Alluvium (deep) sub-unit in $m^2$/day. The transmissivity used is 200$m^2$/day | Transmissivity for the Upper Condamine Alluvium in $m^2$/day. The transmissivity used is as follows:<br>for Oakey Creek and Dalrymple Creek Alluvium sub-areas— 300$m^2$/day;<br>for Central Condamine Alluvium and Cunningham Alluvium subareas—500$m^2$/day. |
| r | Distance between the point of take proposed to be stated on the water entitlement or seasonal water assignment and the nearest registered point of take other than one already stated on the proposed water entitlement | Distance between the proposed registered point of take to be stated on the water entitlement or seasonal water assignment and the nearest registered point of take other than one already stated on the proposed water entitlement. |
| t | Pumping duration in days to be used for the assessment.<br>Pumping durations are as follows: | Pumping duration in days to be used for the assessment.<br>Pumping durations are as follows: |

| | | |
|---|---|---|
| | for entitlements of ‘urban’ purpose —365 days<br>for entitlements of ‘any’ purpose —180 days. | for entitlements of ‘urban’ purpose —365 days;<br>for entitlements with a purpose of ‘any’ or seasonal water assignments—100 days |
| S | Defined storativity for the aquifer of 0.001 | Defined storativity for the aquifer of 0.1 |

There is no opportunity under the QMDB water plans and water management protocols to use alternative techniques for calculating underground water impacts.

## 4.4 Example 1: Water trade in an unconfined aquifer of the Condamine & Balonne Water Plan

An underground water impact assessment is required to support an application to relocate a 300ML entitlement to a nearby property within an unconfined alluvial aquifer of the Condamine Alluvium.

This assessment applies the Theis equation.

The aquifer parameters to be used are those defined in the Water Management Protocol (see section 4.1 of this guideline); transmissivity is 500$m^2$/day, and the storativity is 0.1. The entitlement being traded is 300ML, and the pumping duration to use is 100 days, as it is not a town water supply entitlement. As such, the pumping rate (Q) is (300 x 1,000) / 100 = 3,000$m^3$/day. Using the Theis equation, the drawdown limit of 0.5 metres is exceeded at any registered point of take located within 706 metres of the proposed new entitlement location (see Figure 5). Hence the trade can only comply with the water management protocol rules if there are no registered points of take within 706 metres of the proposed new entitlement location.

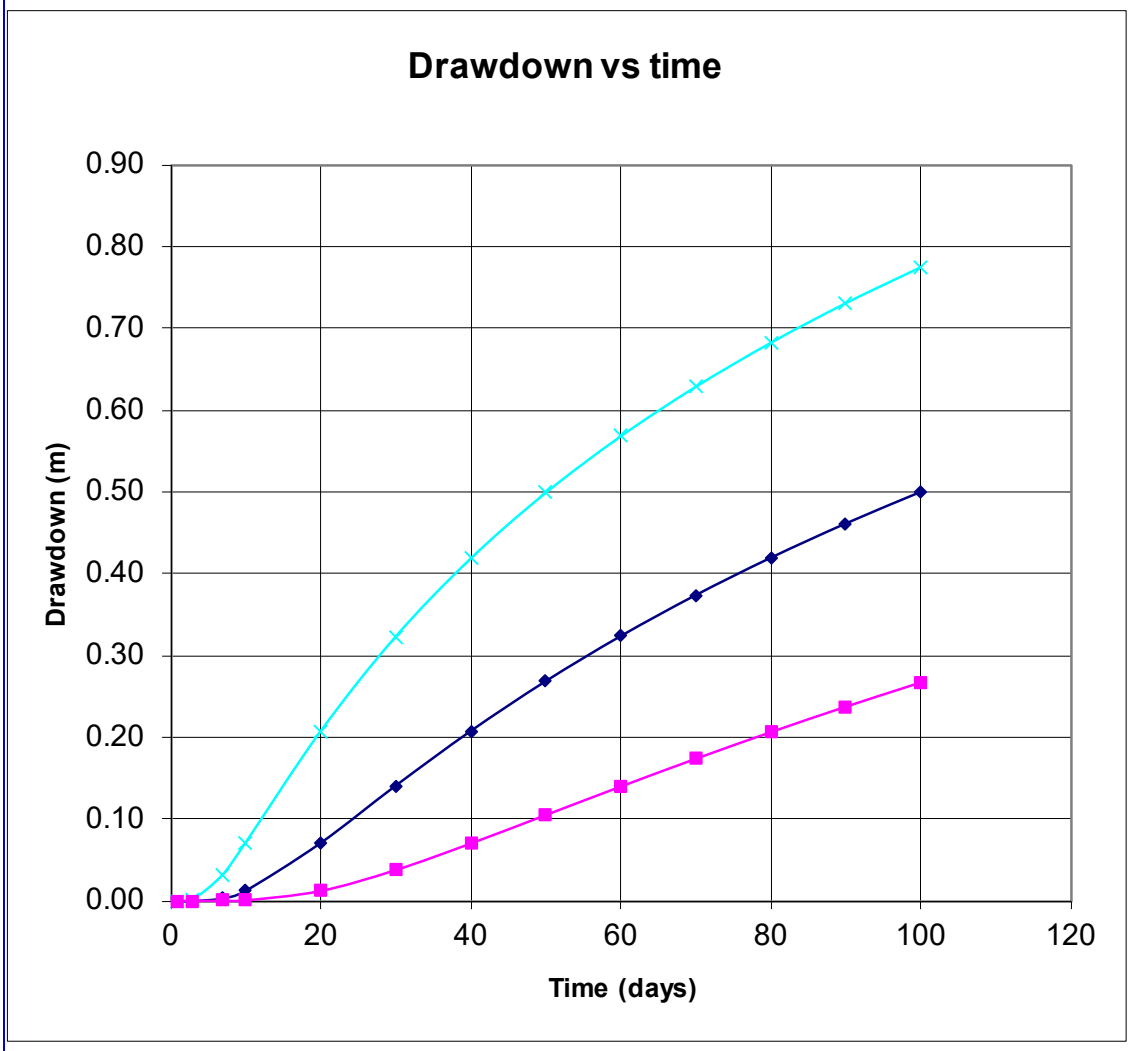
Figure 5 also shows the drawdown curves at distances of 500 metres and 1.0 km from the pumped bore.

Figure 5: Theis equation calculation for the Condamine Alluvium (using the tool developed by Dr Bruce Hunt published by the University of Canterbury and available online at Environment Canterbury Regional Council)

## Time-drawdown calculations using Theis equation

| Aquifer parameters | | |
|---|---|---|
| T | 500 | m2/d |
| S | 0.1 | |
| B | | |
| **Pumping rate** | | |
| Q | 3000 | m3/d |

| Radius (m) | 500 | 706 | 1000 |
|---|---|---|---|
| Time (days) | Drawdown (m) | Drawdown (m) | Drawdown (m) |
| 1 | 0.000 | - | - |
| 3 | 0.001 | 0.000 | - |
| 7 | 0.032 | 0.003 | 0.000 |
| 10 | 0.070 | 0.012 | 0.001 |
| 20 | 0.206 | 0.070 | 0.012 |
| 30 | 0.322 | 0.140 | 0.037 |
| 40 | 0.418 | 0.207 | 0.070 |
| 50 | 0.499 | 0.268 | 0.105 |
| 60 | 0.568 | 0.323 | 0.140 |
| 70 | 0.629 | 0.373 | 0.174 |
| 80 | 0.683 | 0.419 | 0.206 |
| 90 | 0.731 | 0.461 | 0.238 |
| 100 | 0.775 | 0.500 | 0.267 |



## 4.5 Example 2: Water trade in a confined aquifer, Border Rivers & Moonie Water Plan

An underground water impact assessment is required to support an application to relocate a 300ML entitlement to a nearby property within a confined alluvial aquifer of the Border Rivers (deep) Alluvium.

This assessment applies the Theis equation.

The aquifer parameters to be used are those defined in the Water Management Protocol (see section 4.2 of this guideline); transmissivity is 200$m^2$/day, and the storativity is 0.001. The entitlement being traded is 300ML, and the pumping duration to use is 180 days, as it is not a town water supply entitlement. As such, the pumping rate (Q) is (300 x 1,000) / 180 = 1,667 $m^3$/day. Using the Theis equation, the drawdown limit of 3 metres is exceeded at any registered point of take located within 939 metres of the proposed new entitlement location (see Figure 6).

The rules also require drawdown to be less than 10% of the available head in the aquifer. Provided the available head is greater than 30 metres, the 3-metre drawdown limit will be what constrains the trade. The department checks this criterion against bore log and monitoring information. For this example, it is assumed that this check was made, and the available head was found to exceed 30 metres. Hence the proposed trade could only comply with the water management protocol rules if there are no registered points of take located within 939 metres of the proposed new entitlement location.

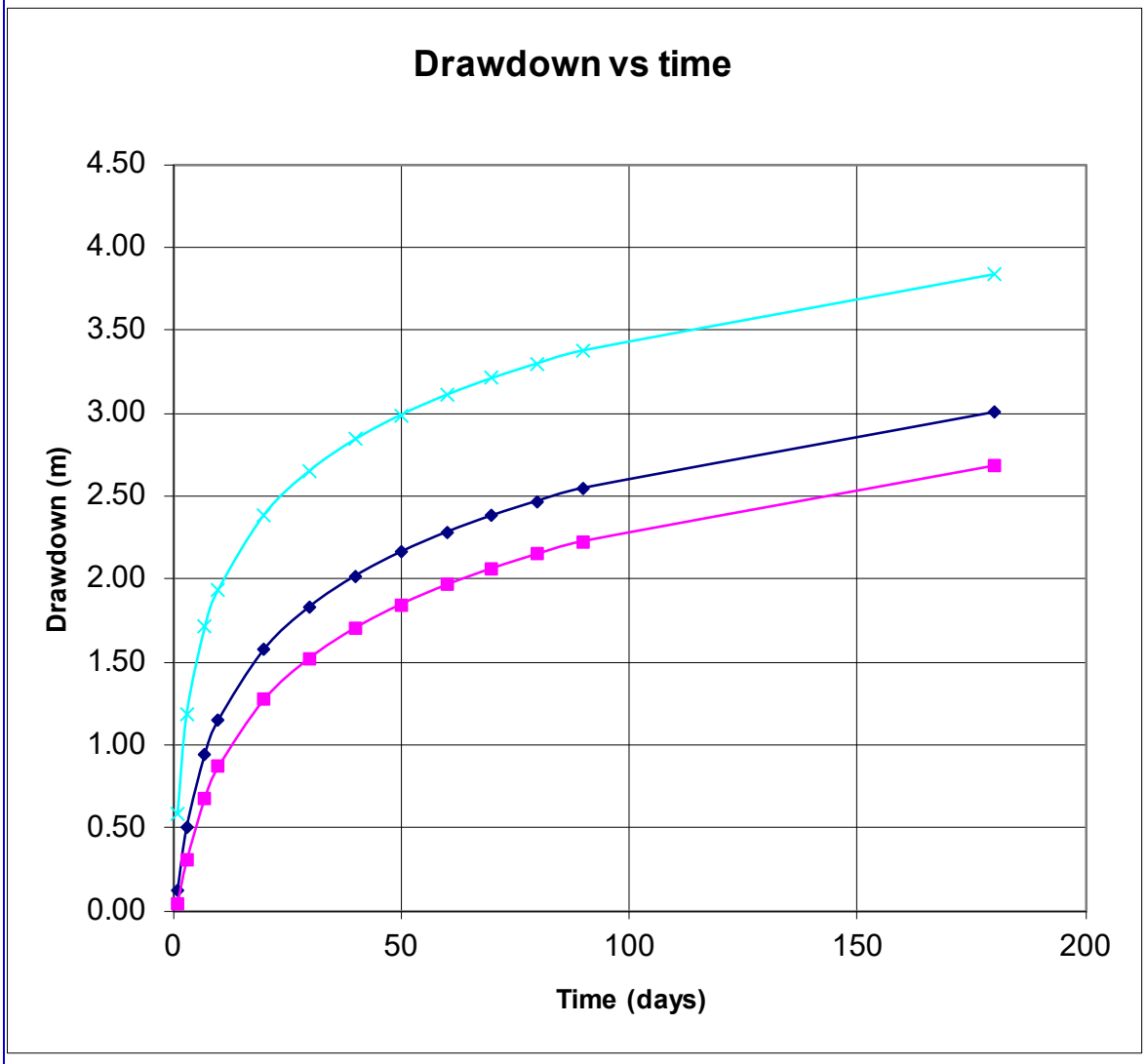
Figure 6 also shows the drawdown curves at distances of 500 metres and 1.2 km from the pumped bore.

Figure 6: Theis equation calculation for the Border Rivers (deep) Alluvium (using the tool developed by Dr Bruce Hunt published by the University of Canterbury and available online at [Environment Canterbury Regional Council])

## Time-drawdown calculations using Theis equation

| Aquifer parameters | | |
|---|---|---|
| T | 200 | m2/d |
| S | 0.001 | |
| B | | |
| **Pumping rate** | | |
| Q | 1666.667 | m3/d |

| Radius (m) | 500 | 939 | 1200 |
|---|---|---|---|
| Time (days) | Drawdown (m) | Drawdown (m) | Drawdown (m) |
| 1 | 0.581 | 0.123 | 0.043 |
| 3 | 1.184 | 0.504 | 0.301 |
| 7 | 1.708 | 0.944 | 0.678 |
| 10 | 1.936 | 1.151 | 0.869 |
| 20 | 2.385 | 1.575 | 1.272 |
| 30 | 2.651 | 1.832 | 1.522 |
| 40 | 2.840 | 2.017 | 1.703 |
| 50 | 2.987 | 2.162 | 1.845 |
| 60 | 3.107 | 2.280 | 1.962 |
| 70 | 3.209 | 2.380 | 2.062 |
| 80 | 3.297 | 2.468 | 2.148 |
| 90 | 3.375 | 2.545 | 2.225 |
| 180 | 3.833 | 3.000 | 2.678 |



# 5. Estimating drawdown impacts under most situations for the GABORA water plan

The GABORA Water Plan establishes rules intended to protect existing water users and GDEs, including springs, from excessive groundwater drawdown impacts. It protects the flow of water to GDEs[2] (section 41) and existing water licences and particular authorisations to take water (section 42). Under section 43 the chief executive may require additional investigation to assess the impact of taking water (that is, estimate drawdown) on:

- the flow of water to groundwater-dependent ecosystems
- Groundwater pressure and levels
- existing water licences and statutory authorisations to take or interfere with water.

For the GABORA Water Plan:

- The **maximum cumulative drawdown for a GDE is 0.4 metres**.
- The **maximum drawdown for a bore is 5.0 metres**.

It is important to understand that the limit established for GDEs is based on cumulative drawdown (due to past licensing decisions as well as the current decision), while the limit for protecting bores and water authorisations is not cumulative (it relates to only the current licensing decision).

The water plan is implemented through a water management protocol. Section 58(2) of the water plan requires the protocol to identify ways for the department to:

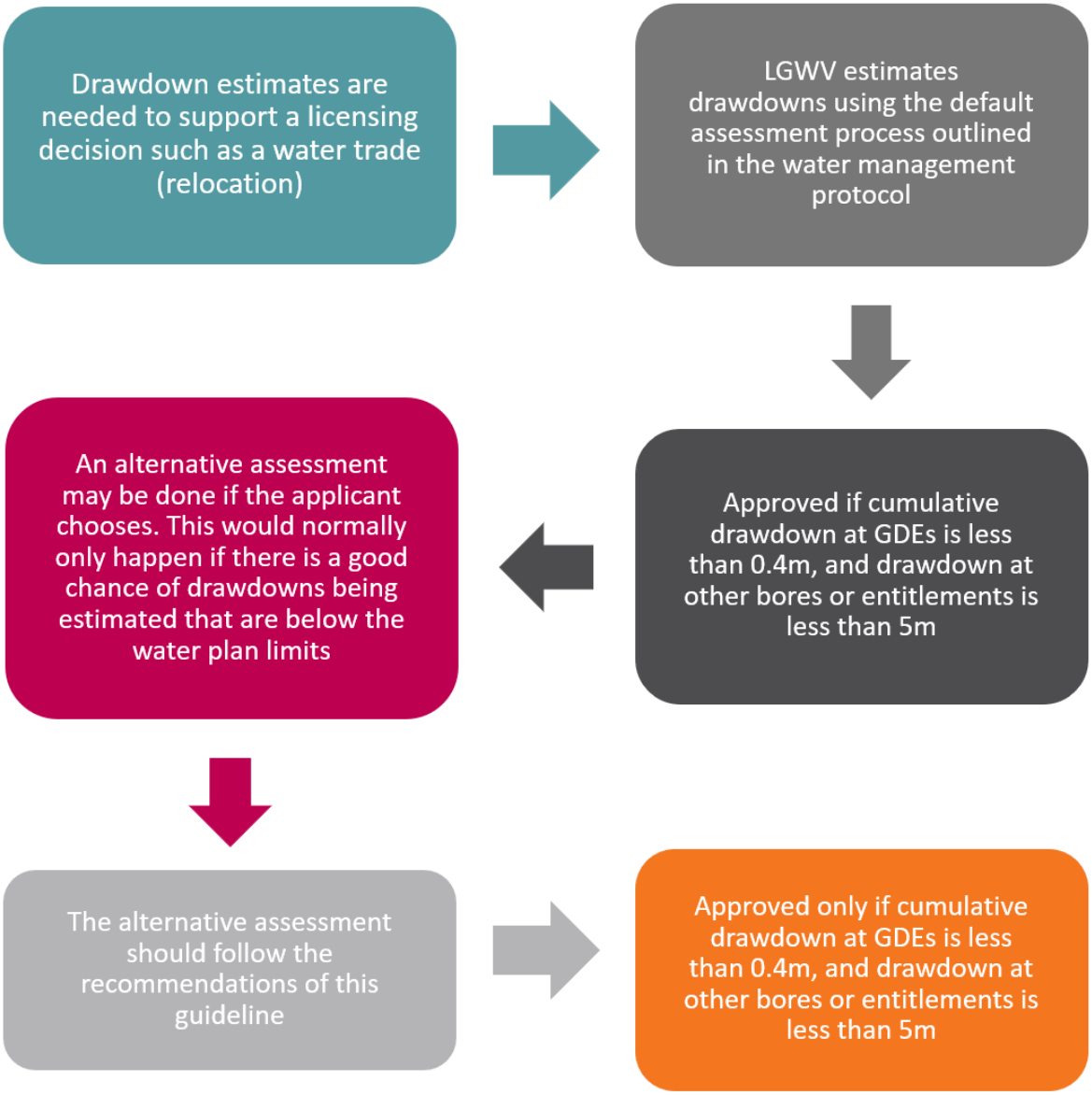
- Estimate cumulative drawdown at GDEs, or otherwise be satisfied the cumulative drawdown at GDEs is less than 0.4 metres.
- Estimate drawdown at relevant locations including existing water entitlements, or otherwise be satisfied the drawdown at these locations is less than the maximum drawdown (which is defined in the water plan dictionary as 5 metres).

Chapter 3 of the GABORA water management protocol deals with the protection of GDEs, and Chapter 4 deals with the protection of existing licences and particular authorisations. These chapters are related to parts of sections 26, 28, 40 to 43, and 58 of the GABORA Water Plan.

A default method of assessment is established in the GABORA Water Management Protocol. Such assessments are done by the department. However, the plan also provides some flexibility in how drawdown can be estimated (referred to as alternative methods in the water management protocol), and such methods are covered in Section 6 of this guideline.

[2] The department maintains a register of GDEs and tracks the cumulative drawdown of previous licence dealings including trades on GDEs (sections 13 and 14 GABORA protocol).

Figure 7: GABORA water plan areas decision making and process flow




### 5.1.1 Protecting existing water users

The default method the protocol uses for estimating drawdown at existing entitlements is having a "minimum" separation distance from the proposed take point to existing take points. Take points are either an existing water bore linked to an authorisation, where it is proposed to be drilled, or the centre of the land tenure that relates to an authorisation that has no linked water bore.

