Development of Groundwater Resource Condition Limits: Upper South East PWAs

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Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
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Acknowledgements

The authors would like to thank DEWNR Science and Information Group's Saad Mustafa, Claire Harding and Cameron Wood for their support in discussion of the nature of groundwater resources of the South East NRM region. The authors also acknowledge the thought and efforts of other hydrogeologists and water managers in the South East, who have been working towards the adoption of more effective management approaches (including the resource condition limit approach) over a long period of time. We would also like to thank Dr Glenn Harrington (IGS) for his external independent peer review of this report which improved the clarity of approach presented.

At the time of writing the Department for Environment and Water (DEW) was the Department for Environment, Water and Natural Resources (DEWNR). It should be acknowledged that all DEWNR branding in this report is considered equivalent to DEW.

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Summary

The Science and Information Group in partnership with Natural Resources South East endeavors to strengthen the science underpinning water allocation plans (WAPs) in the Upper South East (USE) region. The Tintinara–Coonalpyn, Tatiara and Padthaway Prescribed Wells Areas (PWAs) contain significant groundwater resources that are experiencing changing conditions in response to groundwater extraction, landuse and climate change. To ensure that these resources remain viable in the future, it is important to establish what the acceptable limits to resource condition may be within the different hydrogeological zones of each PWA. Such analysis is intended to enable the development of effective management responses to mitigate the risk of these limits being reached. As a starting point, the hydrogeological conceptual models of the groundwater resources in the region have been revised based on the latest understanding of their hydrogeological responses and structure. Distinct conceptual models have been developed for the coastal plain, highland transition, Mallee highlands and confined aquifer systems. These hydrogeological conceptual models are relevant for different Groundwater Management Areas (GMAs) within each of the PWAs and are an improvement on previous conceptual models as they can be applied simply across the hydrogeological zones of the USE region.

The development of the hydrogeological conceptual models allows a clearer communication of the potential limits that exist for each of the resources. These limits can be described using resource condition indicators (RCIs) derived from the high quality groundwater level and salinity monitoring network that exists in the South East. The RCIs developed include: aquifer performance, horizontal and vertical hydraulic gradients, groundwater fluxes towards groundwater dependent ecosystems (GDEs) and both the trends and spatial distribution of groundwater salinity. These RCIs, when combined with the revised hydrogeological conceptual models, are useful for the development of possible resource condition limits (RCLs) for adoption within future WAPs. These RCLs are intended to represent a threshold beyond which there is an unacceptable level of risk to the economic, social and environmental values associated with the resource.

The RCLs developed in this report are designed to be specific to either local or regional hydrogeological responses, giving them relevance to groundwater users and managers. They are also designed to be measureable, allowing easier links to be made with management responses and adoption into future WAPs. It should be noted that not all RCIs are appropriate for development into RCLs in all PWAs (e.g., groundwater fluxes towards aquatic GDEs, if they are not identified to exist within the PWA). Management responses should be initiated by resource condition triggers (RCTs) which warn of an increased risk of an RCL being reached. These management responses could be in the form of further investigations as to the causes or extent of the change in resource condition or more swift actions such as reductions in allocation for a period of time.

The RCLs proposed in this report for the Tintinara–Coonalpyn, Tatiara and Padthaway PWAs include the following:

Coastal plain

- Aquifer performance – maintain a saturated thickness within the Padthaway Formation of > 3 m at the end of each winter monitoring round.
- Hydraulic gradient – maintain a westward hydraulic gradient of > 0.0001 at all times between paired monitoring wells across the western boundary of each PWA.

Highland transition

- Hydraulic gradient – maintain a minimum hydraulic gradient (i.e. greater than the 1985–1995 gradient) at all times between paired monitoring wells from the Mallee highlands to the coastal plain.

Mallee highlands

- Hydraulic gradient – maintain a westward hydraulic gradient of > 0.0004 at all times between paired monitoring wells across the western boundary of the Mallee highlands towards the coastal plain.

Confined aquifer systems

- Aquitard integrity – maintain hydraulic heads above the top of the aquitard at all times in all confined observation wells.
- Hydraulic gradient – observing a permanent cone of depression for five consecutive years in the Boothby GMA

Although not strictly an RCL, it is considered critical to continue salinity monitoring in the unconfined aquifer in all areas to flag the trajectory of salinity trends breaching specific crop salinity thresholds, i.e. 1500 mg/L for grapes and potatoes, 3000 mg/L for spray irrigation of lucerne and 7000 mg/L for flood irrigation of lucerne. In relation to confined aquifer systems, it is also considered critical to continue monitoring of the salinity distributions in confined aquifer systems noting any movement of more saline groundwater relative to cones of depression caused by extraction.

It is intended that the RCLs listed above be tested and incorporated within the development of any future assessments of groundwater resource condition in the region. The Tatiara PWA Groundwater Model (see Li and Cranswick, 2017) will present future scenario projections within the context of a series of possible RCLs as appropriate for consideration in the development of the Tatiara PWA WAP. Possible RCTs are intended to be used in preliminary discussions related to the development of adaptive management policy designed to mitigate the risk of RCLs being exceeded.

1 Introduction

The Science and Information Group has been engaged by Natural Resources South East to help strengthen the science underpinning the water allocation plans (WAPs) in the Tintinara–Coonalpyn, Tatiara and Padthaway Prescribed Wells Areas and will initially produce three technical reports:

- This first report develops a series of resource condition indicators (RCIs) relevant to the hydrogeological setting of the USE region for consideration as possible resource condition limits (RCLs) in future. .
- The second report presents the methodology and initial results of a recharge model developed for the PWAs of the Upper South East (USE) (see Morgan et al., 2017), which is similar to the recharge model recently developed for the Lower South East (Morgan et al., 2015).
- The third report presents details of the construction, calibration and future scenario projections of the revised Tatiara PWA numerical groundwater flow model (Li and Cranswick, 2017).

The Tintinara–Coonalpyn, Tatiara and Padthaway PWAs are located in the USE region (Figure 1.1) and although sharing the same fundamental hydrogeology, they each contain a range of local hydrogeological settings and behaviour. The report develops a series of hydrogeological conceptual models based on existing information and additional interpretation. It also identifies and describes the key resource condition indicators that are relevant to the groundwater resources found in each of the three PWAs. In order to more effectively manage the changes occurring to the condition of the groundwater resources (i.e. declining groundwater levels, increasing groundwater salinity), a series of potential resource condition limits are developed. It is critical that these be specific to the local hydrogeological behaviour of the aquifers under stress and that they be measureable, to allow clear management responses to be developed.