Chapter 4, part 2 of the water management protocol addresses the estimation of drawdown and the methods to satisfy that drawdown at the location of existing water authorisations will not exceed 5 metres:

- A table in Attachment 5 of the protocol specifies minimum separation distances between new licences and existing bores, for the groundwater units and sub-areas of the water plan. These separation distances were calculated using the Theis equation, with parameters as follows:
  - Aquifer transmissivities were assigned to groundwater sub-areas of the water plan based on a literature review and an analysis of the data in the groundwater database (see Attachment 3 of this guideline for an explanation).
  - Aquifer storativity was $5x10^{-4}$.

  - The greatest distance calculated from accounting for both short term (less than 1 year) and potential long-term effects. The greatest distance was chosen from calculating the distance at which 5 m drawdown occurs for:
    - A period of pumping the new entitlement at a constant rate for 100 years,
      - chosen because long term monitoring shows that it takes about this long for steady state pressure conditions to develop following the commissioning of a water bore in GAB aquifers.
    - A short-term pumping rate based on the time it takes to pump the volume of the new entitlement at a pumping rate of
      - 10L/s for aquifers with assigned transmissivity of 10$m^2$/day or 50$m^2$/day,
      - 30L/s for aquifers with assigned transmissivity of 110$m^2$/day or 220$m^2$/day.

- Section 26 (3) of the protocol states that, if the distance between the proposed take of water and an existing take of water in the groundwater unit, is equal to or greater than the minimum separation distance for the decision (from Attachment 5 of the protocol), the chief executive may be satisfied that the drawdown at the location of the existing take of water will be less than the maximum drawdown (i.e., less than 5 metres).
- Section 26 (4) of the protocol limits the use of this default method to when the proposed take volume is less than 10,000 megalitres per year.

Alternative methods to show that drawdown will not exceed the maximum level of 5 metres are provided in section 27 of the protocol. These are not prescriptive and allow technical flexibility. The protocol states:

- The chief executive may estimate the drawdown at a location by undertaking a hydrogeological assessment that includes the results of appropriately conducted studies. These studies can include, but need not be restricted to, groundwater flow modelling, analytical methods, or similar.
- The period covered by such an assessment needs to be at least one hundred years from the commencement of the proposed take of water.
- The chief executive may also consider such assessments undertaken for or by applicants for a decision listed in section 40 of the plan.

### 5.1.2 Protecting groundwater dependent ecosystems

Chapter 3 of the GABORA water management protocol addresses the estimation of cumulative drawdown at GDEs. It also identifies methods to satisfy that cumulative drawdown at the location of GDEs will not exceed 0.4 metres. These methods include:

- Accounting for and recording all drawdown estimates at GDEs made for licensing decisions since the start of the 2006 GAB water plan, as well as under the current GABORA water plan 2017. The licensing decisions made since commencement of the GABORA water plan in 2017, and before December 2021, are summarised below:
  - 67 water licence relocations, totalling 4,228ML
  - 22 stock and domestic licences were granted at locations within 5km of a GDE
  - Two licences were amended to facilitate make good agreements (totalling 14ML)
  - Three licences totalling 950ML were granted from the state reserve
  - 760ML was offered to recent tenderers for general reserve water
  - One state reserve licence (473ML) was surrendered
- Adding new drawdown estimates at each GDE (referred to in the protocol as long-term drawdowns), for new licensing decisions, to the previous cumulative drawdown estimates at each

GDE, and then assessing these against the water plan limit of 0.4 metres cumulative drawdown for each GDE.

$$New\ cumulative\ drawdown = Old\ cumulative\ drawdown + Long\ term\ drawdown\ for\ the\ current\ decision$$

- Recording the locations of the relevant GDEs, their source aquifers, and the cumulative drawdown at each GDE, in a GDE register.
  - While many GDEs have been assigned to a single source aquifer by either the Queensland Herbarium, or other published work such as that by the Office of Groundwater Impact Assessments, some GDEs have been assigned to all aquifers that occur below them, until a source aquifer assessment is undertaken.
  - GDEs sourced from part of an aquifer overlain by mudstone[3], were assigned to a lower unit (confined aquifer) in the GDE register, while those in part of an aquifer not overlain by mudstone were assigned to an upper unit (less confined) in the GDE register. Using this approach, watercourse GDEs and most GAB recharge area springs were assigned to an upper unit where drawdown extends over shorter distances. GAB discharge springs were generally assigned to a lower unit, where drawdown can extend across the aquifer over much greater distances.
  - Figure 8 shows the locations of the GDEs in the GABORA GDE register. A copy of the GDE register is available on the Queensland Globe and via the Queensland Spatial Catalogue (QSpatial). See Appendix C for instructions on how to find this data online. This online version is only current for the date it was hosted online. For current versions of the register, containing the current cumulative drawdowns, please contact the department.
- A default method for estimating long-term drawdowns at GDEs, for specific licensing decisions, is established in Chapter 3 (section 15) and Attachment 4 of the GABORA water management protocol.
  - Long-term drawdown multipliers are calculated using the tables in Attachment 4 of the protocol, and these are multiplied by the proposed additional take of water that is being assessed, to estimate long-term drawdown.

    $$Long\ term\ drawdown =$$

    $$Proposed\ additional\ take\ of\ water\ x\ Long\ term\ drawdown\ multiplier\ (from\ Attachment\ 4)/1000$$
- The long-term drawdown multipliers were calculated using the Theis equation, with parameters as follows:
  - The period of pumping was 100 years.
  - Aquifer storativity was 5x10-4 for lower units, and 5x10-3 for upper units.
  - Aquifer transmissivities were assigned to groundwater sub-areas of the water plan based on a literature review and an analysis of the data in the groundwater database (see Appendices E to G of this guideline for an explanation).
- Drawdown in GAB aquifers can extend over large distances.
  - Origin Energy's current water injection project in the Surat Basin has resulted in groundwater pressure rises of more than 1 metre at distances of 75-100km from the injection site, after only several years of operation.
  - Drawdown propagates through an aquifer in the same way that pressure-rises propagate from an injection site. This means that drawdown estimates for an extraction period of 100 years

[3] This refers to aquitard formations that include shale, siltstone and interbedded sandstones, as well as mudstones. An example is the Rolling Downs Aquitard, a regional aquitard mapped by Geoscience Australia in the Hydrogeological atlas of the Great Artesian Basin

can potentially have effects over much greater distances than the 75-100km observed for Origin's injection operations.

  - Section 15 (6) of the protocol identifies that drawdown can propagate up to 240km in upper units, and up to 710km in lower units, over 100 years, using the default method based on the Theis equation. GDEs located within these distances of a proposed licensing decision have the potential to alter the cumulative drawdown at GDEs.

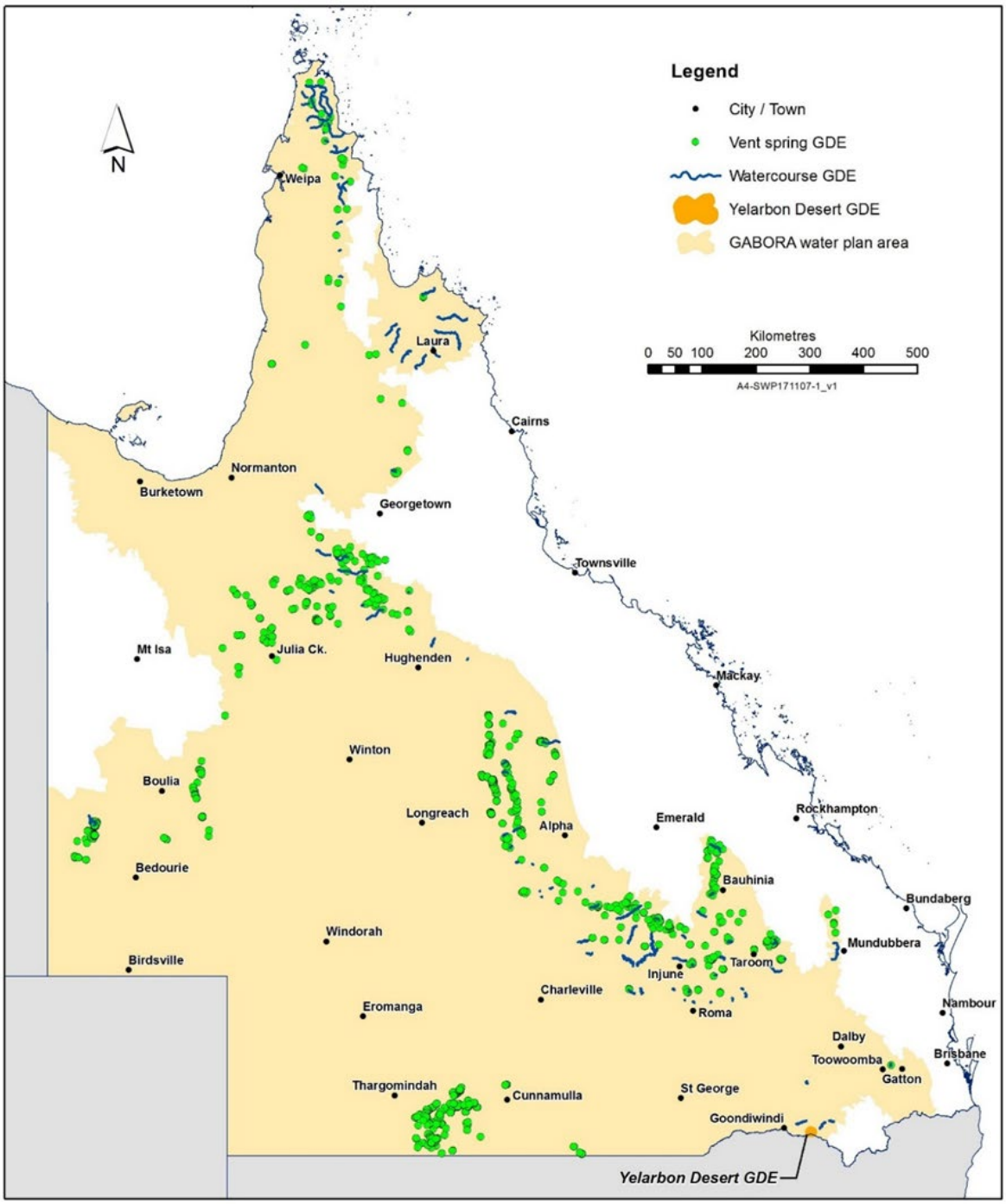
- Alternative methods to the default method are allowed to be used, allowing technical flexibility for improving estimates of long-term drawdown or cumulative drawdown at GDEs. Section 16 of the protocol states:
  - The chief executive may estimate long-term drawdown or the cumulative drawdown by undertaking a hydrogeological assessment that includes the results of appropriately conducted studies. These studies may include, but need not be restricted to, groundwater flow modelling, analytical methods, or similar.
  - The period covered by such an assessment needs to be at least one hundred years from the commencement of the proposed additional take of water.
  - The chief executive may also consider such assessments undertaken for or by applicants for a decision listed in section 40 of the plan.

### 5.1.3 Stock and domestic (S&D) water licences

Applications for S&D water licences must follow the rules in sections 17 and 28 of the protocol. This means that such applications can readily satisfy the drawdown requirements of the protocol, if they are located at least 5 kilometres from a GDE, and at least 300 metres from an existing take of water, in the same aquifer as the application.

Applicants who want to have a bore closer than 5 kilometres to a GDE, or within 300 metres of another bore or licence, can have their application assessed against their specific estimated drawdown impacts on GDEs and existing water users. In these situations, the department will estimate their drawdown impacts using the Theis equation. Should these departmental assessments estimate drawdown impacts that exceed the water plan limits, the applicants are able to have an alternative assessment done, and this guideline would be appropriate for helping the licence applicant, or their hydrogeological consultant, to decide on an appropriate drawdown estimation method.

**Figure 8: Groundwater dependent ecosystems in the GABORA water plan area**



## 5.2 Example 3: Water trade in a confined aquifer of the GABORA Water Plan

A drawdown estimate is required to support an application to relocate a 50ML entitlement to a nearby property within a confined aquifer of the Hutton Sandstone in the Surat Basin.

This assessment applies the minimum separation distances from Attachment 5 of the GABORA water management protocol, that are based on the Theis equation. Using Attachment 5 of the GABORA water management protocol identifies the minimum separation distance as 600 metres. Hence the relocation cannot occur if there is any existing authorised take of water from the Hutton Aquifer within 600 metres of the proposed new entitlement location. The aquifer parameters for Surat Hutton that were used to develop this distance in Attachment 5 of the protocol are described in section 5.1 and Appendix 4 of this guideline; transmissivity was $50m^2$/day, and the storativity was $5 \times 10^{-4}$. The pumping rate was 10L/second for a duration of 58 days (the time taken to extract 50ML at 10L/second). In this scenario, as described in section 5.1.1, the drawdown estimated using a short-term pumping rate exceeded the drawdown estimated using a 100 year pumping rate, and as such is the distance used to define the minimum separation distance.

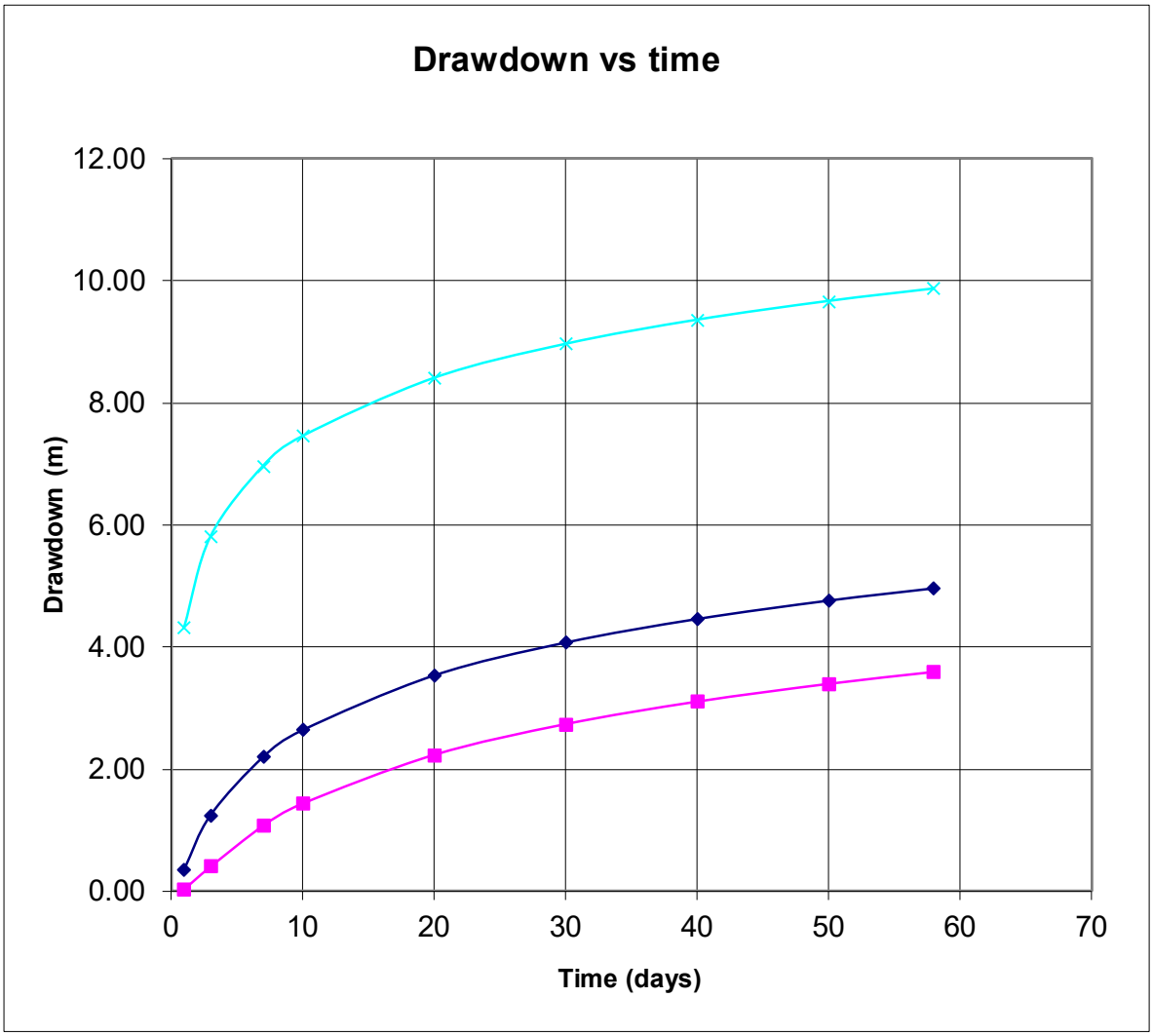
Figure 9 shows the drawdown curves at distances of 100 metres, 600 metres, and 1 km from the pumped bore after 58 days of pumping.

Figure 9: Theis equation calculation for the Surat Hutton groundwater sub-area of the GABORA water plan, showing a bore setback distance calculation (using the tool developed by Dr Bruce Hunt, published by the University of Canterbury (Environment Canterbury Regional Council)).

## Time-drawdown calculations using Theis equation

| Aquifer parameters | | |
|---|---|---|
| T | 50 | m2/d |
| S | 5.00E-04 | |
| B | | |
| **Pumping rate** | | |
| Q | 10 | l/s |

| Radius (m) | 100 | 600 | 1000 |
|---|---|---|---|
| Time (days) | Drawdown (m) | Drawdown (m) | Drawdown (m) |
| 1 | 4.313 | 0.358 | 0.034 |
| 3 | 5.801 | 1.245 | 0.402 |
| 7 | 6.960 | 2.198 | 1.073 |
| 10 | 7.449 | 2.638 | 1.436 |
| 20 | 8.400 | 3.532 | 2.232 |
| 30 | 8.957 | 4.069 | 2.736 |
| 40 | 9.352 | 4.454 | 3.103 |
| 50 | 9.659 | 4.755 | 3.394 |
| 58 | 9.863 | 4.956 | 3.588 |



The rules also require drawdown to be estimated at GDEs in the Hutton aquifer, and for the cumulative drawdown at these GDEs to be less than 0.4 metres. There are many GDEs associated with the Hutton Aquifer, and the water plan drawdown criterion for GDEs is based on the cumulative drawdown effect of all licensing decisions made in the Hutton Aquifer since the GAB ROP commenced in 2007. This means a more complex assessment is needed than that used for establishing the minimum set back distance from existing bores. To demonstrate the process involved, this example will assess only one GDE. It will be assumed that a spring sourced from a part of the aquifer that is confined by the overlying Injune Creek Group and located 100 kilometres away already has a cumulative drawdown due to previous licence dealings of 0.1 metres. This means that the current trade can only have a long-term drawdown at this spring of 0.3 metres (0.4 – 0.1 = 0.3).

Using Attachment 4.2 of the water management protocol identifies a long-term drawdown multiplier of 1.67760 for the GDE located 100 kilometres away. This means the long-term drawdown due to the 50ML trade is 50 X 1.6776/1000 = 0.084 metres, and the cumulative drawdown at this spring would become 0.184 metres due to the proposed trade (0.1 + 0.084 =0.184). As this is less than 0.4 metres, this trade would not be constrained by drawdown at this spring.

The aquifer parameters used to establish the long-term drawdown multipliers for Surat Hutton in Attachment 4.2 were: transmissivity = $50m^2$/day, storativity = $5x10^{-4}$, pumping duration 100 years. A 50ML entitlement extracted at a continuous rate equates to a 1.585L/s pumping rate.

Figure 10 shows the Theis drawdown curves after 100 years of pumping, at distances of 30 km, 100 km, and 150 km from the pumped bore.

Figure 10: Theis equation calculation for the Surat Hutton groundwater sub-area of the GABORA water plan, showing a GDE drawdown calculation (using the tool developed by Dr Bruce Hunt, published by the University of Canterbury and available online at Environment Canterbury Regional Council).

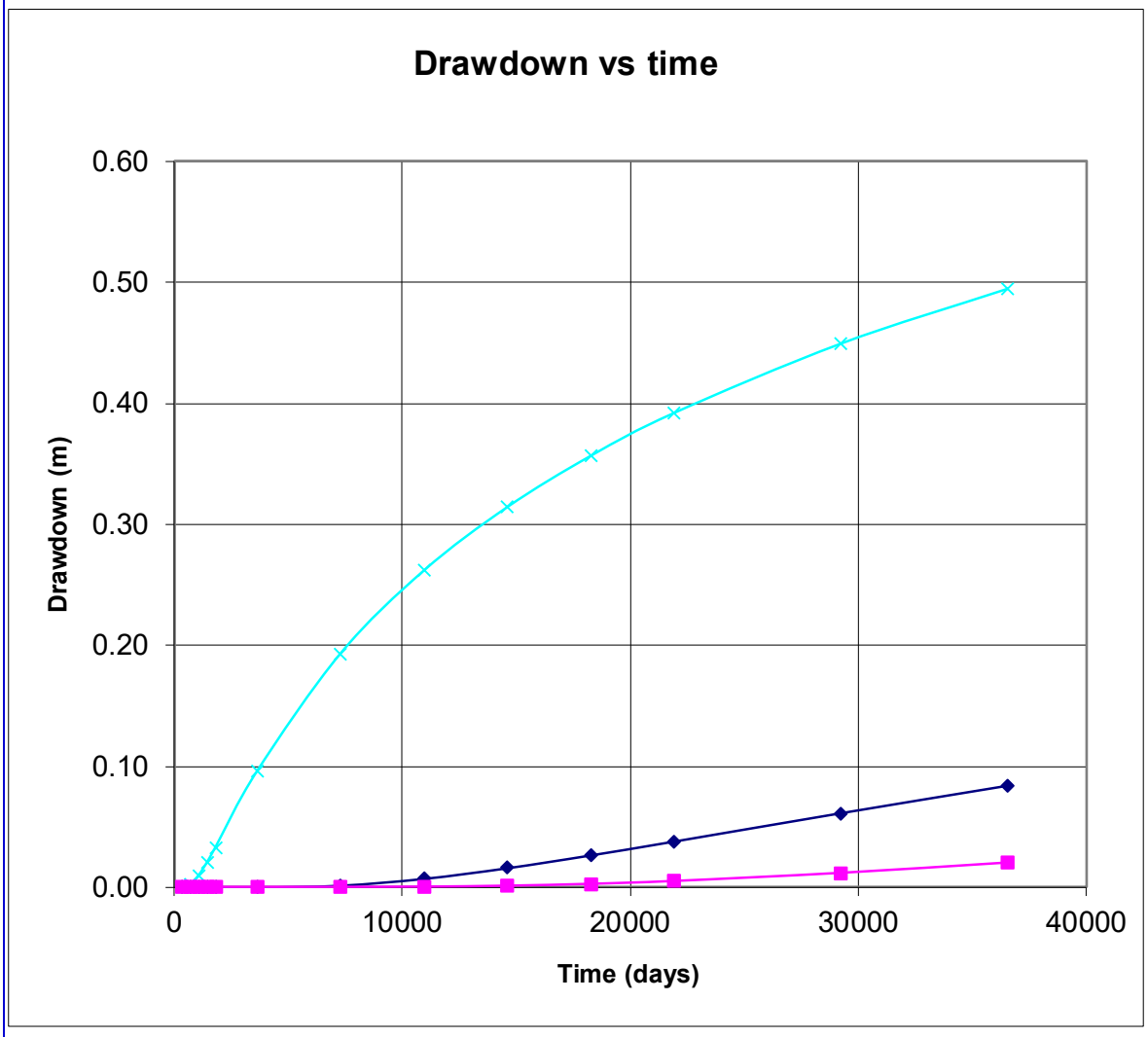
## Time-drawdown calculations using Theis equation

| Aquifer parameters | | |
|---|---|---|
| T | 50 | m2/d |
| S | 5.00E-04 | |
| B | | |

| Pumping rate | | |
|---|---|---|
| Q | 1.585 | l/s |

=50ML/yr

| | km | 30 | 100 | 150 |
|---|---|---|---|---|
| | Radius (m) | 30000 | 100000 | 150000 |
| years | Time (days) | Drawdown (m) | Drawdown (m) | Drawdown (m) |
| 1 | 365 | 0.000 | - | - |
| 2 | 731 | 0.003 | - | - |
| 3 | 1096 | 0.010 | - | - |
| 4 | 1461 | 0.021 | - | - |
| 5 | 1826 | 0.033 | 0.000 | - |
| 10 | 3653 | 0.096 | 0.000 | - |
| 20 | 7305 | 0.193 | 0.002 | 0.000 |
| 30 | 10958 | 0.262 | 0.007 | 0.000 |
| 40 | 14610 | 0.314 | 0.016 | 0.001 |
| 50 | 18263 | 0.357 | 0.027 | 0.003 |
| 60 | 21915 | 0.392 | 0.038 | 0.005 |
| 80 | 29220 | 0.449 | 0.061 | 0.012 |
| 100 | 36525 | 0.495 | 0.084 | 0.021 |



# 6. Alternative assessment methods for the GABORA water plan

To investigate the impact of taking water, under section 43 of the GABORA Water Plan, the following may be required to be carried out:

- Studies relating to the relevant groundwater-dependent ecosystems and the groundwater units connected to the ecosystems; or
- A hydrogeological assessment.

## 6.1 Groundwater drawdown estimation options

The Theis equation described in Section 3 is a legitimate and defensible approach to estimating drawdown for relatively straightforward water trades and licence dealings under the GABORA Water Plan. As trade complexity, or volume, or the potential range and location of drawdown changes, the approach to evaluating drawdown may need to become more detailed and complex.

The GABORA Water Plan allows a broad range of supporting evaluations to be undertaken. The following is a list of the more common groundwater drawdown estimation processes used. The complexity of these processes increases as you go down the list:

- **Theis Equation** to estimate groundwater drawdown from the pumping of a single production bore.
- **Multi-bore Theis equation analysis**, which is suitable for estimating cumulative drawdown caused by the operation of a number of bores. This is usually suited for a relatively small number of bores.
- **Theis Equation applying boundary condition effects** (through mirror bore theory). This improves estimates of groundwater drawdown by accounting for the role of aquifer boundaries in the groundwater system, such as edges of aquifers and connected watercourses, which may inhibit or enhance estimated drawdown in an aquifer.
- **2D spatial modelling** using a simple numerical modelling tool (such as MLU for Windows software). This allows for more realistic conceptual models of the aquifer, should the Theis conceptual model be inadequate, including accounting for the role of boundaries in enhancing or limiting drawdown propagation in an aquifer.
- **3D single-layer, numerical groundwater flow model**. This has similar advantages to 2D spatial modelling but also allows for improved representation of the spatial variations in hydraulic properties across the aquifer.
- **3D multi-layer, numerical groundwater flow model**. This is required where drawdown propagation across an aquifer is controlled to a significant extent by the potential movement of water in the vertical direction between distinct aquifers.

The selection of which technique is best suited to the evaluation of a water trade or entitlement dealing requires hydrogeological judgement, and consideration of the detail and complexity of the trade.

Technique selection also needs to consider the time and cost to complete. It is not appropriate to over-engineer the process and err on the side of complexity, as this will impose cost and time impacts. Similarly, it may not be appropriate to apply a Theis equation to a complex and high-volume water trade.

The approach selected needs to be fit-for-purpose, with the aim that the technique chosen for estimating groundwater drawdown matches the technical challenges of the trade or entitlement dealing. This guideline is provided to assist with choosing an appropriate technique, so that the assessment used is fit-for-purpose.

**It is important to maintain communication with the Department through the process of technique selection to allow feedback and direction to be provided in each case.**

### 6.1.1 Information sources for alternate evaluation techniques

A common reason for applying an alternate method to estimate drawdown impacts under the GABORA Water Plan is that the default method has not considered some important aspects of the hydrogeology of aquifers. These aspects of the hydrogeology need to have a significant effect on drawdown estimations before it is worth undertaking an alternative assessment. It might be the case that there is additional relevant technical information available that wasn't considered in the default assessment, or that there is potential to collect such information. Alternative methods might also change the findings of the drawdown estimation if they apply an improved conceptual model of the aquifer (that is, boundaries can be considered, or leaky aquitards etc).

An alternative assessment for estimating drawdown will need a variety of data to proceed:

- **Bore and water entitlement information**. The groundwater database contains information about water bores in Queensland and is available for download online through the Q-Spatial website. Water entitlement information can be viewed online through the Water Entitlement Viewer and downloaded through the Queensland Oppen Data Portal. Appendix C contains more information about accessing this data.
- **Groundwater dependent ecosystem information** is contained in the GABORA GDE register. Appendix C contains more information about accessing this data.
- **Geological information,** specifically the spatial definition of aquifers and other relevant features. This might include the depth and thickness of the aquifer, the depth to groundwater (static, or unpumped) within the aquifer, and the regional distribution of its extent, thickness of cover material and the location of potential features which might affect the availability of water – in a positive or negative manner.
- **Aquifer Information,** being reasonable and site-relevant values of transmissivity and storativity. These are critical components to every technique of drawdown estimation, including the simplest evaluation technique of the Theis equation.
  - Transmissivity is the product of aquifer thickness and permeability (and is a measure of the ability of groundwater to move within the aquifer) and is typically measured in $m^2$/day.
  - Storativity is an estimate of water storage characteristics of the aquifer, or more specifically, how much water the aquifer can release, and is unitless.

#### 6.1.1.1 Geological information

Information about the geology of aquifers can be collected from a range of sources and can be highly variable in the quality and detail available.

The simplest source of data is the geology or stratigraphy log of the bore being considered for the water trade or entitlement dealing. In most cases, the 'bore card' for the bore, managed by the Queensland Government and publicly available through Queensland Globe, will provide the basic geologic information listed above for the immediate site / bore. A review of bore cards for other nearby bores can improve understanding by confirming the distribution of the aquifer at distances away from the bore under investigation.

There are larger data sets also available, which might include digital geological layers (at a regional scale, e.g., 10's to 100's of km) that have been constructed for much more complex studies and are available in a GIS format. These can also be constructed specifically for the purpose of the water trade or entitlement dealing, by an appropriately qualified and experienced hydrogeologist. All of Australia is also covered by 1:250,000 geological mapping which is available in hard copy or digital (scanned) format.

In some areas, there has also been specialised and focussed technical studies completed, which if public, can also assist in understanding the geological nature of the aquifer.

The level of detail needed for aquifer geometry will be a result of the level of evaluation to be undertaken. Complex, 3D representation of regional systems would only be required for the most complex evaluation techniques such as detailed 3D numerical modelling.

#### 6.1.1.2 Estimating aquifer parameters of transmissivity and storativity

Transmissivity and Storativity are evaluated by analysing data collected during pumping tests on water bores. Transmissivity is calculated from the drawdown response to pumping from a bore in an aquifer, for a pre-determined period of time. Drawdown can be measured during the test in the pumped bore as well as in other nearby bores to improve the interpretation. Storativity cannot be calculated from a single bore pump test. Drawdown measurements from other nearby bores are needed to calculate storativity.

Pumping test results are collated and used to inform a range of hydrogeological studies. Tabulated values of each parameter can be determined for any aquifer if testing data is suitable and distributed, noting some aquifers have enough data for ranges of values to be developed.

In the GAB there is a relatively large transmissivity data set related to the assessment of long-term groundwater pressure monitoring that has been done at production bores across the GAB. Even so, given the large size of the GAB, in places this can be a sparse dataset. The transmissivity values used in developing the GABORA water management protocol are explained in Appendices 4 to 6.

There are also transmissivity and storativity values available from prior studies or assessments, If local values are not available there might be some from assessments done in parts of the aquifer distant from the site of the proposed evaluation. Where no values are available for an aquifer, it is worth consulting the scientific literature, that contains a great deal of studies with published typical values and range bounds for generic aquifers, such as sandy gravels, or sandstones, that are based on large datasets supported by technical evaluations.

Large and complex numerical modelling studies can also be used to achieve an estimate of aquifer parameters based on long term groundwater level records and the model calibration and improvement process. There are public datasets available that are constructed from this approach. An example of this type of data, and of relevance to the GABORA water plan, is located here Groundwater Modelling Report – Surat CMA (Appendix E: Parameter bounds) (resources.qld.gov.au) – this is a tabulated summary of horizontal and vertical hydraulic conductivity, and specific storage[4], for a large range of geological units present in, and overlying, the geology of the Surat Basin.

Drawdown impacts in confined aquifers can expand over potentially large distances, as explained in Section 3 of this guideline. Choosing the appropriate aquifer parameters to use when estimating drawdown over such large distances requires care. The aquifer parameters used should be representative of the part of the aquifer through which the cone of depression will expand during the period relevant to the drawdown estimate being made. The parameters relevant to estimating drawdown at the pumping bore are not necessarily the most appropriate for estimating drawdown hundreds of kilometres away. Useful approaches can be to use the geometric mean of parameters that have been measured in the part of the aquifer located between the production bore and the location of the drawdown estimate, or to use parameters that best represent regional conditions in the aquifer. The technical reasoning for choosing the parameters that are used needs to be explained in relation to the aquifer conceptualisation that supports the drawdown estimate.

If aquifer parameters vary significantly between the source of pumping and the location of a drawdown estimate (such as a GDE or another water bore), then an evaluation method that accounts for this variation, may be required. Examples of situations where this might be needed include, a structure such as a fault displaces the aquifer, significant changes in lithology or thickness of an aquifer, or a change in aquifer conditions from confined to unconfined.

[4]Transmissivity is equivalent to hydraulic conductivity times aquifer thickness, and storativity is equivalent to specific storage times aquifer thickness.

#### 6.1.1.3 The potential benefit of collecting additional data

Sometimes, an assessment will benefit from collecting additional data. This can happen if the aquifer parameters that were used in establishing the relevant GABORA water management protocol requirements are inappropriate for the part of the aquifer being evaluated, or if there is a gross lack of existing information to support the water trade or entitlement dealing in the first instance.

In such cases, a test drilling program may be required, and might (as an example) include the drilling of a test production bore, and an accompanying monitoring bore located a suitable distance apart. The test production bore would then be test pumped with both bores monitored to derive locally suitable aquifer parameters.

Such an approach is a significant commitment in effort and cost. New drill holes provide additional geological information – assuming it is needed, and a test pumping program will permit evaluation of locally relevant aquifer parameter ranges (again, assuming this will contribute to the assessment in a meaningful way). However, this new data might not change the regional interpretation or the assessment of impacts at a site that is a long way from the bore to be pumped. In many situations (but not all), adding new local information from new test bores will not alter an aquifer system conceptualisation, or drawdown estimates, to any significant extent. Test drilling and test pumping should only be considered for an assessment where it can be demonstrated that this new information will have a high likelihood of significantly improving drawdown estimates.

Drawdown estimates near the bore to be pumped will better reflect actual conditions if the data used in the evaluation relates directly to the part of the aquifer under consideration. Local scale impacts near a production bore might best be estimated using aquifer parameters related to that production bore. However, regional impacts are more likely to reflect regional aquifer conditions. As such, if single representative values of transmissivity and storativity are to be used in a regional scale drawdown estimate, they should be Carefully considered and justified by a suitably experienced hydrogeologist.

If the local testing of the aquifer results in significant difference in aquifer parameters from the values presented in Appendices D and E, then this needs to be explained through the conceptualisation. Although the technique for evaluating local drawdown may use these locally derived conditions, they should not be applied to the broader aquifer extent if the conceptualisation does not support their regional scale application. In this case, the assessment would need to recognise and account for the change in aquifer conditions, both in the conceptualisation, and in the drawdown estimate.

The ease of access to existing water bores for doing pump tests or sites for new drilling are also important considerations.

The scale of the assessment also needs to be considered. If drawdown estimates are needed at a relatively local scale, such as for a close spring or neighbours water bore, new local scale information might have a significant effect on the estimate being made. However, if drawdown is being estimated at a distant spring, perhaps a hundred kilometres from the proposed new entitlement, new information from close to the proposed entitlement might be of less value. In this situation it is the regional scale aquifer parameters, or aquifer conditions located close to the distant spring, that might be of most interest. It might be the case that new information that is close to the spring, rather than close to the proposed new entitlement, could have the most effect on the drawdown estimate. In other cases, a reassessment of the regional scale aquifer parameters, relevant to the parts of the aquifer located between the proposed entitlement and the distant spring, could be more valuable than collecting new information from bores located near the proposed entitlement.

It is recommended the department be consulted before committing to any data collection program related to estimating drawdown under the GABORA water plan. Simpler approaches to determine potential impacts should be considered first, to assist in deciding if such a program of work is needed, in terms of the likelihood of the water trade or entitlement dealing proceeding, and the requirement for suitable data to help support the evaluation.

### 6.1.2 Guide to selecting an appropriate drawdown estimation method

This section is intended to guide hydrogeological consultants, their clients, and the department when selecting a suitable technique for estimating groundwater drawdown impacts under the GABORA

Water Plan, to inform decisions about proposed water trades or other licence dealings. The process explained in this section will help identify a fit-for-purpose approach for each water trade or licence dealing under consideration.

The process comprises three steps:

- Step 1: Determine the complexity of the assessment based on location.
- Step 2: Determine the risk posed by the proposed entitlement dealing or trade, based on the complexity from Step 1, and the volume of entitlement involved.
- Step 3: The likely work required is based on the risk posed by the trade or entitlement dealing.

If there is any doubt about the process, the outcome should be discussed with the department before proceeding.

#### 6.1.2.1 Step 1: Assessment complexity based on proximity of existing bores, entitlements, and GDEs

The first step in this process is to identify the number of existing bores, entitlements, and GDEs, where the default GABORA protocol methods identified that excessive drawdown would occur (see Table 2). Then assign the highest complexity determined for either bores or GDEs.

For example, if the default GABORA protocol method identified seven bores that would have greater than 5m drawdown, and two GDEs with greater than 0.4 m drawdown, then these present a medium-complexity (for bores) and high-complexity (for GDEs): so, an overall high-complexity would be assigned in this example.

**Table 2: Complexity associated with the proximity of existing bores, entitlements, and GDEs**

| Complexity of assessment based on proximity of existing water bores, entitlements, and GDEs | | | |
|---|---|---|---|
| Number of bores or entitlements that the default GABORA protocol method identified as having greater than 5m drawdown | <5 | 5-10 | >10 |
| GDE complexes that the default GABORA protocol method identified as having greater than 0.4m drawdown because of the proposed dealing | 0 | 1 | >1 |
| Complexity | Low | Medium | High |

#### 6.1.2.2 Step 2: Determine risk

The second step is to consider the final volume of traded water (ML/year) involved in the water trade or entitlement dealing. Using the outcome of step 1, determine the risk from Table 3. The result for the example used in step 1 is shown, with a resulting risk score of ‘4’ for a high complexity from step 1, and a proposed trade of 350ML.

**Table 3: Risk score**

| | | Entitlement Volume (ML/annum) | | |
|---|---|---|---|---|
| | | <= 50 | > 50 - <= 500 | >500 |
| Complexity (from step 1) | Low | 1 | 2 | 3 |
| | Medium | 2 | 3 | 4 |
| | High | 3 | 4 | 5 |

### 6.1.2.3 Step 3: Determine the likely work needed for the assessment.

Using the risk score from step 2 (Table 3), the following guide in Table 4 can be used to broadly scope the work required to complete a fit-for-purpose drawdown estimation. This considers four aspects of the work:

- Source information needed – choosing or developing aquifer material parameters and aquifer geometry information.
- Need for fieldwork – the potential that the assessment cannot solely rely on existing data and some additional information is needed to be collected, or technical assumptions need to be confirmed.
- Indicative cost – is a function of the field and evaluation effort needed. General ranges only are presented.
- Technical assessment – the most likely, technique that will be best suited for estimating drawdown.

This is a guide only and hydrogeological judgement supported by discussions with the department should be used to confirm the actual work program and technical assessment methods to be used.

**Table 4: Likely scope of work needed to estimate drawdown**

| Risk score (from step 2) | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Source information needed | Existing public domain data & mapping | | Increasing reliance on other reporting<br>Aquifer testing for more representative aquifer parameters might be useful.<br>Local or regional hydrogeologic interpretation. | | |
| Need for fieldwork | no | unlikely | | possibly | likely |
| Indicative cost | low | Low to moderate | moderate | | high |
| Technical assessment | Theis equation<br>Multiple bore Theis equation if required | Theis equation or 2D planar modelling.<br>Multiple bore Theis equation if required | 2D planar modelling | 2D planar modelling, or 3D single layer modelling, or 3D multi-layer modelling | |

## 6.2 Examples

A series of water trade examples are provided to discuss the approaches discussed in the previous sections.