The resource condition limit approach is described in the following chapter and represents a shift away from assuming that sustainability can be achieved if allocation is set to be less than long-term estimates of recharge – which is problematic if the observed condition of the resources are not stable or improving (i.e. with increased risk to the ongoing use and/or quality of the resource). For example a resource condition limit in a particular management area may be to maintain a specified groundwater level within an aquifer, below which the risk to the resource, groundwater users and the environment is unacceptable. Such a risk could be mitigated through adaptive management decisions that are triggered when actual changes are observed in the condition of the resource prior to the resource condition limit being reached (i.e. reductions in allocation with the intent of reducing extraction, only when necessary to prevent unacceptable risks). These components of adaptive management are necessarily to be developed through engagement with all stakeholders prior to the adoption of WAPs.

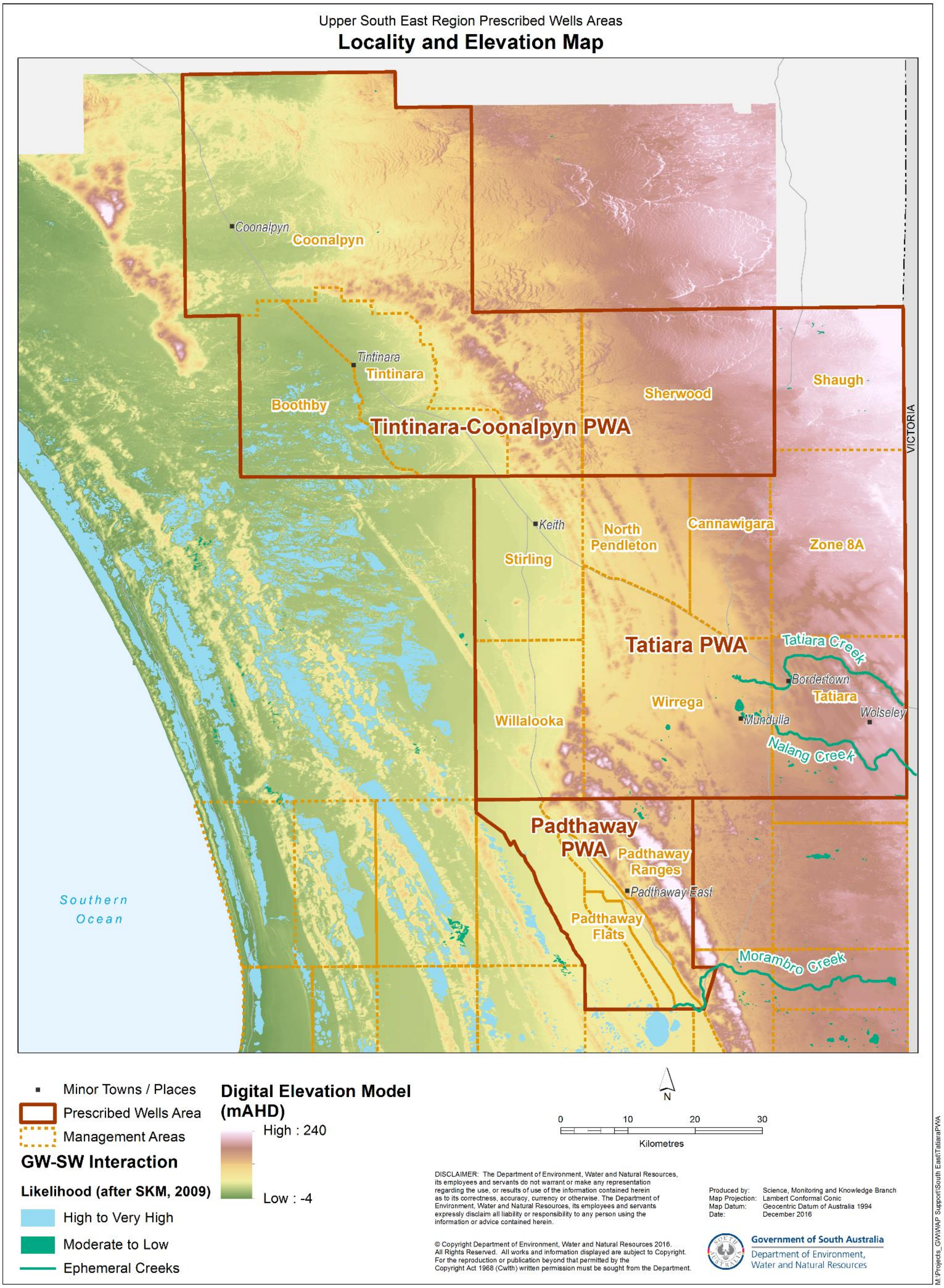


Figure 1.1. Locality map of the prescribed wells areas found within the Upper South East region

1.1 Resource condition limit approach

As WAPs evolve, they are increasingly focusing management efforts on keeping the condition of the resource within acceptable limits – i.e. within thresholds beyond which there is an unacceptable level of risk to the economic, social and environmental values associated with the resource.

The **resource condition limit (RCL)** approach has been proposed in the South East NRM region by Harrington and Currie (2008), and is also documented by Richardson et al. (2011) and Anderson et al. (2014), and is applicable globally. This approach requires the identification of biophysical indicators (described here as resource condition indicators) that track the response of the groundwater system to various stresses such as extraction, landuse change or climate change. RCLs should be specific to the local behaviour and condition of the groundwater resource and also be measureable, so that monitoring of the appropriate resource condition indicators can trigger management actions that aim to prevent each RCL from being exceeded.

Resource condition indicators (RCIs) are typically parameters that can be directly monitored, such as groundwater levels or salinity, but can also be derived from other field observations, such as estimates of groundwater discharge into a surface waterbody or estimates of aquifer storage. The next step is to determine the acceptable levels of change to the condition of the system, with reference to these RCIs. The level of change that may be considered acceptable should be informed by several considerations, including a technical understanding of the vulnerability of the resource and ecosystems that are dependent on it, as well as the economic and social importance of the resource. The determination of agreed RCLs thus requires input from various stakeholders and an iterative approach should be taken such that all parties gain a sense of ownership and confidence in the approach.