### 6.2.1 Example 1: water trade in a 'low-use' part of a confined aquifer of the GABORA plan

In this example, a water trade is proposed from one property to another for an entitlement in a confined aquifer of the GABORA Water Plan. The trade proposed is to relocate 100ML to an existing entitlement of 120ML, resulting in the existing 100ML entitlement becoming a 220ML entitlement at its current location. The trade is within the same aquifer, and the location is in an area of low groundwater development distant from springs. The default GABORA protocol method identified the proposed trade would cause greater than 5m drawdown at less than 5 bores, and no springs or GDEs were identified as having 0.4 metres drawdown.

The process flow for this example is explained below. In this case a low complexity assessment is recommended.

**Step 1: Determine complexity of the assessment**

| Complexity of assessment based on proximity of existing water bores, entitlements, and GDEs | | | |
|---|---|---|---|
| Number of bores or entitlements that the default GABORA protocol method identified as having greater than 5m drawdown | <5 | 5-10 | >10 |
| GDE complexes that the default GABORA protocol method identified as having greater than 0.4m drawdown because of the proposed dealing | 0 | 1 | >1 |
| Complexity | Low | Medium | High |

**Step 2: Determine risk**

In this case, the entitlement volume is 220ML, returning a risk score of 2.

| | | Entitlement Volume (ML/annum) | | |
|---|---|---|---|---|
| | | <= 50 | > 50 - <= 500 | >500 |
| Complexity (from step 1) | Low | 1 | 2 | 3 |
| | Medium | 2 | 3 | 4 |
| | High | 3 | 4 | 5 |

**Step 3: Identify the likely scope of work for the assessment**

| Risk score (from step 2) | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Source information needed | Existing public domain data & mapping | | Increasing reliance on other reporting<br>Aquifer testing for more representative aquifer parameters might be useful.<br>Local or regional hydrogeologic interpretation. | | |
| Need for fieldwork | no | unlikely | | possibly | likely |
| Indicative cost | low | Low to moderate | moderate | | high |
| Technical assessment | Theis equation<br>Multiple bore Theis equation if required | Theis equation or 2D planar modelling.<br>Multiple bore Theis equation if required | 2D planar modelling | 2D planar modelling, or 3D single layer modelling, or 3D multi-layer modelling | |

This translates to a program of work that relies largely on public domain data and application of the Theis equation or simple 2D planar modelling. As the example only requires the estimation of impact for a small number of bores, a single Theis equation is probably suitable. Three-dimensional modelling is not considered necessary or suitable in this example, and additional field work is also not considered necessary.

However, applicants for licence dealings and the consultants who work for them, are free to choose to do any work that is additional to that recommended in this guideline. The department will however take longer to review more complex assessments, and this might lead to longer decision times for applications.

### 6.2.2 Example 2: Water trade in a 'high-use' part of a confined aquifer of the GABORA plan

In this example, a water trade is proposed that is like that covered in Example 1, but in a different location. The trade proposed is to relocate 100ML to an existing entitlement of 120ML, resulting in the existing 100ML entitlement becoming a 220ML entitlement at its current location. The trade is within the same aquifer, but local groundwater development is more intense than in Example 1, as 16 bores, and multiple springs were identified through the default GABORA protocol methods as having unacceptable drawdowns due to the proposed trade.

The process flow for this example is explained below. In this case a high complexity assessment is recommended.

**Step 1: Determine complexity of the assessment**

| Complexity of assessment based on proximity of existing water bores, entitlements, and GDEs | | | |
|---|---|---|---|
| Number of bores or entitlements that the default GABORA protocol method identified as having greater than 5m drawdown | <5 | 5-10 | >10 |
| GDE complexes that the default GABORA protocol method identified as having greater than 0.4m drawdown because of the proposed dealing | 0 | 1 | >1 |
| Complexity | Low | Medium | High |

**Step 2: Determine risk**

In this case, the entitlement volume is 220ML, as for example 1. However, the high complexity of the assessment in this case returns a risk score of 4.

| | | Entitlement Volume (ML/annum) | | |
|---|---|---|---|---|
| | | <= 50 | > 50 - <= 500 | >500 |
| Complexity (from step 1) | Low | 1 | 2 | 3 |
| | Medium | 2 | 3 | 4 |
| | High | 3 | 4 | 5 |

**Step 3: Identify the likely scope of work for the assessment**

| Risk score (from step 2) | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Source information needed | Existing public domain data & mapping | | Increasing reliance on other reporting<br>Aquifer testing for more representative aquifer parameters might be useful.<br>Local or regional hydrogeologic interpretation. | | |
| Need for fieldwork | no | unlikely | | possibly | likely |
| Indicative cost | low | Low to moderate | moderate | | high |
| Technical assessment | Theis equation<br>Multiple bore Theis equation if required | Theis equation or 2D planar modelling.<br>Multiple bore Theis equation if required | 2D planar modelling | 2D planar modelling, or 3D single layer modelling, or 3D multi-layer modelling | |

Example 2 requires a more detailed assessment of potential impact than in Example 1, that allows representation of impacts on multiple groundwater users and assessment of cumulative drawdown at GDEs. A single layer 3D numerical model is suggested, although local conditions may dictate a slightly more complex simulator, or, they may permit the use of a 2D planar model.

The assessment may also benefit from local aquifer testing for more locally representative aquifer parameters.

## 6.3 Emerging understanding of the Precipice Sandstone

Our knowledge of Queensland's aquifers continues to grow as more information becomes available. The deepest aquifers are often the ones we know relatively little about, usually because it costs more to drill into them, or because shallower sources of water have been previously accessed. One of the deepest GAB aquifers is the Precipice Sandstone. We have learnt a lot about this formation since the

GABORA water plan commenced in 2017 because of some significant science done by the University of Queensland in collaboration with industry partners. This work is summarised in Hayes et al 2020.

We now think the Precipice Sandstone is likely to be comprised of not one, but at least two separate aquifers – (1) an upper aquifer, that includes parts of the lower Evergreen Formation, with low-moderate transmissivity and perhaps a broad spatial extent, and (2) a smaller extent, lower Precipice Sandstone aquifer, with very high transmissivity (say 1000$m^2$/day). This makes management of the groundwater in these aquifers challenging, because the GABORA water plan established rules for the Precipice Sandstone as though it was a single aquifer.

Significant work is required before it is feasible to modify our management arrangements for the Precipice Sandstone. Further work is also needed to reassign GDEs and existing water bores and entitlements to the different aquifers. The department welcomes the involvement of any parties interested in contributing to improving our understanding of groundwater in the Precipice Sandstone, and how this new understanding can be used to improve our management arrangements for protecting the flow of groundwater to GDEs and for protecting existing entitlements from excessive drawdown.

This emerging understanding of the Precipice Sandstone creates some challenges for estimating drawdown in this formation. The current rules established in the GABORA water plan and water management protocol still need to be followed. The default drawdown estimation method of the GABORA water management protocol continues to be used for the Precipice Sandstone, as for other aquifers. However alternative assessments should consider the new understanding we have of the Precipice Sandstone and accordingly conceptualise their drawdown assessments, using the best hydrogeological evidence that is available. This might make such assessments more complex, and perhaps more expensive, than those in other aquifers.

## 6.4 What is needed in a report that estimates drawdown for the GABORA water plan

The department uses the results of alternative assessments for estimating drawdown to support its decisions about water licence relocations (trades) and other licence dealings. As such, the assessments need to be reported in a way that makes a clear and concise connection between the report findings and the requirements of the GABORA water plan. The reports need to clearly identify the following:

- the locations of the proposed dealing including the location of existing entitlements and proposed new locations
- the existing and proposed volumes of water entitlements and groundwater units and sub-areas involved in the dealing
- the assessment's estimated drawdown at all water bores and/or entitlements that were identified in the default GABORA protocol assessment as being potentially impacted by drawdown greater than 5 metres
- the estimated long-term drawdown at all GDEs sourced from the same aquifer(s) as the proposed dealing(s).
  - This will usually involve many more GDEs than those identified as having greater than 0.4m cumulative drawdown during the default GABORA protocol assessment.
  - In situations where entitlement is being relocated from one location to another, this might involve an assessment of drawdown recovery caused by the entitlement being moved away from one location, as well as new drawdown impacts due to the entitlement being moved to the new location.
  - In situations involving entitlements being relocated from one aquifer to another, this might involve an assessment of drawdown recovery at GDEs in one aquifer, as well as drawdown impacts at GDEs in another.

  - This allows the department to use the results of the assessment in its tracking of cumulative drawdown at all GDEs.

- Any other matters that the department identifies as needing to be addressed in the report. Assessments should be discussed with the relevant departmental staff before they are started, and ongoing discussions during the assessment are encouraged.

# 7. Summary

Assessment of underground water impacts to support the assessment of water trade applications or the granting of unallocated water is legislated through water plans and water management protocols. Estimates of groundwater drawdown impact are needed to support potential water trades or other entitlement dealings under the QMDB water plans, and for many water licence dealings, including water trades, under the GABORA water plan.

In the QMDB Water Plans, the Condamine and Balonne, and the Border Rivers and Moonie, groundwater drawdown impact assessments are constrained to using the Theis equation with the parameters defined in the relevant water management protocols.

In the GABORA Water Plan, default methods of drawdown assessment based on the Theis equation are outlined in the water management protocol, however the water plan also allows for alternative methods where hydrogeological judgement can be applied, and groundwater drawdown can be estimated using analytical or numerical predictive techniques. The technique selected for a water trade or other licence dealing under this plan needs to be fit-for-purpose. This guideline assists water users, their hydrogeological consultants, and the department, in deciding on the most appropriate drawdown estimation technique, based on the profile of the water trade, and the proximity of other groundwater users and GDEs. This aims to help water users and hydrogeological consultants to understand how much effort will be required to support a water licence dealing application such as a water trade.

The drawdown estimation methods and drawdown impact limits for each of the GABORA and QMDB water plans are summarised in Table 5.

**Table 5: Summary of drawdown assessment requirements in the QMDB and GABORA water plans**

| System | Water Plan | Drawdown Calculation | Unacceptable Impact Statement |
|---|---|---|---|
| **QMDB** | **Border Rivers and Moonie** | $s' = \frac{Q.W(u)}{4\pi T}$ | The application would result in an unacceptable impact if any of the potential drawdown impacts determined in section 167 are **greater than either 10% of the available head in the aquifer or 3 metres, at any registered point of take other than the point(s)** currently stated on the entitlement being dealt with. *(WMP 2019, section 168)* |
| | **Condamine and Balonne** | | If any of the potential drawdown impacts determined in section 228 are greater than **0.5 metres at any registered point of take, other than the points currently stated on the entitlement being changed**, the application would result in an unacceptable impact. *(WMP 2019, section 229)* |
| GABORA | Great Artesian Basin and Other Regional Aquifers | A simple assessment – based on precalculated drawdown estimates using the Theis equation and regionally representative hydraulic parameters for aquifers - can be made using Chapters 3 and 4, and Attachments 4 and 5 of the GABORA water management protocol<br>Alternative methods can also be used (sections 16 and 27 GABORA Management Protocol). | The application would result in an unacceptable impact if: **cumulative estimated drawdown at GDEs exceeds or equals 0.4 metres** (section 41 GABORA Water Plan), or, if **estimated drawdown at other water user bores or entitlements exceeds or equals 5 metres** (section 42 GABORA Water Plan.) |

This document is a guide, and every water trade and licence dealing will be unique. The department should be consulted early and throughout the process to develop a shared understanding of the type of work likely to be required to support a licence application or a water trade.

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# 9. Document control

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**Keywords**

Queensland Government; guideline; groundwater; impact; water plans; drawdown

# Appendix A Water allocations, licences, and trades

In Queensland, consumptive take of water is managed under the Water Act 2000 (Qld), with more specific management rules established in the Water Regulation 2016, water plans, and water management protocols for the respective water plan areas.

## A-1 Water entitlements and water plans

Water plans are based on scientific assessments and broad consultation with the community. They limit the amount of water that may be taken from a water resource by requiring most water users to have a water entitlement such as a water allocation or water licence. Entitlements generally have volumetric limits associated with them, but GAB entitlements for stock watering, domestic, cultural, or environmental purposes are instead limited by conditions placed on the entitlement.
Water plans also define some low volume water use activities that are allowed to happen without needing a water entitlement, provided they adhere to the limits established in the relevant water plan and Water Regulation. Typically, these low volume use activities can include stock watering (but not feedlots) and single household domestic use, and other activities prescribed in the Water Regulation, such as dairy washing. Other low volume use that occurs for a defined period, can occur under water permits, where a water plan allows this.

A water allocation is a tradeable asset. It is an authority or permanent entitlement to take water that is a share of the available water resource in a water management area. A water licence is in some ways like a water allocation, in that it defines water access rights, but licences generally attach to land, meaning the licence holder changes with any changes in land ownership, and they cannot be traded as a defined asset separately to the land. Licences are also for a defined period and can be granted without an assigned volumetric limit. Water licences can be amended, cancelled, or surrendered according to rules established in the Water Act.

Groundwater allocations have the following elements:

- **Nominal volume** is the volume of water available under the entitlement over the long term (this is also the tradeable currency for the water allocation).
- **Volumetric limit** is the maximum amount of water that can be taken. This can be subject to a water sharing rule established as a condition on a water allocation.
- **Location** from which the water may be taken, being the zone and point of take.
- **Purpose**, being the purpose for which water may be taken.
- **Other** conditions which may be assigned or are required by a water plan to be assigned.

Groundwater licences may have the following elements:

- The **term** of the licence (the period over which it authorises water to be taken).
- The **water** to which it relates (for groundwater this is usually a groundwater management area, or part of that area).
- The **location** from which the water may be taken, usually defined as a land parcel, or similar.
- the conditions of the licence.
- **Nominal entitlement** is the volume of water authorised to be taken during a water year under a water licence. This is the volume that may potentially be relocated.
- **Announced entitlement** is a percentage of a nominal entitlement, decided and published by the Department, according to water sharing rules that relate to a water management area.
- **Annual entitlement for a water year** is the volume of water that may be taken during a particular water year (this is the volume that can be used, carried over, or seasonally assigned). It is the

nominal entitlement multiplied by the annual entitlement, and adjusted for any carry over or forward draw applicable to that licence for that water year.

- **Purpose**, being the purpose for which water may be taken.
- **Other** conditions which may be assigned or are required by a water plan to be assigned.

Seasonal assignment of water licences is allowed for certain licences, according to rules defined in water plans, water management protocols, or the Water Regulation.

## A-2 Water Trades

A water allocation has a title and can be bought and sold, or leased, independently of land titles. This enables water allocation holders to buy water to expand their operations or sell water they don't need. Water trading is voluntary, and prices are set by the market. Anyone can buy a water allocation – you do not need to be a landholder – however, movement of the water is restricted by trading rules specified in a water management protocol or the Water Regulation 2016.

Water licences cannot be traded independent of land unless there are management rules in place which allow permanent transfers (relocations) to occur. There are two types of trade: permanent trade (relocation of a licence), or temporary trade (seasonal water assignments). The rules for managing relocations and seasonal water assignments are outlined in the respective water management protocol applicable to the area.

## A-3 Unallocated Water

Water plans can make water available in unallocated water reserves, that can be granted as new water entitlements. There are different types of unallocated water reserves in water plans,

- general reserves that are often released by tender or auction, and available for most purposes
- state reserves that are usually released through an application process, and available only for specific purposes such as projects of regional or state significance, or urban water supply.
- reserves for projects that benefit Aboriginal peoples or Torres Strait Islanders, that are released through processes separate from other unallocated water reserves.
- other reserves that water plans can define.

# Appendix B The Theis equation

Much of the following was sourced from the Aqtesolv web site in December 2021.

Charles Vernon Theis (1900-1987) was the first hydrologist to develop a rigorous mathematical model of transient flow of water to a pumping bore by recognising the physical analogy between heat flow in solids and groundwater flow in porous media.

The Theis (1935) solution (or Theis nonequilibrium method) introduced a ground-breaking tool for determining the hydraulic properties (transmissivity and storativity) of nonleaky confined aquifers.

The Theis equation for flow to a fully penetrating bore discharging at a constant rate in a homogeneous, isotropic and nonleaky confined aquifer of infinite extent is as follows:

$$s = \frac{Q}{4\pi T}\int_{u}^{\infty}\frac{e^{-y}}{y}dy \qquad (1)$$

where: $u = \frac{r^2 S}{4Tt}$

The Theis equation uses parameter values related to the aquifer (transmissivity (T) and storativity (S)), the pumping rate (Q), and duration of proposed pumping (t), to calculate drawdown effects as they propagate away from a pumping bore (or a controlled flow artesian bore). This allows calculation of:

- drawdown (s) at a certain distance (r) from the pumping bore at a specified time (t)
- drawdown at a certain time at a specified distance
- or the time and distance at which a certain drawdown will be reached

Hydrogeologists commonly refer to the integral in (1) as the Theis well function, abbreviated as W(u). This allows the Theis equation to be written more simply as follows:

Theis equation: $s = \frac{Q}{4\pi T}W(u)$

Theis well function:

$$W(u) = -0.577216 - In(u) + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} + \cdots$$

The Theis equation is useful across a range of different aquifer types and is a standard tool for most hydrogeologists. While it was originally developed for use in confined aquifers only, it is also useful in most unconfined aquifers, provided drawdown is causing relatively minor changes to the saturated thickness of the aquifer. In 1944 Jacobs developed a correction factor that accounts for these changes, allowing the Theis equation to be used in unconfined aquifers. However, the Jacobs correction is usually only applied in situations where dewatering of the aquifer's saturated thickness is a significant issue. In situations where drawdown is causing only minor changes to the saturated thickness of an aquifer, the Jacobs correction makes little difference to the Theis equation's estimated drawdowns, so is often not applied.

The Jacobs correction is: $s' = s - s^2/2b$

Where b is saturated thickness of the aquifer, s is observed drawdown, and s' is the corrected drawdown

Table B.1 below shows that in a situation such as when estimating drawdown of 0.5m in an unconfined aquifer such as the Condamine Alluvium, the Jacobs correction need not be applied as it

makes very little difference to the drawdown estimate, except in extremely thin parts of the aquifer, where water bores are generally not constructed.

**Table B.1: The Jacobs correction makes only minor changes to the 0.5 metre Theis equation drawdown predictions in the Condamine Alluvium**

| Predicted drawdown, s | Aquifer thickness, b | $s^2/2b$ | $s - s^2/2b$ | Theis equation prediction error when the Jacobs correction is not used in unconfined aquifers |
|---|---|---|---|---|
| 0.5 m | 100 m | 1 mm | 0.499 m | 0.26 % |
| 0.5 m | 80 m | 2 mm | 0.498 m | 0.31 % |
| 0.5 m | 60 m | 2 mm | 0.498 m | 0.42 % |
| 0.5 m | 40 m | 3 mm | 0.497 m | 0.63 % |
| 0.5 m | 20 m | 6 mm | 0.494 m | 1.25 % |
| 0.5 m | 10 m | 13 mm | 0.487 m | 2.5 % |
| 0.5 m | 5 m | 25 mm | 0.475 m | 5.0 % |

The Theis equation can be solved by hand calculation or computed using specialised software or numerical methods developed for use in spreadsheets or computer code.

# Appendix C How to find GABORA related data online

**How to access GDE information**

- In Queensland Globe – Add the *Inland waters* layers; Choose *Water management information* layers; Choose *Water plans and other items* layers; Choose *Water plan GABORA* layers. Open the 3 layers that make up the GDE register:
  - Groundwater dependent ecosystem springs
  - Groundwater dependent ecosystem areas
  - Groundwater dependent ecosystem watercourses.

Click on individual GDEs on the map to see the register details for that GDE, including location, source aquifer groundwater unit/s and cumulative drawdown.

- In QSpatial – Search for “GDE” and request a download of the data to be emailed to you. There are 3 spatial datasets comprising the GDE register that need to be downloaded. These will need to be opened using GIS software:
  - Groundwater dependent ecosystems areas – Queensland
  - Groundwater dependent ecosystem watercourses – Queensland
  - Groundwater dependent ecosystem springs – Queensland.

Please be aware that the online versions of the GABORA GDE register contain cumulative drawdowns for GDEs relevant for the date this data was published online. The department updates these online data every 1-2 years only, so this online cumulative drawdown data should not be relied upon for doing drawdown estimation assessments intended to support water licence dealings under the GABORA water plan. Current versions of the cumulative drawdown dataset are available from the department, if required.