In an unconfined aquifer, an RCL could be the groundwater levels at which it becomes uneconomical for irrigators to lower pumps or deepen wells, or the groundwater level which causes a surface waterbody to become disconnected from the watertable. In a confined aquifer, it could be the pressure levels which are likely to lead to depressurization of the confined aquifer and associated risks, or the level at which the confined aquifer is no longer artesian. Water managers can determine these RCLs in a number of ways, the simplest being to identify historical situations where the resource has declined to the state where economic or environmental impacts have been severe or unacceptable. Where insufficient information exists to identify RCLs in this way, it is necessary to make predictions about how the system will respond to unprecedented or continued stresses, noting the level of uncertainty involved, and then determine the limits through a process of community consultation. RCLs can also be based on the known or perceived impacts to values associated with the groundwater resource (i.e. ecological and social values). RCLs will be most effective when they are specific and measureable, with clear management responses to be triggered in order to prevent the RCL from being reached.

If the condition of the groundwater resource is changing towards a particular RCL there should be one or a series of a **resource condition triggers (RCTs)** to warn of this change. This would allow adaptive management decisions to be made, thereby reducing the risk of reaching that RCL. If an RCT is reached, two types of management responses could be initiated; one would trigger further investigation as to the causes of the changing resource condition (e.g. a groundwater level decline can be caused either by climate variation or other stresses such as extraction), while the other response may require more swift action (e.g. reduction in allocations for a period of time). RCTs that initiate more detailed investigations would be applied as early warnings of increased risk to the resource condition and/or where there is uncertainty regarding whether the change in the resource condition can be managed. Swift action RCTs would be initiated where for example, groundwater extraction in a specific management area has a known impact on the condition of the resource and also that reduction in such extraction is likely to allow the condition to improve (e.g. based on numerical model results or other analysis).

Recommended extraction limits (RELs) are the volumes of extraction for consumptive use that can be sustained over time that do not result in the exceedance of RCLs. If management of extraction needs to be responsive to the condition of the resource, threshold levels can be set beyond which a management response is triggered (i.e. RCTs) – an adaptive management approach that allows water users a reasonable amount of security in their access to the resource, while also offering protection to other groundwater users or GDEs from unacceptable impacts.

When using RCLs, it is no longer necessary to conceptualise the capacity of the resource as the long-term average annual volume of water entering or leaving a system. Instead, the emphasis is placed on the condition of the system that needs to be maintained over a certain timeframe in order to meet the various demands on a resource during that period. The RELs that are set for each GMA or hydrogeological zone then reflect the capacity of the resource to meet various current and future demands (including non-licensed use provided they are small volumes compared to licensed use), while maintaining that condition.

A notable implication of this approach is that the RELs may potentially exceed the overall annual average recharge or discharge of the system; for instance during the period when a groundwater system moves from one equilibrium state to a new one, or where there is sufficient storage in an aquifer to allow gradual depletion where the risk of long-term impacts is not high enough to reasonably limit present day extraction. Any such decision making would clearly require the involvement in a range of stakeholders.

1.2 Objectives

The objectives of this report related to the groundwater resources of the Tintinara–Coonalpyn, Tatiara and Padthaway PWAs are to:

1) Synthesise and develop hydrogeological conceptual models that describe the structure and behaviour of the groundwater resources in response to the inputs and stresses that influence their sustainability
2) Describe the range of resource condition indicators most relevant to the groundwater systems of each of the PWAs
3) Present a number of potential resource condition limits that are specific and measureable and could be incorporated into future WAPs after consultation with stakeholders
4) Propose a series of possible resource condition triggers that allow adaptive management decisions to be made thereby reducing the risk of reaching a resource condition limit.

2 Hydrogeological conceptual models

2.1 Previous conceptual models

2.1.1 Padthaway PWA

The conceptual model for the hydrogeology of the Padthaway PWA was presented by Brown (1998) following investigations by Harris (1970; 1971; 1972) and others. The cross-section below from Brown (1998) shows Bridgewater Formation overlying the Gambier Limestone in the Naracoorte Range in the east while the inter-dunal flat to the west is comprised of the Padthaway Formation (and the basal Keppoch Clay Member), a thin Bridgewater Formation, and then by the Coomandook Formation (Figure 2.1). Groundwater extraction on the flats is replenished from local recharge, irrigation drainage and throughflow from the Naracoorte Ranges to the east. Extraction and low rainfall years can result in declining groundwater trends while salinity increases are the result of irrigation recycling and the mobilization of salt previously stored in the unsaturated zone of the Naracoorte Ranges which flows towards and through the Padthaway Flats (Harrington et al., 2006).