**How to access water bore and water entitlement information**

- The groundwater database contains information about water bores in Queensland and is available for download online through the QSpatial website. Search for “groundwater database” and request a download of the data to be emailed to you.
- Water licence information can be viewed online through the Water Entitlement Viewer, and downloaded through the Queensland Data Portal or QSpatial website.
  - If using the Data Portal, directly download the relevant files from the web. One file contains the attributes for active water licences in Qld, another contains the locations of active water licences.
  - If using QSpatial, search for “water licences” and request a download of the data to be emailed to you. This will need to be opened using GIS software.

# Appendix D Transmissivities for the GABORA water management protocol default drawdown estimation method

The minimum bore separation distances and long-term drawdown multipliers in Attachments 4 and 5 of the GABORA Water Management Protocol 2017 were calculated using the Theis equation, as explained in section 4 of this guideline. This Appendix D of the guideline explains how the values for transmissivity used in the Theis equation calculations for those protocol attachments, were arrived at.

A 2016 review of groundwater reports and published technical papers identified ranges of transmissivity and storativity relevant to GABORA aquifers. The results of this review are summarised in Table D.1.

The Queensland groundwater database also contains transmissivity data from over 2,000 GABORA water plan bores. This data is the result of past analyses done on measurements taken during flow tests conducted on production bores. The results are summarised in Table D.2. Figure D.1 shows the range of average transmissivities calculated (geometric mean) for those sub-areas with sufficient data for statistical analysis. Descriptive statistics and histograms for transmissivity for these units, based on this data, are shown in Appendix E.

The GABORA water management protocol 2017 simplified the bore separation criteria established in the 2007 GAB ROP, improved fairness for new water users, and improved water security for water bores in low transmissivity aquifers. The 2007 ROP separation rules favoured large water users at the expense of small water users such as S&D bores. Under the 2017 rules, all water users are treated the same, as this is the intent of the maximum drawdown rules established in the GABORA water plan.

The 2017 GABORA water management protocol is based on assigning each GABORA aquifer to one of four groups of aquifers based on transmissivity, as shown in Table D.1 and Figure D.1. Sub-areas without sufficient transmissivity data in the groundwater database were assigned to groups based on their hydrogeologic similarity to sub-areas that have data, as recorded in Tables D.1 and D.2. Each of these groups of aquifers were assigned a representative transmissivity for calculating appropriate bore separation distances and long-term drawdown multipliers for the GABORA water management protocol.

Appendix F shows maps of the areas of the Hooray, Hutton, and Precipice aquifers that are effectively excluded from new licences by the minimum bore separation criteria established in the protocol, for 2ML licences, 100ML licences, and 450ML licences. These maps are based on the location of existing bores in 2017, so are indicative, but not precise representations of areas for potential new bore sites today. They are useful for understanding the effects of the bore separation rules on GABORA aquifers. There is generally potential scope for new bore drilling, including for make-good, licence relocation (trade), and grants of unallocated water, and stock bores, that take less than about 50 - 100ML per year. For licences taking greater than this, there are limited new bore sites available in the more heavily used parts of aquifers, such as the Roma – Toowoomba area, and especially in the aquifers with lower transmissivity. However, this is done to provide security of access to existing water users, protecting past investments in water supplies that support existing businesses and communities.

**Table D.1: Summary of findings related to aquifer transmissivity for GABORA water plan aquifers. Transmissivity values shown are in $m^2$/day.**

| Basin | Aquifer | Transmissivity used to develop the 2006 GAB ROP | Literature review findings | | $T_{GWDB}$ | Comments | Transmissivity used to develop the 2017 WMP |
|---|---|---|---|---|---|---|---|
| | | | $T_{Low}$ | $T_{High}$ | | | |
| Surat | Wallumbilla | 50 | 13 | 82 | limited data | Eromanga Basin data was also considered | 10 |
| | Bungil | 50 | 1 | 19 | 4 | | 10 |
| | Mooga | 50 | 7 | 22 | 6 | | 10 |
| | Gubberamunda | 50 | 13 | 78 | 12 | | 10 |
| | East Springbok Walloon | 50 | 1 | 13 | 30 | | 50 |
| | West Springbok Walloon | 150 | | | 42 | | |
| | Hutton | 150 | 1 | 19 | 31 | | 50 |
| | Precipice | 150 | 1 | 1029 | 61 | | 50 |
| Bowen | Clematis | 50 | 1 | 126 | 16 | | 10 |
| Clarence Moreton | Walloon | 50 | - | - | limited data | Information from the Surat Basin was also considered | 50 |
| | Marburg | 50 | 11 | 108 | limited data | | 50 |
| | Woogaroo | 50 | 9 | 2100 | limited data | | 50 |
| Mulgildie | Hutton | 150 | - | - | No data | Information from the Surat Basin was also considered | 50 |
| | Precipice | 150 | 0.4 | 155 | No data | | 50 |

| Basin | Aquifer | Transmissivity used to develop the 2006 GAB ROP | Literature review findings | | $T_{GWDB}$ | Comments | Transmissivity used to develop the 2017 WMP |
|---|---|---|---|---|---|---|---|
| | | | $T_{Low}$ | $T_{High}$ | | | |
| Laura | Rolling Downs | 50 | - | - | No data | Information from the GAB was also considered | 10 |
| | Gilbert River equivalent | 50 | 23 | 1137 | limited data | Information from the GAB was also considered | 50 |
| Karumba | Wyaaba beds | 250 | 183 | 700 | limited data | High T cavernous limestone. Similar bore separation to better GAB aquifers is appropriate | 220 |
| | Bulimba Formation | 250 | 5 | 3000 | 124 | | 110 |
| Carpentaria | Normanton | - | 7 | 3000 | No data | Information from the Eromanga Basin was also considered | 10 |
| | Rolling Downs | 50 | - | - | limited data | Information from the Eromanga Basin was also considered | 10 |
| | Southern Carpentaria Gilbert River Aquifer | 50 | 1 | 2990 | 42 | | 50 |
| | Gulf Gilbert River Aquifer | | | | limited data in GWDB | Information from the Southern Carpentaria Basin was also considered | 50 |
| | Cape Gilbert River Aquifer | | | | | 2014 DSITIA model report has median T= 200, and uses T=100 to make lower estimate of groundwater throughflow. | 110 |

| Basin | Aquifer | Transmissivity used to develop the 2006 GAB ROP | Literature review findings | | $T_{GWDB}$ | Comments | Transmissivity used to develop the 2017 WMP |
|---|---|---|---|---|---|---|---|
| | | | $T_{Low}$ | $T_{High}$ | | | |
| Eromanga | Winton Mackunda | - | 6 | 78 | limited data | Information from the Wallumbilla was also considered | 10 |
| | Wallumbilla | 50 | 1 | 18 | 15 | | 10 |
| | Cadna-owie | 50 | 3 | 434 | 8 | | 10 |
| | South Hooray | 150 | | | 43 | | 50 |
| | West Hooray | 50 | | | 57 | | 50 |
| | North Hooray | 150 | | | 96 | | 110 |
| | East Hooray | 150 | | | 119 | | 110 |
| | Adori Injune Creek | 150 | 1 | 1 | 121 | | 110 |
| | Hutton | 150 | 3 | 580 | 218 | | 220 |
| | Precipice | 150 | 12 | 400 | limited data | Information from the Surat Basin was also considered | 50 |
| Galilee | Clematis | 50 | 11 | 1100 | limited data | Information from the Bowen Basin was also considered | 10 |
| | Betts Creek beds | - | 3 | 400 | limited data | | 10 |

**Figure D.1: Summary of sub-area transmissivity data from the GWDB**

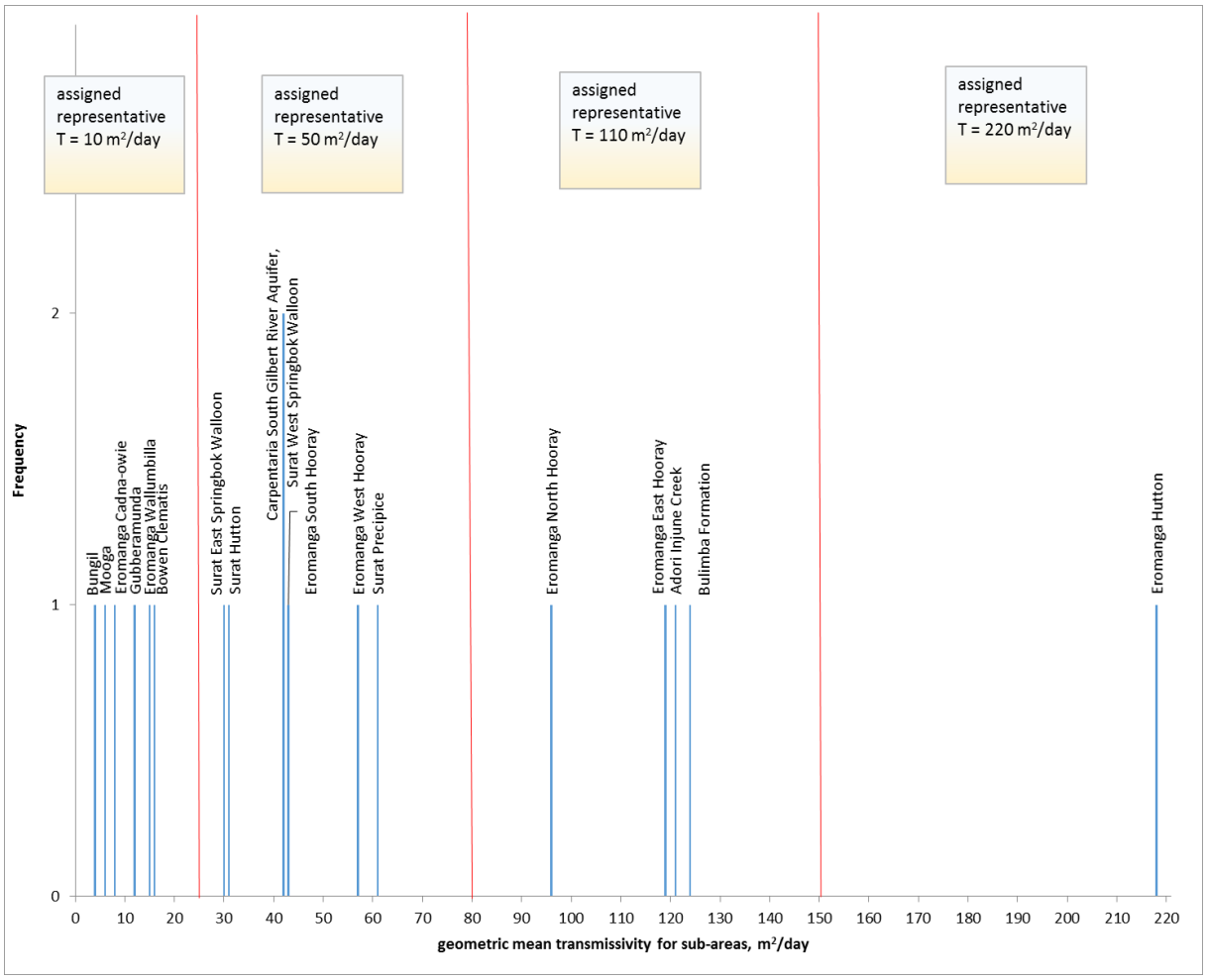
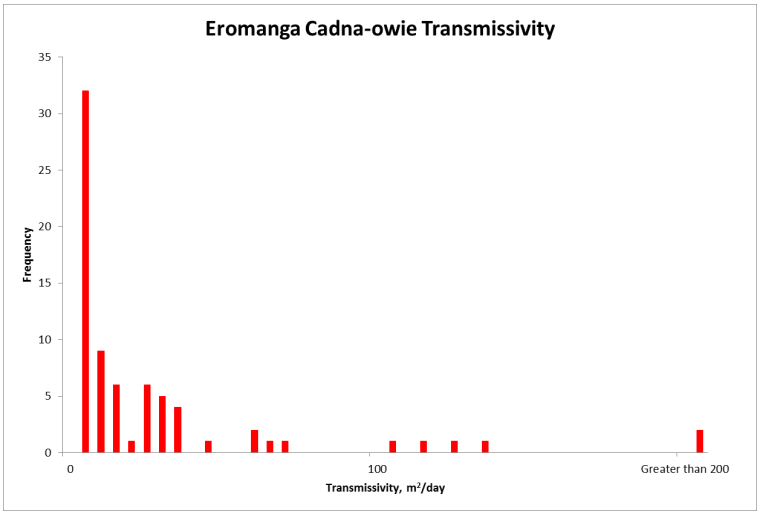


**Table D.2: Representative transmissivities ($m^2$/day) used for calculating drawdown for the GABORA water management protocol.**

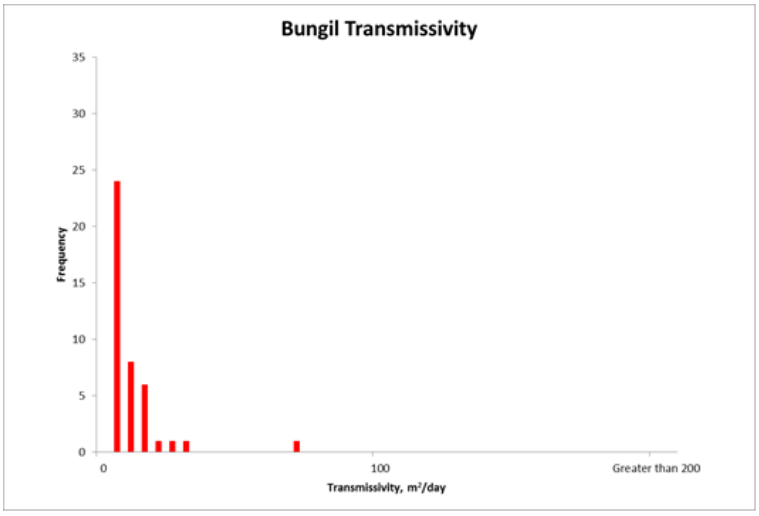
| Sub-areas that were assigned transmissivity based on GWDB data (see Figure 1) | Sub-areas with limited data in the GWDB that were assigned transmissivity based on:<br>similarity to other sub-areas<br>modelling studies<br>understanding of the aquifer hydrogeology | | Representative transmissivity assigned to sub-areas for the GABORA water management protocol 2017 |
|---|---|---|---|
| • Bowen Clematis<br>• Cadna-owie (all sub-areas)<br>• Eromanga Wallumbilla<br>• Gubberamunda<br>• Mooga | • Betts Creek Beds<br>• Cape Rolling Downs<br>• Carpentaria South Wallumbilla<br>• Galilee Clematis<br>• Gulf Rolling Downs | • Laura Rolling Downs<br>• Normanton<br>• Surat Wallumbilla<br>• Winton Mackunda | 10 |
| • Carpentaria South Gilbert River Aquifer<br>• Eromanga South Hooray<br>• Eromanga West Hooray<br>• Surat Precipice<br>• Surat East Springbok Walloon<br>• Surat Hutton<br>• Surat West Springbok Walloon | • Crows Nest Marburg<br>• Crows Nest Woogaroo<br>• Eastern Downs Marburg<br>• Eastern Downs Precipice<br>• Eastern Downs Springbok Walloon<br>• Eromanga Precipice<br>• Gatton Esk Road Marburg<br>• Gatton Esk Road Woogaroo<br>• Gulf Gilbert River Aquifer | • Laura Gilbert River equivalents<br>• Mulgildie North Hutton<br>• Murphys Creek Marburg<br>• Murphys Creek Woogaroo<br>• Redbank Creek Woogaroo<br>• Southern Clarence Moreton Marburg<br>• Southern Clarence Moreton Walloon<br>• Southern Clarence Moreton Woogaroo | 50 |
| • Adori Injune Creek<br>• Bulimba Formation<br>• Eromanga East Hooray<br>• Eromanga North Hooray | • Cape Gilbert River Aquifer | | 110 |
| • Eromanga Hutton | • Wyaaba Beds | | 220 |

# Appendix E Transmissivity histograms for GABORA aquifers based on data in the Queensland groundwater database

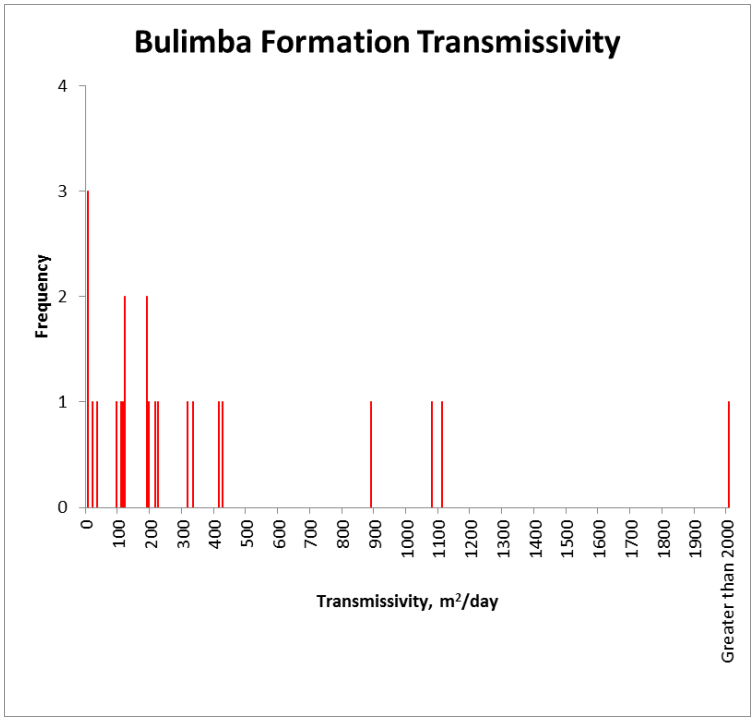
| Descriptive Statistics for GWDB transmissivity data for bores tested in the Eromanga Cadna-owie groundwater sub-area | |
|---|---|
| Geometric mean | 7.85083 |
| Mean | 36.2568 |
| Standard Error | 12.9781 |
| Median | 7 |
| Mode | 1 |
| Standard Deviation | 111.642 |
| Sample Variance | 12463.9 |
| Kurtosis | 41.8342 |
| Skewness | 6.16664 |
| Range | 851 |
| Minimum | 1 |
| Maximum | 852 |
| Sum | 2683 |
| Count | 74 |



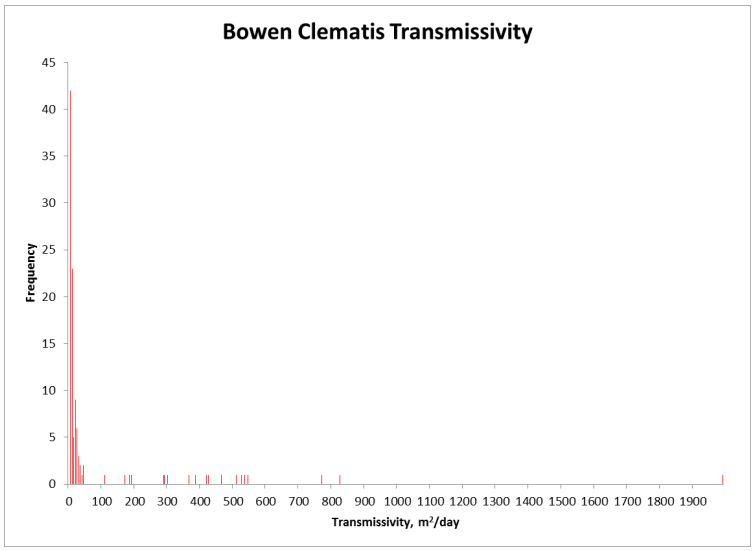

| Descriptive Statistics for GWDB transmissivity data for bores tested in the Bungil groundwater sub-area | |
|---|---|
| Geometric mean | 4.10207 |
| Mean | 7.71429 |
| Standard Error | 1.73315 |
| Median | 4.5 |
| Mode | 1 |
| Standard Deviation | 11.2321 |
| Sample Variance | 126.160 |
| Kurtosis | 19.0701 |
| Skewness | 3.89947 |
| Range | 66 |
| Minimum | 1 |
| Maximum | 67 |
| Sum | 324 |
| Count | 42 |