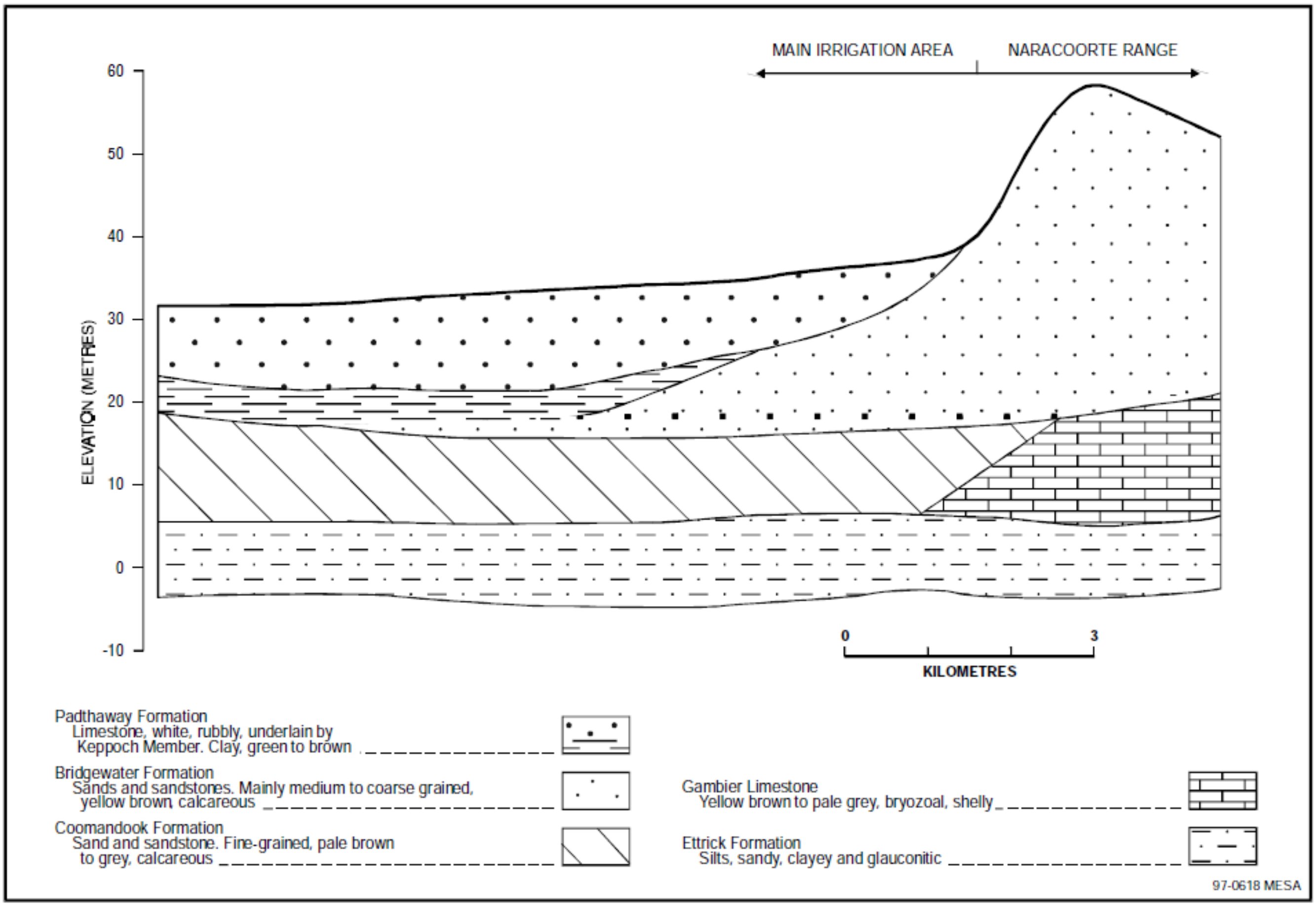


Figure 2.1. Hydrogeological cross-section in the Padthaway PWA (Brown, 1998)

The cross-section later developed by Harrington et al. (2006) shows the aquitard units more clearly and the underlying units down to the basement rock (Figure 2.2). Confined aquifers may exist in the Mepunga and Dilwyn Formations but these are not used extensively and are not well described in this area.

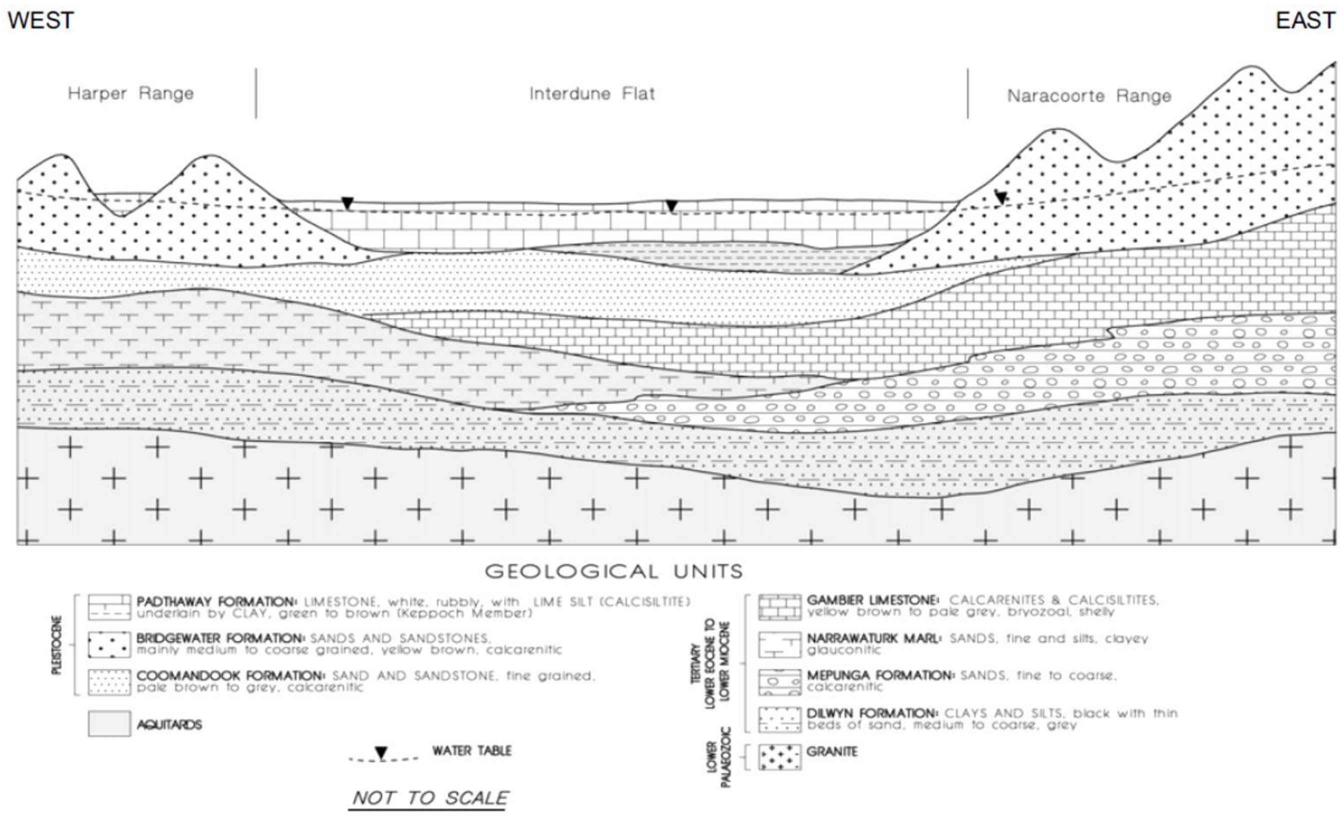


Figure 2.2. Hydrogeological cross-section in the Padthaway PWA (Harrington et al., 2006)

2.1.2 Tatiara PWA

In the Tatiara PWA, conceptual models were developed by Stadter and Love (1987) following earlier work in the south-west of the PWA by Williams (1979) and Stadter (1984). Figure 2.3 and Figure 2.4 show east–west cross-sections in the north and south of the PWA respectively. The PWA is separated into the western coastal plain and the more elevated highlands to the east. The coastal plains are believed to be hydrogeologically similar to those of the Padthaway PWA but are likely to overlie sediments of the Murray Basin instead of those of the Otway Basin. It is unlikely that the Bridgewater Formation is continuous and thick below the Padthaway Formation as drawn by Stadter and Love (1987) as this is a coastal/barrier dune deposit. The Coomandook Formation is thought to be more extensive laterally as presented in Rochow (1969), Firman (1971), Rochow (1971) and Belperio (1995). The Mallee highlands consist primarily of Loxton-Parilla Sands which are mostly unsaturated and underlain by the Murray Group limestone. In the southern cross-section of Stadter and Love (1987), there are granitic intrusions which outcrop (e.g. Mount Monster) and the unconfined aquifer is particularly thin in this area. The Ettrick Formation acts as the primary aquitard which confines the Renmark Group sub-aquifers which have variable presence across the PWA and are not used significantly.

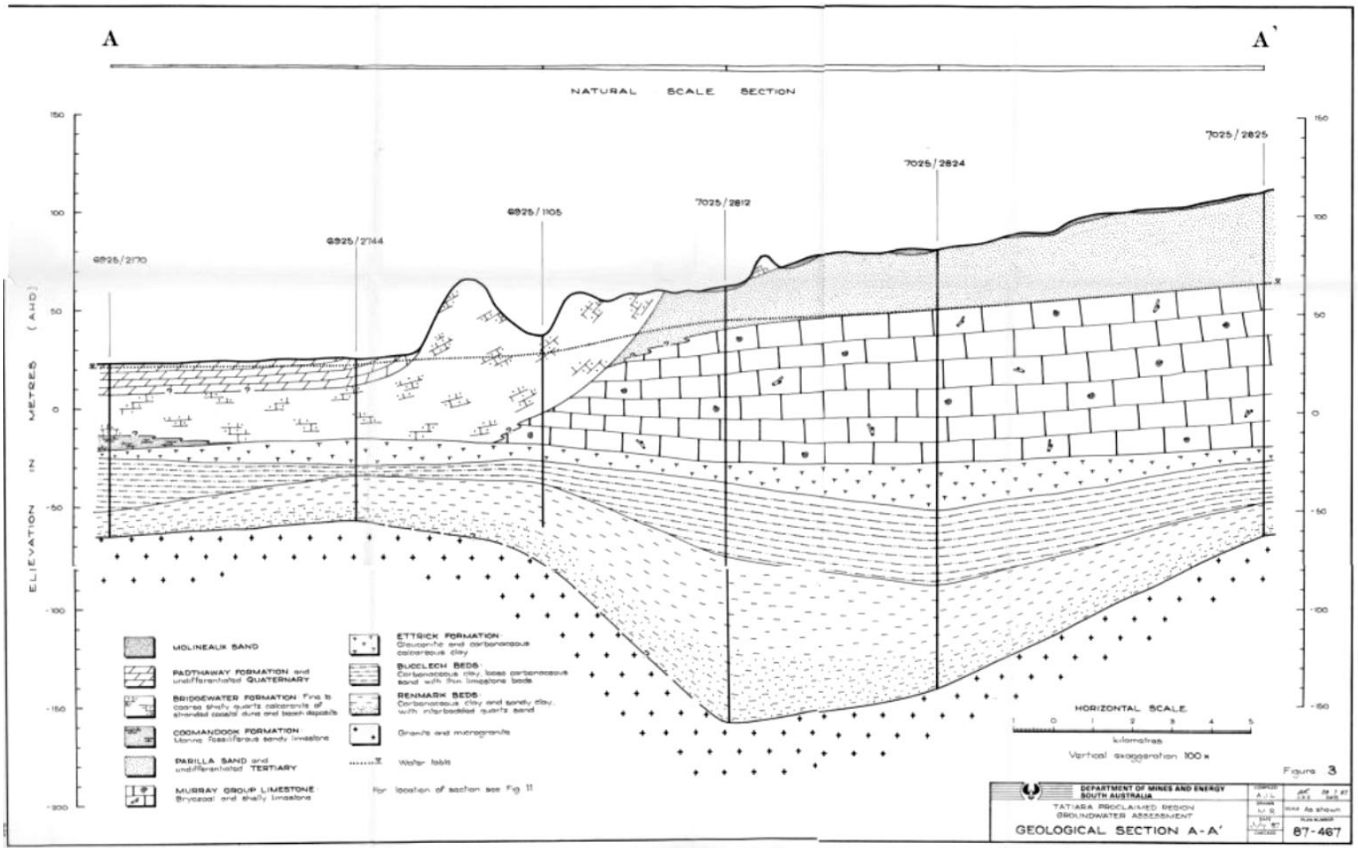


Figure 2.3. Hydrogeological cross-section in the northern Tatiara PWA (Stadter and Love, 1997)