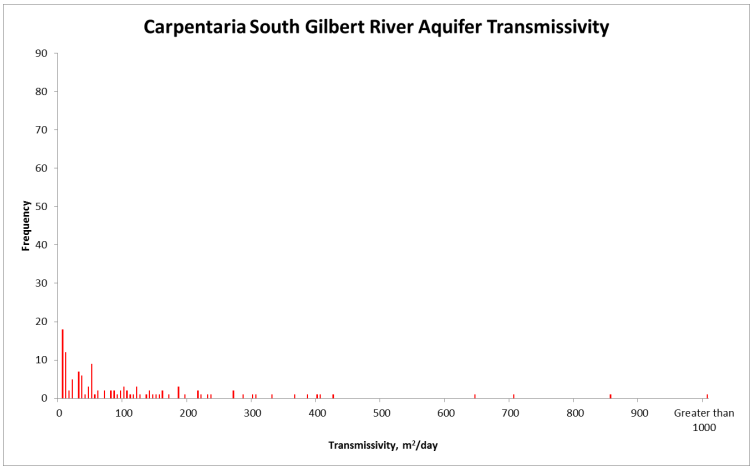
| Descriptive Statistics for GWDB transmissivity data for bores tested in the Bulimba groundwater sub-area | |
|---|---|
| Geometric mean | 124.368 |
| Mean | 368.826 |
| Standard Error | 110.833 |
| Median | 188 |
| Standard Deviation | 531.536 |
| Sample Variance | 282531 |
| Kurtosis | 7.72009 |
| Skewness | 2.61185 |
| Range | 2309 |
| Minimum | 1 |
| Maximum | 2310 |
| Sum | 8483 |
| Count | 23 |



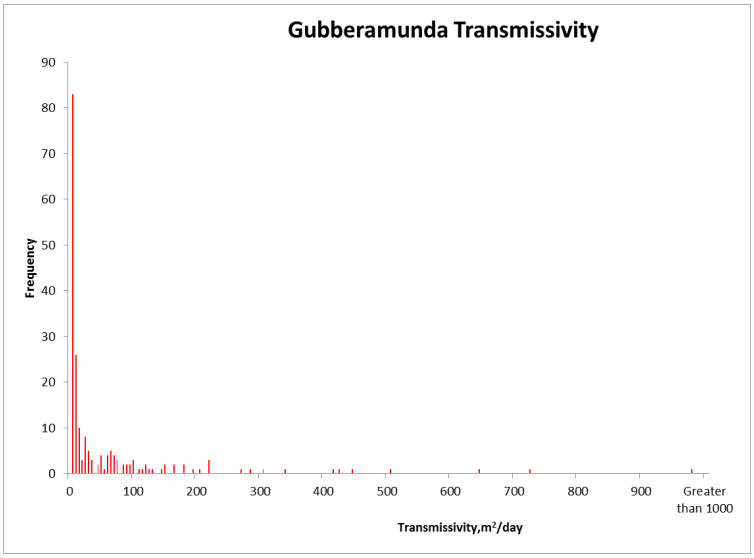

| Descriptive Statistics for GWDB transmissivity data for bores tested in the Bowen Clematis groundwater sub-area | |
|---|---|
| Geometric mean | 12.9356 |
| Mean | 89.3514 |
| Standard Error | 23.2481 |
| Median | 8 |
| Mode | 4 |
| Standard Deviation | 244.934 |
| Sample Variance | 59992.7 |
| Kurtosis | 33.6353 |
| Skewness | 5.07360 |
| Range | 1989 |
| Minimum | 1 |
| Maximum | 1990 |
| Sum | 9918 |
| Count | 111 |



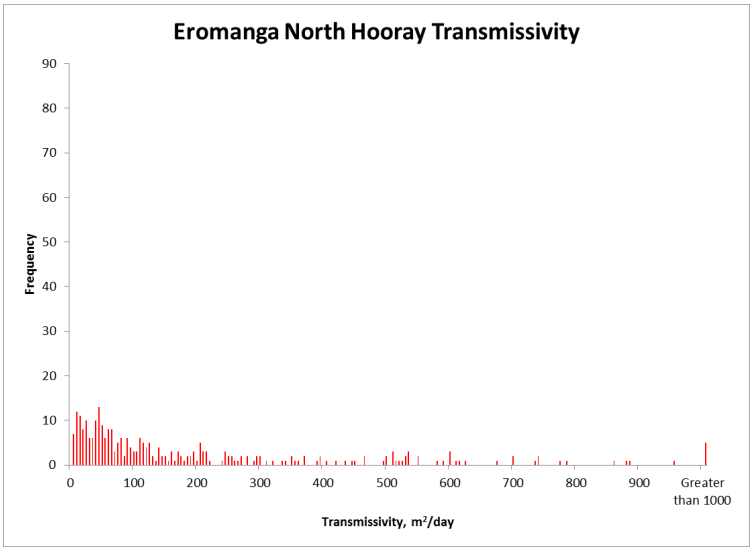
| Descriptive Statistics for GWDB transmissivity data for bores tested in the Carpentaria South Gilbert River Aquifer groundwater sub-area | |
|---|---|
| Geometric mean | 40.1153 |
| Mean | 119.050 |
| Standard Error | 18.8014 |
| Median | 49 |
| Mode | 1 |
| Standard Deviation | 205.099 |
| Sample Variance | 42065.4 |
| Kurtosis | 31.0534 |
| Skewness | 4.76467 |
| Range | 1699 |
| Minimum | 1 |
| Maximum | 1700 |
| Sum | 14167 |
| Count | 119 |



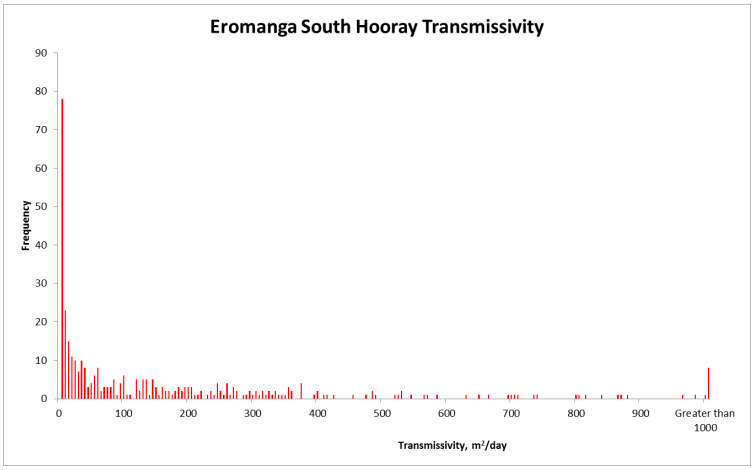

| Descriptive Statistics for GWDB transmissivity data for bores tested in the Gubberamunda groundwater sub-area | |
|---|---|
| Geometric mean | 12.163 |
| Mean | 57.337 |
| Standard Error | 8.8092 |
| Median | 8 |
| Mode | 1 |
| Standard Deviation | 124.27 |
| Sample Variance | 15443 |
| Kurtosis | 22.085 |
| Skewness | 4.2147 |
| Range | 979 |
| Minimum | 1 |
| Maximum | 980 |
| Sum | 11410 |
| Count | 199 |



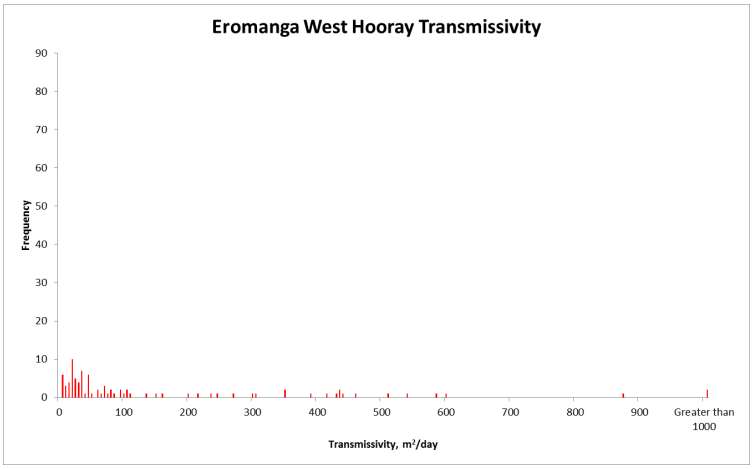
| Descriptive Statistics for GWDB transmissivity data for bores tested in the Eromanga North Hooray groundwater sub-area | |
|---|---|
| Geometric mean | 12.163 |
| Mean | 57.337 |
| Standard Error | 8.8092 |
| Median | 8 |
| Mode | 1 |
| Standard Deviation | 124.27 |
| Sample Variance | 15443 |
| Kurtosis | 22.085 |
| Skewness | 4.2147 |
| Range | 979 |
| Minimum | 1 |
| Maximum | 980 |
| Sum | 11410 |
| Count | 199 |



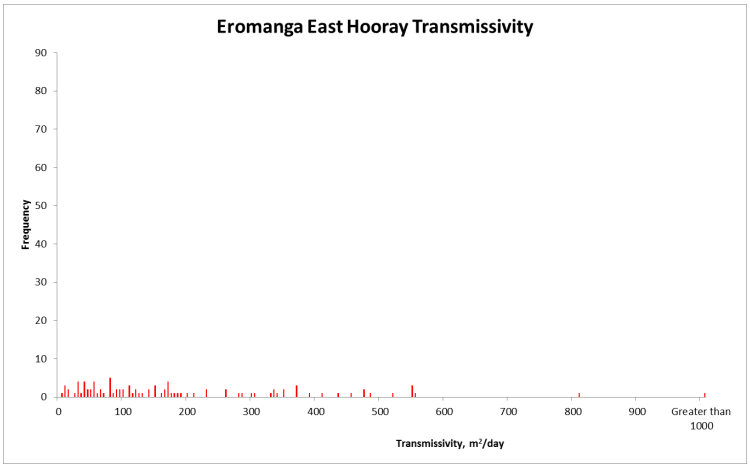

| Descriptive Statistics for GWDB transmissivity data for bores tested in the Eromanga South Hooray groundwater sub-area | |
|---|---|
| Geometric mean | 43.13606 |
| Mean | 249.584 |
| Standard Error | 67.36985 |
| Median | 58 |
| Mode | 1 |
| Standard Deviation | 1283.568 |
| Sample Variance | 1647547 |
| Kurtosis | 317.535 |
| Skewness | 17.30539 |
| Range | 23839 |
| Minimum | 1 |
| Maximum | 23840 |
| Sum | 90599 |
| Count | 363 |



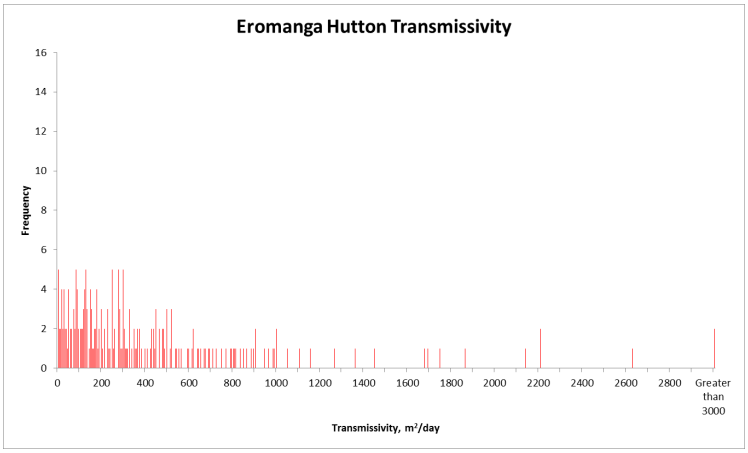
| Descriptive Statistics for GWDB transmissivity data for bores tested in the Eromanga West Hooray groundwater sub-area | |
|---|---|
| Geometric mean | 57.245 |
| Mean | 154.25 |
| Standard Error | 24.757 |
| Median | 45 |
| Mode | 17 |
| Standard Deviation | 233.56 |
| Sample Variance | 54550 |
| Kurtosis | 7.4256 |
| Skewness | 2.5336 |
| Range | 1242 |
| Minimum | 2 |
| Maximum | 1244 |
| Sum | 13728 |
| Count | 89 |



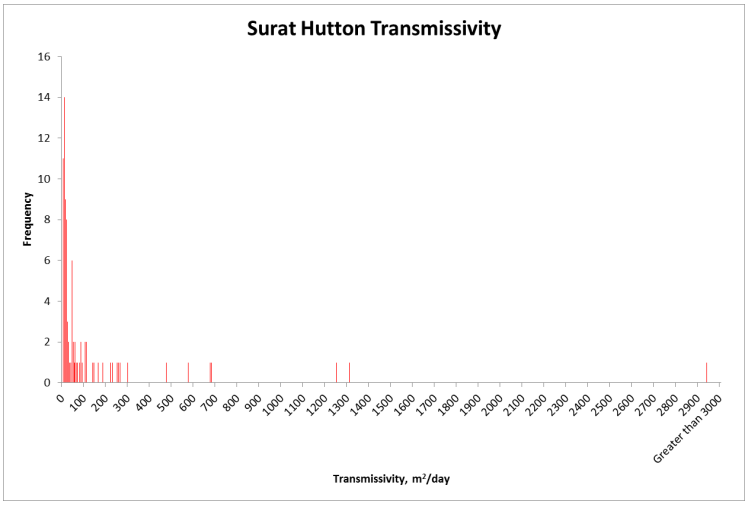

| Descriptive Statistics for GWDB transmissivity data for bores tested in the Eromanga East Hooray groundwater sub-area | |
|---|---|
| Geometric mean | 119.04 |
| Mean | 195.86 |
| Standard Error | 18.879 |
| Median | 139 |
| Mode | 150 |
| Standard Deviation | 185.94 |
| Sample Variance | 34573 |
| Kurtosis | 4.0892 |
| Skewness | 1.7403 |
| Range | 1036 |
| Minimum | 2 |
| Maximum | 1038 |
| Sum | 18998 |
| Count | 97 |



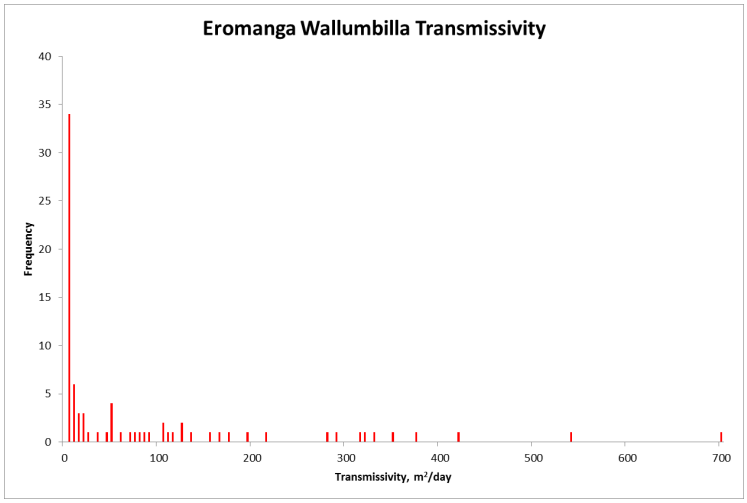
| Descriptive Statistics for GWDB transmissivity data for bores tested in the Eromanga Hutton groundwater sub-area | |
|---|---|
| Geometric mean | 217.883 |
| Mean | 447.059 |
| Standard Error | 46.0739 |
| Median | 279 |
| Mode | 300 |
| Standard Deviation | 684.937 |
| Sample Variance | 469139 |
| Kurtosis | 47.6185 |
| Skewness | 5.77880 |
| Range | 7195 |
| Minimum | 1 |
| Maximum | 7196 |
| Sum | 98800 |
| Count | 221 |



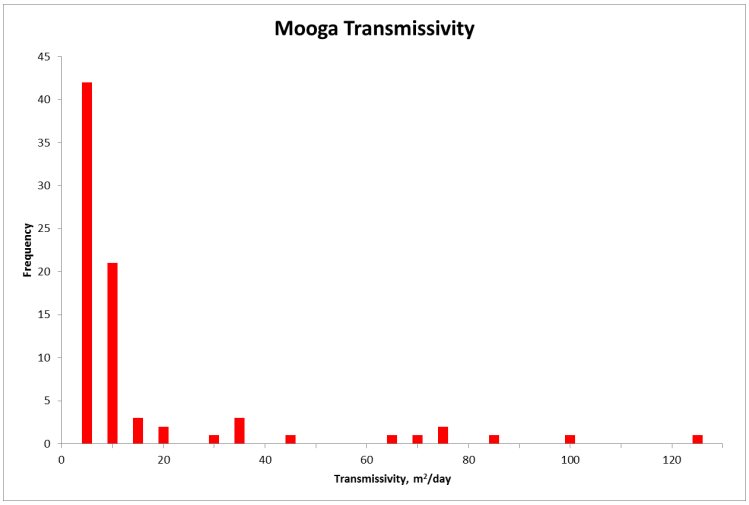

| Descriptive Statistics for GWDB transmissivity data for bores tested in the Surat Hutton groundwater sub-area | |
|---|---|
| Geometric mean | 30.8074 |
| Mean | 138.483 |
| Standard Error | 40.5777 |
| Median | 22 |
| Mode | 12 |
| Standard Deviation | 378.484 |
| Sample Variance | 143250 |
| Kurtosis | 36.5265 |
| Skewness | 5.55284 |
| Range | 2939 |
| Minimum | 1 |
| Maximum | 2940 |
| Sum | 12048 |
| Count | 87 |



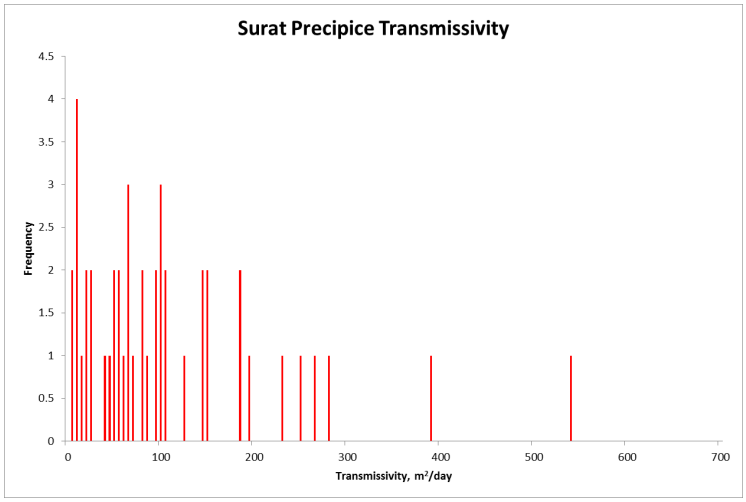
| Descriptive Statistics for GWDB transmissivity data for bores tested in the Eromanga Wallumbilla groundwater sub-area | |
|---|---|
| Geometric mean | 14.680 |
| Mean | 80.901 |
| Standard Error | 14.996 |
| Median | 13 |
| Mode | 1 |
| Standard Deviation | 134.97 |
| Sample Variance | 18216 |
| Kurtosis | 6.2912 |
| Skewness | 2.3877 |
| Range | 699 |
| Minimum | 1 |
| Maximum | 700 |
| Sum | 6553 |
| Count | 81 |



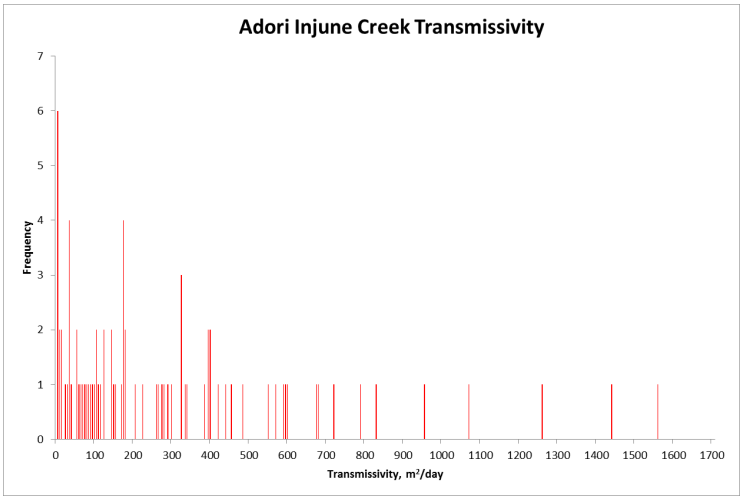

| Descriptive Statistics for GWDB transmissivity data for bores tested in the Mooga groundwater sub-area | |
|---|---|
| Geometric mean | 5.606 |
| Mean | 13.63 |
| Standard Error | 2.659 |
| Median | 5 |
| Mode | 2 |
| Standard Deviation | 23.78 |
| Sample Variance | 565.6 |
| Kurtosis | 8.049 |
| Skewness | 2.848 |
| Range | 123 |
| Minimum | 1 |
| Maximum | 124 |
| Sum | 1090 |
| Count | 80 |