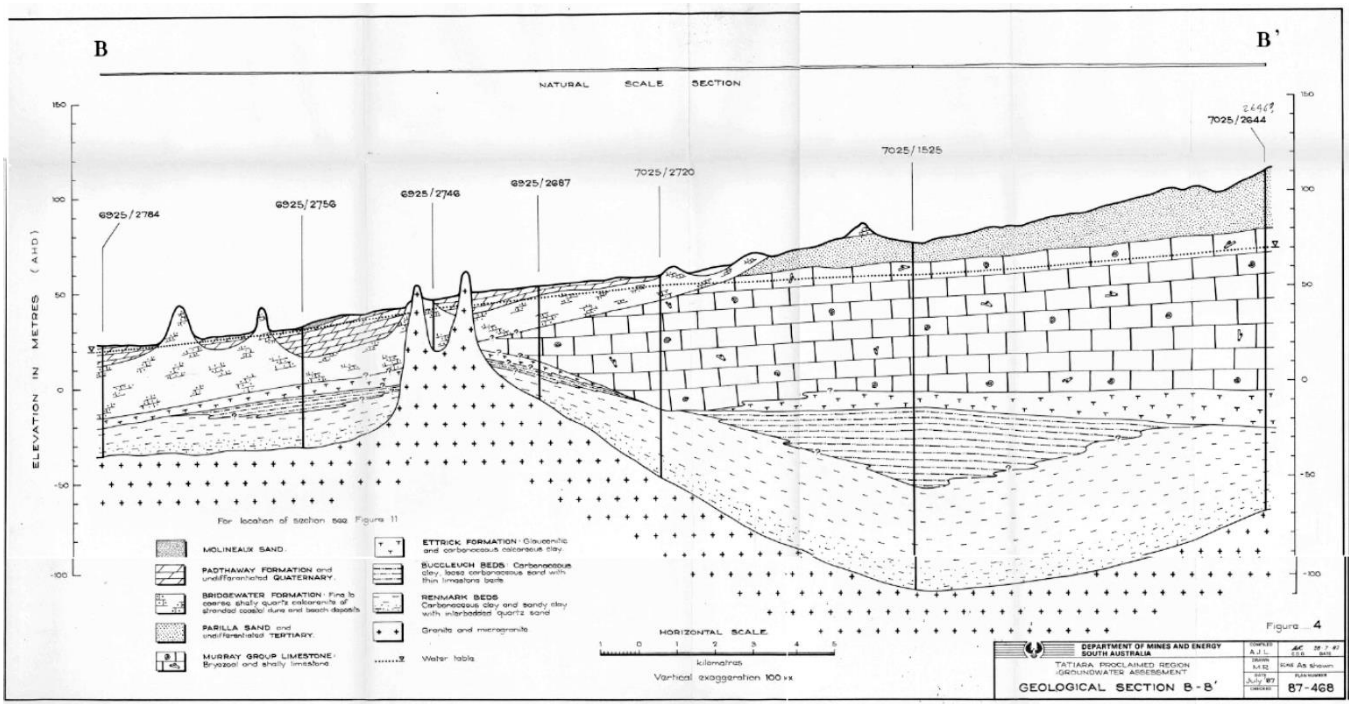


Figure 2.4. Hydrogeological cross-section in the southern Tatiara PWA (Stadter and Love, 1997)

The southern cross-section was developed into a block diagram as presented in Stadter and Love (1989) which illustrates the primary recharge and discharge processes in the PWA (Figure 2.5). These include throughflow from the east, diffuse rainfall recharge, point recharge through the surface water drainage into runaway holes, groundwater extraction and groundwater evapotranspiration from shallow watertables in the west. Initially, groundwater salinity increases were attributed to vertical mixing within the unconfined aquifer (Williams, 1979). However, more recently irrigation recycling is responsible for continuing trends of increasing salinity on the coastal plain (Brown et al., 2006). Groundwater level declines occur in many areas due to periods of low rainfall recharge in combination with continuing groundwater extraction. Notable freshwater lenses are also known to exist in the vicinity of Poocher and Mundulla Swamps whose spatial extent is dependent on point recharge from Tatiara and Nalang Creek flows respectively (in combination with the impact of any groundwater extraction within the lenses).

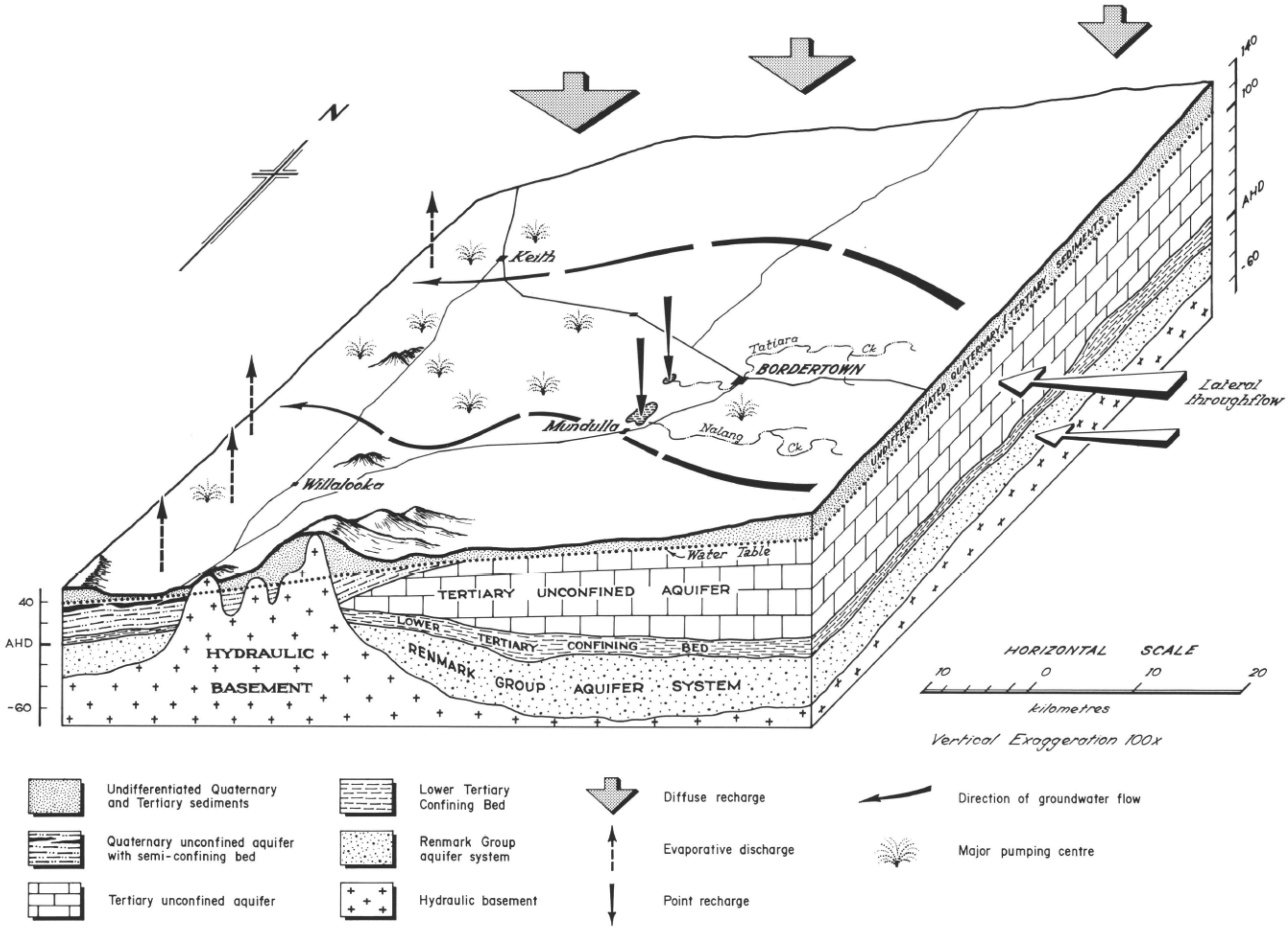


Figure 2.5. Hydrogeological block diagram for the Tatiara PWA (Stadter and Love, 1989)

2.1.3 Tintinara–Coonalpyn PWA

The hydrogeology of the Tintinara–Coonalpyn PWA is similar to that of the northern Tatiara PWA cross-section of Stadter and Love (1987). Barnett (2002) developed a block diagram to show the differences between the eastern highlands and the coastal plain where the unconfined aquifer is contained within the Murray Group limestone and Quaternary limestone respectively (Figure 2.6). The Quaternary limestone is comprised of the Padthaway, Bridgewater and Coomandook Formations which have been grouped for simplicity in this PWA. The confined aquifers exist in the Renmark Group to the east and also the Buccleuch Group to the west of the Marmon Jabuk Fault. Considerable volumes of groundwater are extracted from the confined aquifer systems in this PWA (Barnett, 2002). Rising groundwater salinity in unirrigated parts of the unconfined aquifer of the PWA was formerly associated with the effects of land clearance, while any continued salinity increase within irrigated areas is likely due to irrigation recycling (Barnett, 2007). Groundwater levels in the unconfined aquifer continue to decline due to continued groundwater extraction and low rainfall years on the coastal plain, but are relatively stable on the Mallee highlands. The confined aquifer generally mirrors the trends of the unconfined aquifer due to hydrostatic loading effects (Barnett, 2007). In other areas the confined aquifers display large seasonal pressure fluctuations in response to extraction, as is typical for a confined systems. Some observation wells show permanent drawdowns and there are some cones of depressions around extraction centers (e.g. Tintinara).

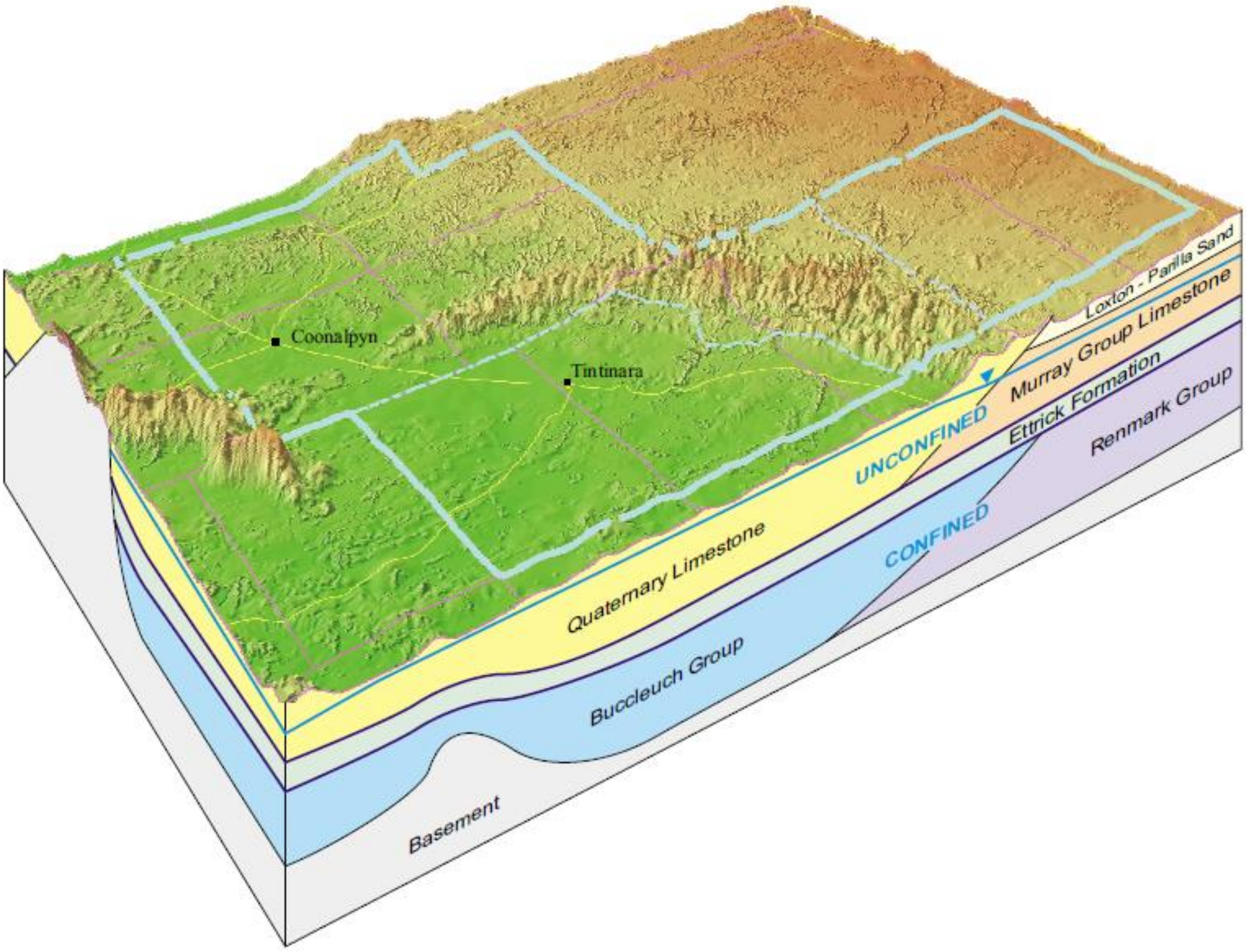


Figure 2.6. Hydrogeological block diagram for the Tintinara–Coonalpyn PWA (Barnett, 2002)