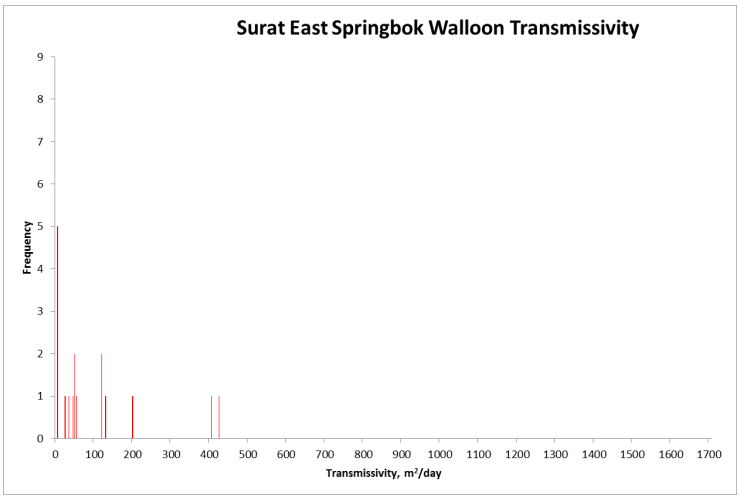
| Descriptive Statistics for GWDB transmissivity data for bores tested in the Surat Precipice groundwater sub-area | |
|---|---|
| Geometric mean | 61.416 |
| Mean | 105.48 |
| Standard Error | 15.693 |
| Median | 79 |
| Mode | 64 |
| Standard Deviation | 106.44 |
| Sample Variance | 11329 |
| Kurtosis | 5.5708 |
| Skewness | 2.0744 |
| Range | 535 |
| Minimum | 3 |
| Maximum | 538 |
| Sum | 4852 |
| Count | 46 |



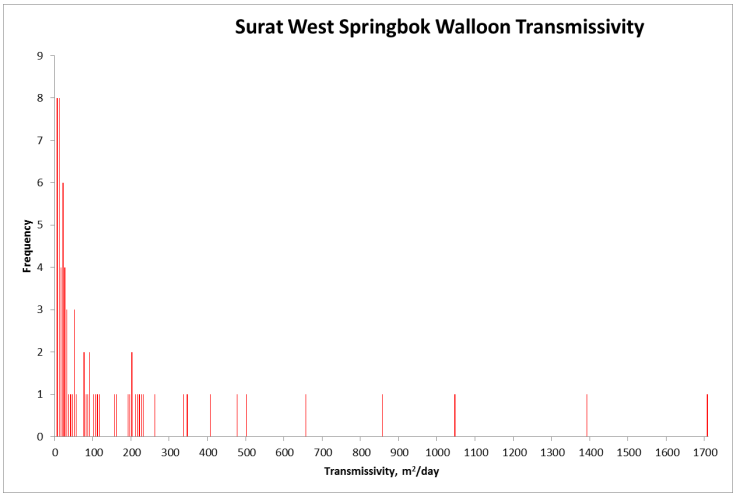

| Descriptive Statistics for GWDB transmissivity data for bores tested in the Adori Injune Creek groundwater sub-area | |
|---|---|
| Geometric mean | 120.564 |
| Mean | 291.683 |
| Standard Error | 36.1755 |
| Median | 173.5 |
| Mode | 1 |
| Standard Deviation | 327.583 |
| Sample Variance | 107310 |
| Kurtosis | 3.94575 |
| Skewness | 1.89839 |
| Range | 1557 |
| Minimum | 1 |
| Maximum | 1558 |
| Sum | 23918 |
| Count | 82 |



| Descriptive Statistics for GWDB transmissivity data for bores tested in the Surat East Springbok Walloon groundwater sub-area | |
|---|---|
| Geometric mean | 29.553 |
| Mean | 96.824 |
| Standard Error | 31.944 |
| Median | 46 |
| Mode | 2 |
| Standard Deviation | 131.71 |
| Sample Variance | 17347 |
| Kurtosis | 2.6779 |
| Skewness | 1.8488 |
| Range | 423 |
| Minimum | 1 |
| Maximum | 424 |
| Sum | 1646 |
| Count | 17 |




| Descriptive Statistics for GWDB transmissivity data for bores tested in the Surat West Springbok Walloon groundwater sub-area | |
|---|---|
| Geometric mean | 42.402 |
| Mean | 163.14 |
| Standard Error | 35.984 |
| Median | 46 |
| Mode | 1 |
| Standard Deviation | 305.34 |
| Sample Variance | 93230 |
| Kurtosis | 12.354 |
| Skewness | 3.3433 |
| Range | 1700 |
| Minimum | 1 |
| Maximum | 1701 |
| Sum | 11746 |
| Count | 72 |

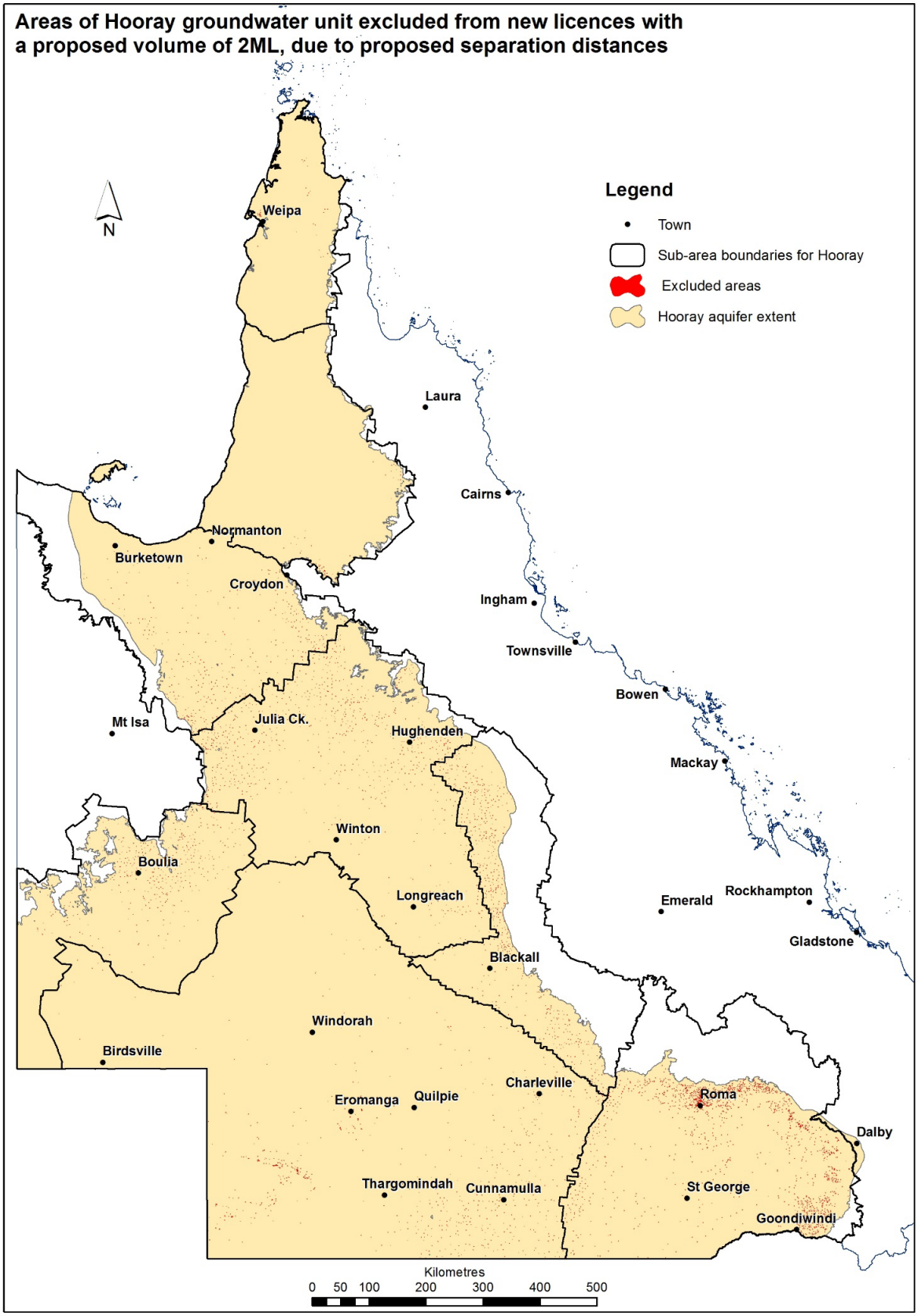


# Appendix F The effect of the bore separation rules on new bore sites in GABORA aquifers

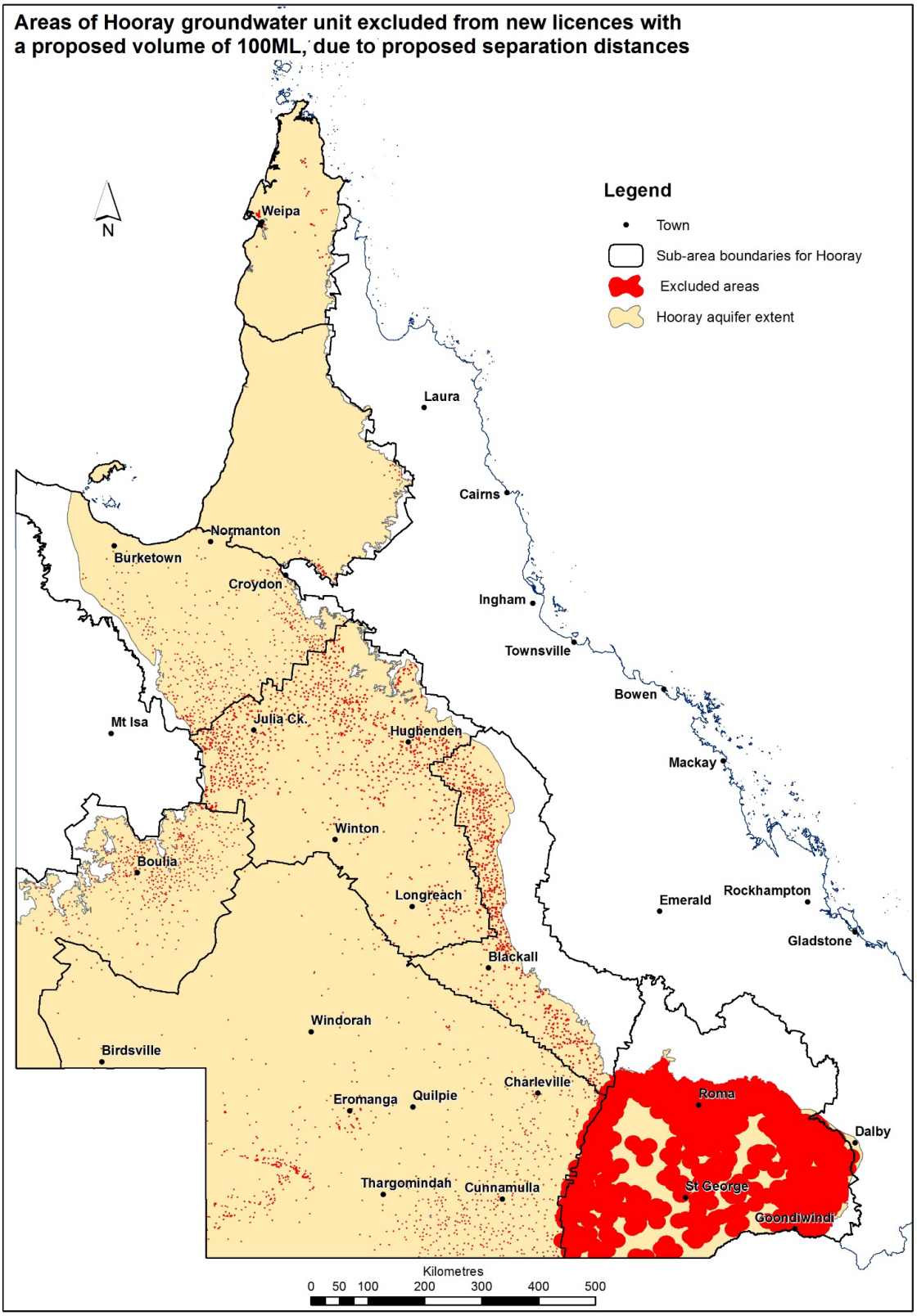
The maps shown in this Appendix F were prepared to illustrate the effects of the bore separation rules of the GABORA water management protocol, when they were proposed in 2017, before the protocol was approved and published. The 3 main aquifers; Hooray, Hutton, and Precipice, are each shown in 3 maps (making a total of nine maps). For each groundwater unit there are 3 maps showing the areas of aquifer in which the bore separation rules prevent the drilling of new water bores, in red, for proposed takes of water that are: 2ML, 100ML, and 450ML. They are based on the locations of bores in 2017, so are indicative, but not precise representations of areas for potential new bore sites today. However, they provide an indication of the areas of the Hooray, Hutton, and Precipice aquifers that are effectively excluded from new licences by the minimum bore separation criteria established in the 2017 protocol.

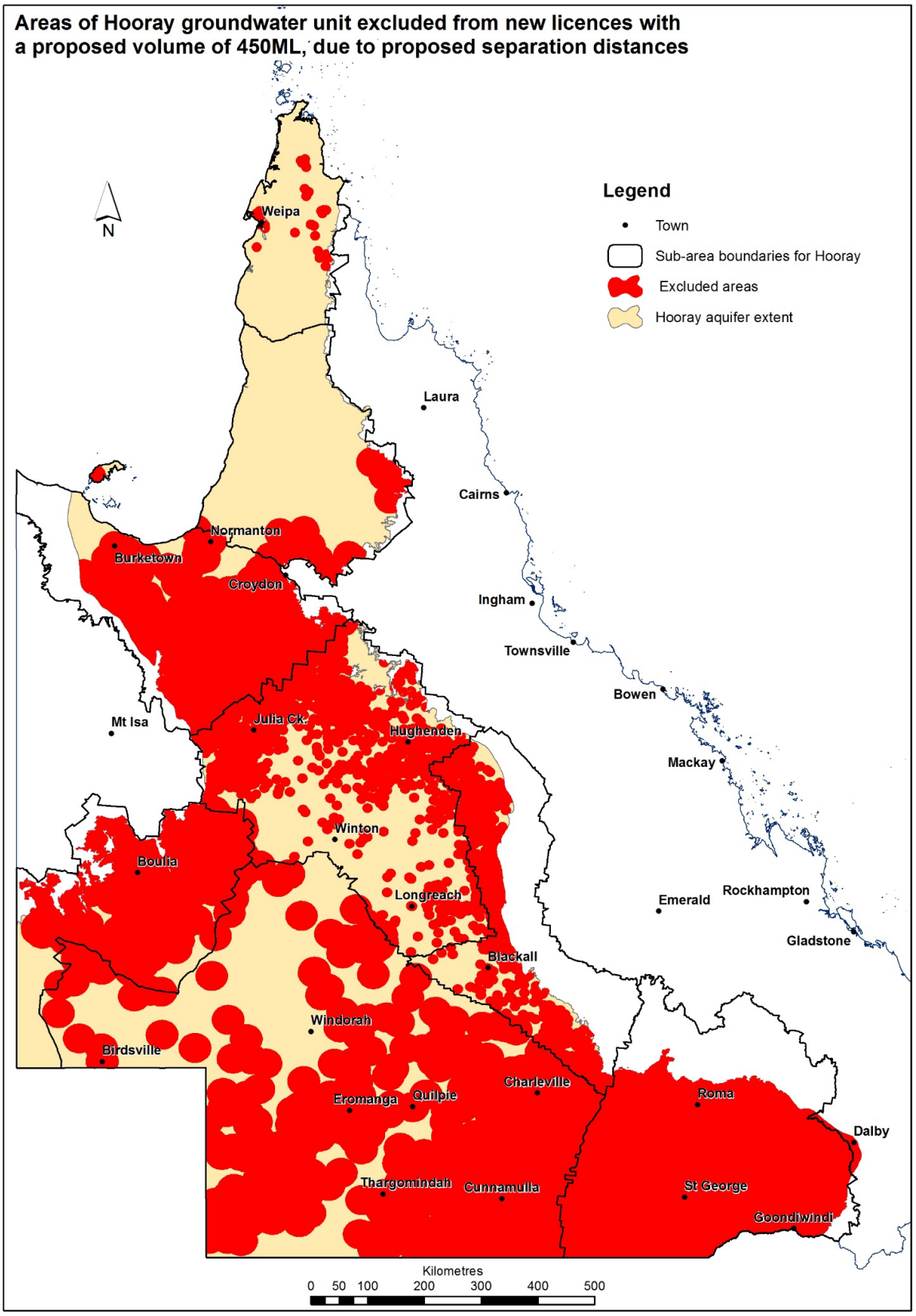
There is generally scope for new bore drilling, including for make-good, licence relocation (trade), and grants of unallocated water, and stock bores, that take less than about 50 - 100ML per year. For licences taking greater than this, there are limited new bore sites available in the more heavily used parts of aquifers, such as the Roma – Toowoomba area, and especially in the aquifers with lower transmissivity.

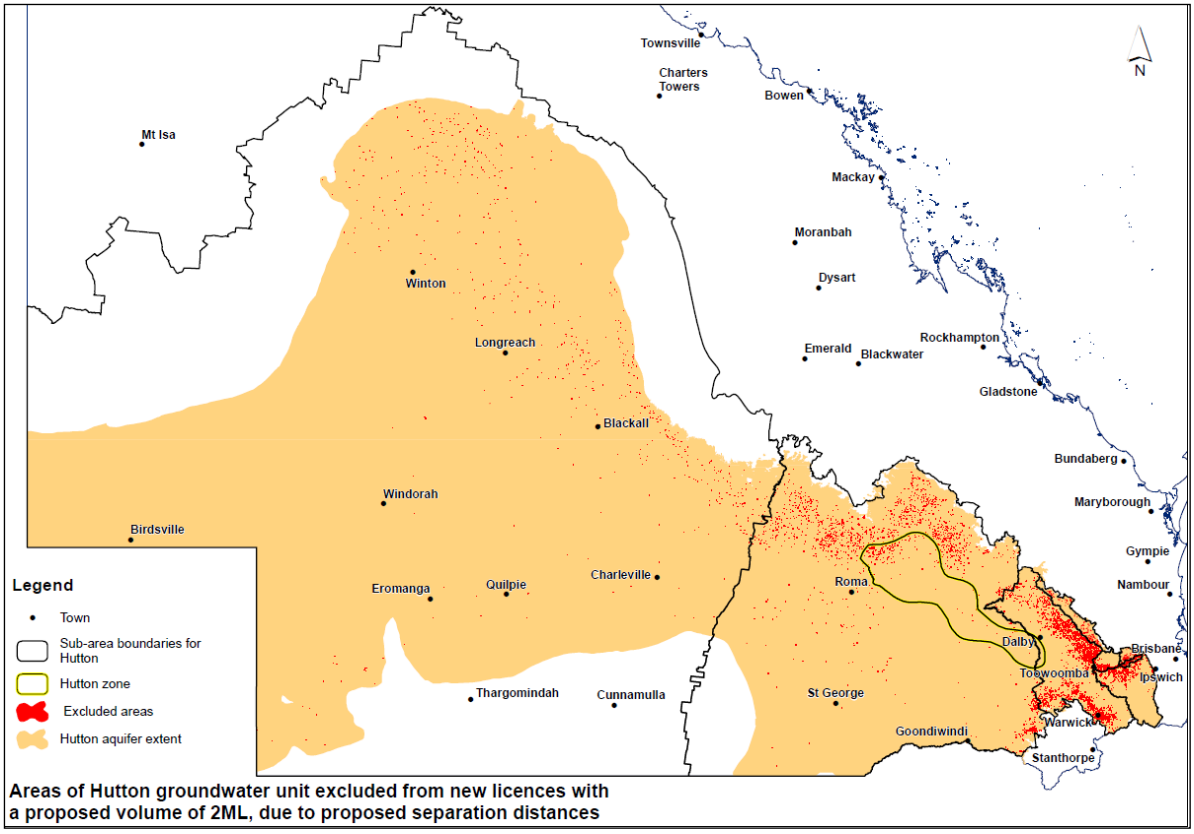
However, this is done to provide security of access to existing water users, protecting past investments in water supplies that support existing businesses and communities.


Areas of Hooray groundwater unit excluded from new licences with a proposed volume of 2ML, due to proposed separation distances
N
Legend
Town
Sub-area boundaries for Hooray
Excluded areas
Hooray aquifer extent
Weipa
Laura
Cairns
Normanton
Burketown
Croydon
Ingham
Townsville
Bowen
Mt Isa
Julia Ck.
Hughenden
Mackay
Winton
Boulia
Longreach
Emerald
Rockhampton
Gladstone
Blackall
Windorah
Birdsville
Charleville
Eromanga
Quilpie
Roma
Dalby
Thargomindah
Cunnamulla
St George
Goondiwindi
Kilometres
0 50 100 200 300 400 500

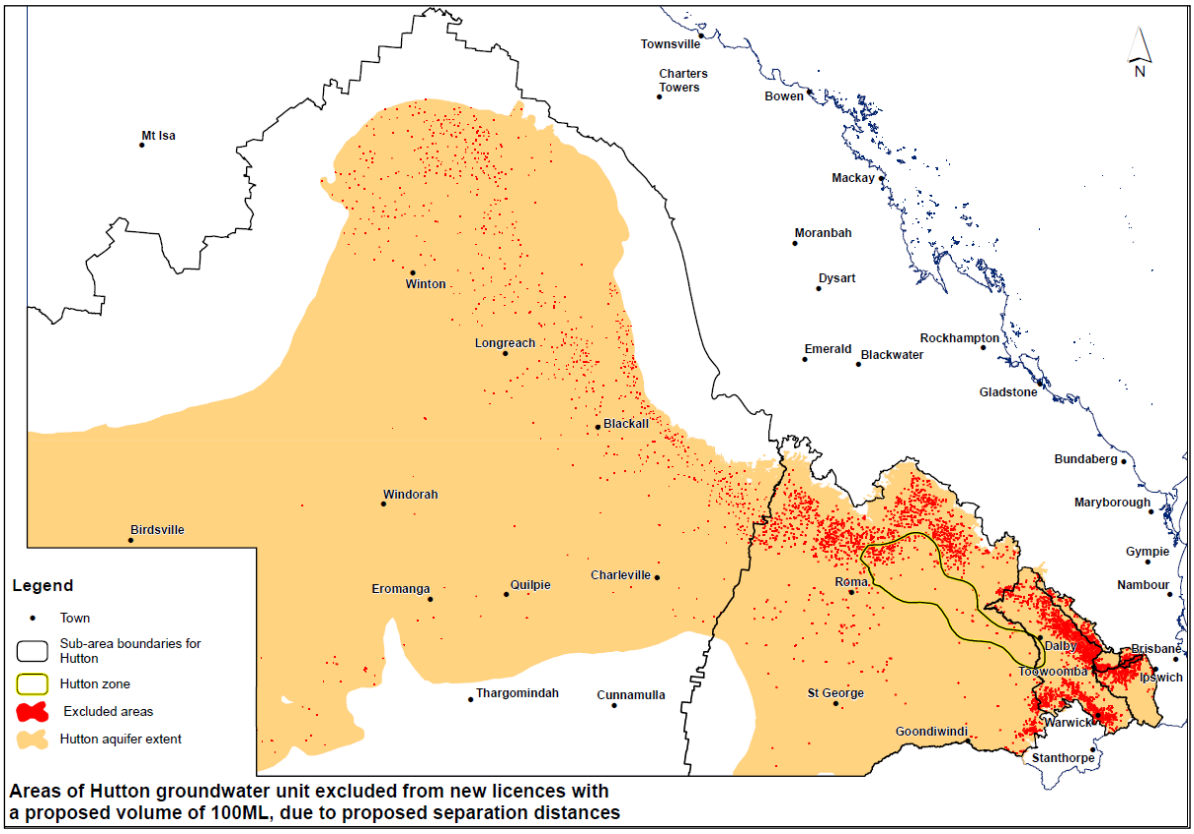
**Areas of Hooray groundwater unit excluded from new licences with a proposed volume of 100ML, due to proposed separation distances**



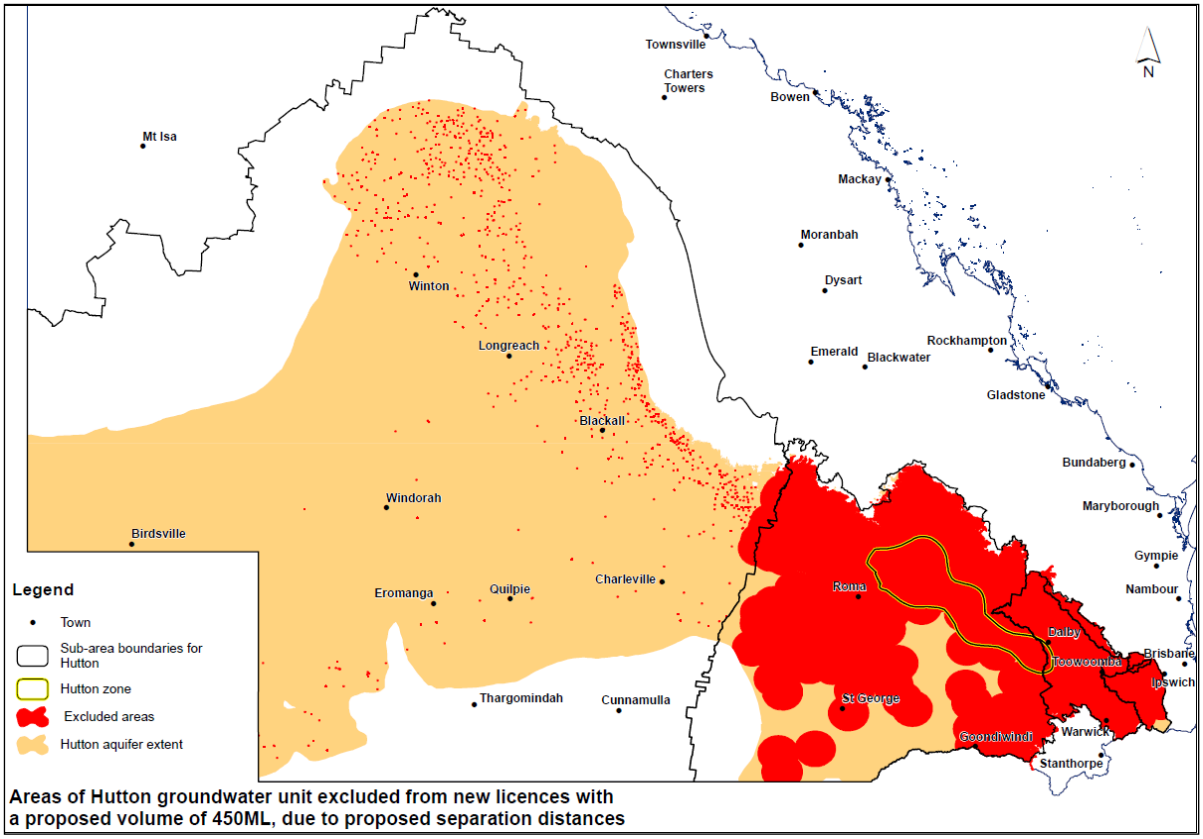

Areas of Hooray groundwater unit excluded from new licences with a proposed volume of 450ML, due to proposed separation distances
N
Legend
Town
Sub-area boundaries for Hooray
Excluded areas
Hooray aquifer extent
Weipa
Laura
Cairns
Normanton
Burketown
Croydon
Ingham
Townsville
Bowen
Mt Isa
Julia Ck.
Hughenden
Mackay
Winton
Boulia
Longreach
Emerald
Rockhampton
Gladstone
Blackall
Windorah
Birdsville
Charleville
Roma
Eromanga
Quilpie
Dalby
Thargomindah
Cunnamulla
St George
Goondiwindi
Kilometres
0 50 100 200 300 400 500



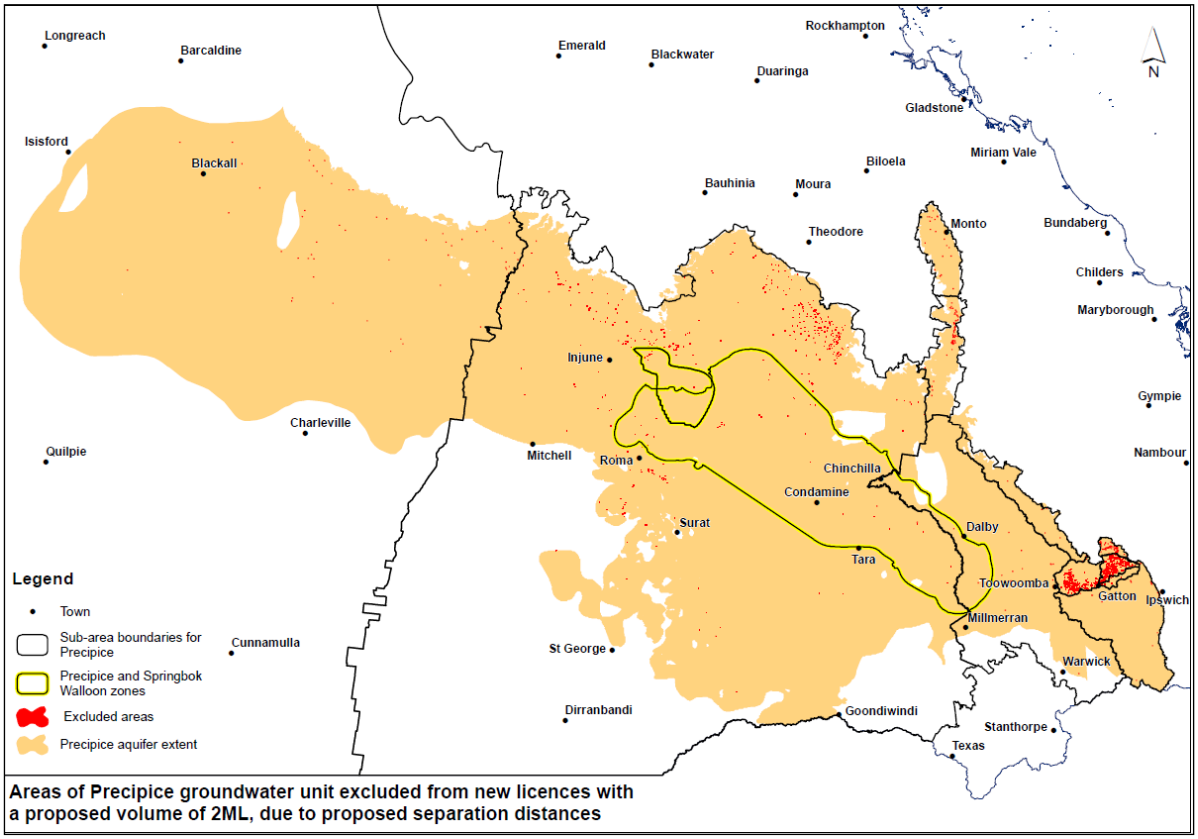

**Areas of Hutton groundwater unit excluded from new licences with a proposed volume of 2ML, due to proposed separation distances**



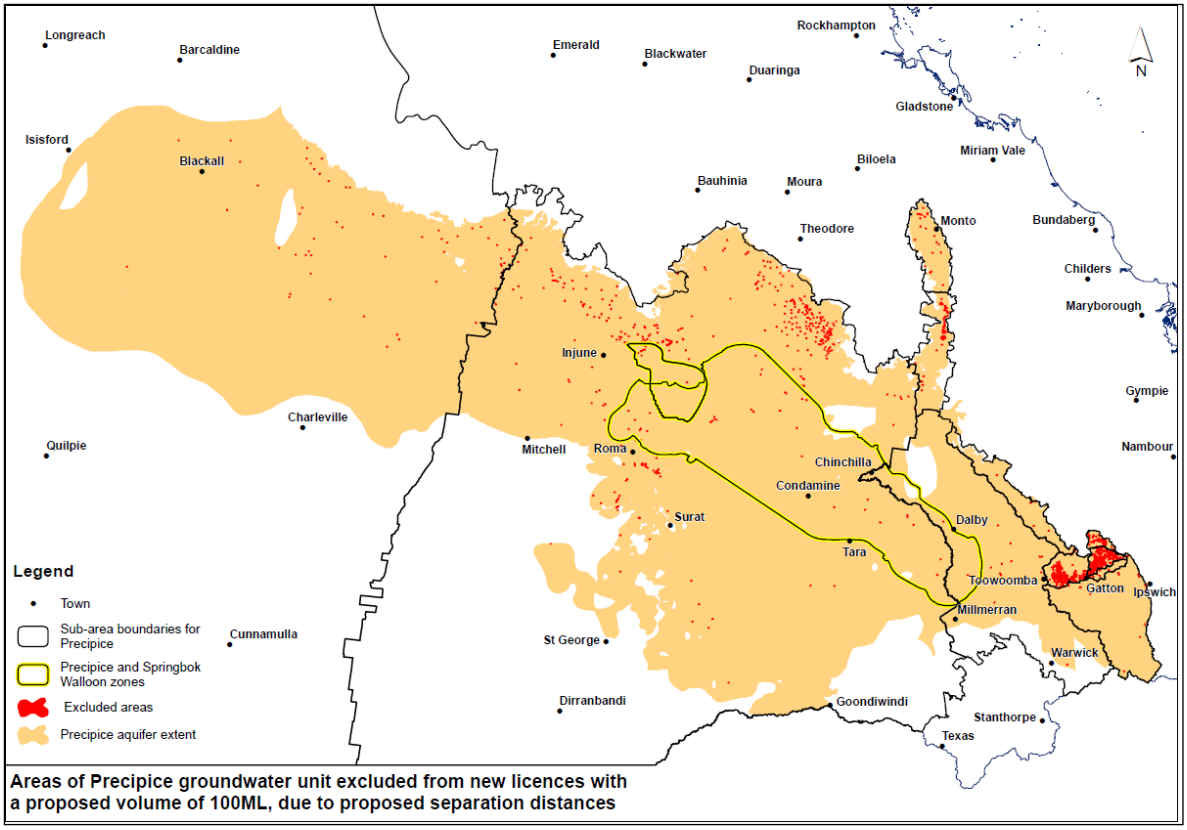

**Areas of Hutton groundwater unit excluded from new licences with a proposed volume of 100ML, due to proposed separation distances**



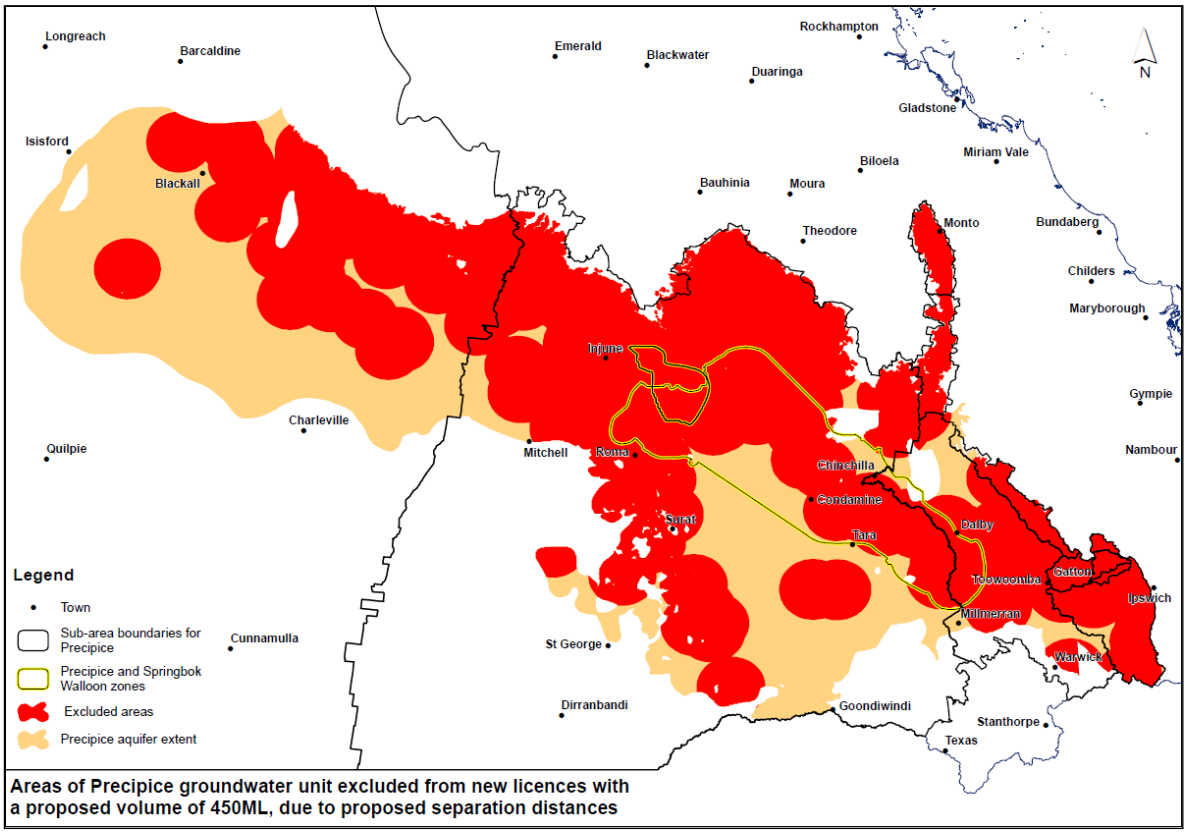

Areas of Hutton groundwater unit excluded from new licences with a proposed volume of 450ML, due to proposed separation distances




Areas of Precipice groundwater unit excluded from new licences with a proposed volume of 2ML, due to proposed separation distances




**Areas of Precipice groundwater unit excluded from new licences with a proposed volume of 100ML, due to proposed separation distances**




**Areas of Precipice groundwater unit excluded from new licences with a proposed volume of 450ML, due to proposed separation distances**

# Appendix G Blank GABORA decision pathway for alternative assessments

**Step 1: Complexity associated with the proximity of existing bores, entitlements, and GDEs**

| Complexity of assessment based on proximity of existing water bores, entitlements, and GDEs | | | |
|---|---|---|---|
| Number of bores or entitlements that the default GABORA protocol method identified as having greater than 5m drawdown | <5 | 5-10 | >10 |
| GDE complexes that the default GABORA protocol method identified as having greater than 0.4m drawdown because of the proposed dealing | 0 | 1 | >1 |
| Complexity | Low | Medium | High |

**Step 2: Risk score**

| | | Entitlement Volume (ML/annum) | | |
|---|---|---|---|---|
| | | <= 50 | > 50 - <= 500 | >500 |
| Complexity (from step 1) | Low | 1 | 2 | 3 |
| | Medium | 2 | 3 | 4 |
| | High | 3 | 4 | 5 |

**Step 3: Determine the likely work needed for the assessment.**

| Risk score (from step 2) | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Source information needed | Existing public domain data & mapping | | Increasing reliance on other reporting<br>Aquifer testing for more representative aquifer parameters might be useful.<br>Local or regional hydrogeologic interpretation. | | |
| Need for fieldwork | no | unlikely | | possibly | likely |
| Indicative cost | low | Low to moderate | moderate | | high |
| Technical assessment | Theis equation<br>Multiple bore Theis equation if required | Theis equation or 2D planar modelling.<br>Multiple bore Theis equation if required | 2D planar modelling | 2D planar modelling, or 3D single layer modelling, or 3D multi-layer modelling | |

Department of Local Government,
Water and Volunteers
GPO Box 2247, Brisbane,
Queensland 4001
13 QGOV (13 74 68)
info@dlgwv.qld.gov.au
**dlgwv.qld.gov.au**

DELIVERING FOR QUEENSLAND

Queensland Government