2.2 Groundwater Management Areas and hydrogeological zones

Broad hydrogeological zones have been defined for the entirety of the South East region by Harrington and Currie (2008). These zones were delineated based on specific aquifer responses (i.e. groundwater level and salinity trends, seasonal variation) and aquifer characteristics (aquifer thickness, location relative to underlying geological structures). This type of zonation is highly appropriate for the implementation of adaptive management approaches. Unfortunately these zones or versions thereof have not yet been adopted, and so there are many current GMAs that fall across multiple zones. This makes management based on the condition and behaviour of the resource more challenging as the hydrogeology can vary within a single GMA (e.g. Wirrega GMA in the Tatiara PWA). In this study, a boundary has been selected between a number of the Harrington and Currie (2008) hydrogeological zones which represents the transition between the coastal plain and the Mallee highlands (Figure 2.7). Three generalized hydrogeological conceptual models have now been developed for the unconfined aquifer using this delineation and the hydrogeological behaviour characterised by Harrington and Currie (2008), in combination with the conceptual models presented by other authors as shown above. This generalization has been made for the purposes of developing specific and measureable resource condition indicators and/or limits later in this report that can be applied simply to the Upper South East PWAs. Conceptual models for the hydrogeology of the unconfined aquifer are presented for the:

- Coastal plain
- Highland transition
- Mallee highlands

The GMAs of the Tintinara–Coonalpyn, Tatiara and Padthaway PWAs do not necessarily fit cleanly into a single conceptual model (i.e. GMAs cover areas in different hydrogeological zones). Hence the conceptual model that is most representative of each GMA has been selected for simplicity as shown in Table 2.1. A broad conceptual model is also presented displaying typical west to east changes between these hydrogeological zones for the unconfined aquifer (Figure 2.8) while each is described in detail in the following sections. Additionally, a conceptual model for the confined aquifer systems has been developed for broad application to the confined groundwater management areas found in each PWA including:

- Tintinara–Coonalpyn PWA: Tauragat, Tolmer, Kynoch
- Tatiara PWA: Keith, Zone 9A, Zone 8A, Zone 7A and Wirrega
- Padthaway PWA: Wirrega

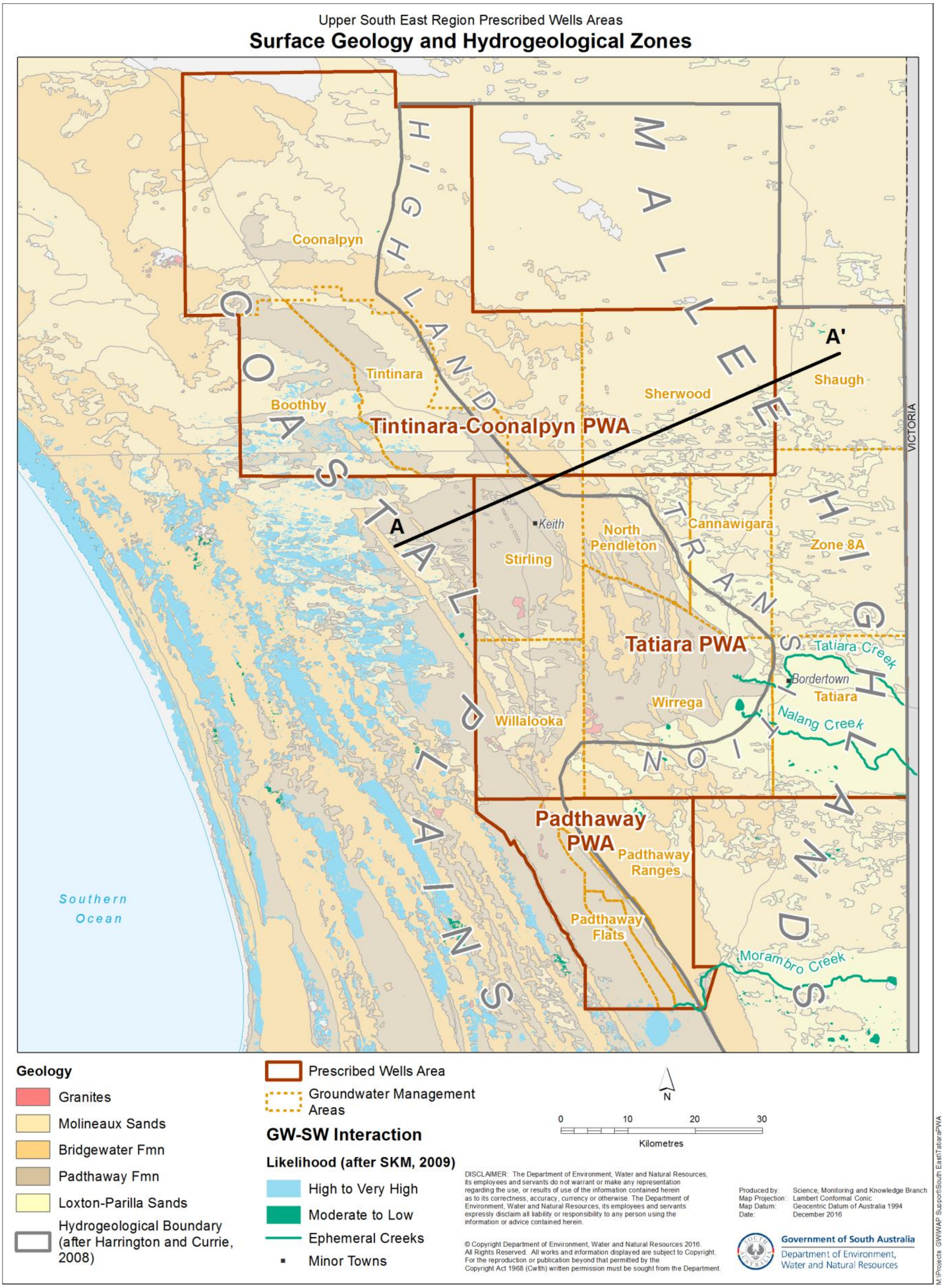


Figure 2.7. **Groundwater Management Areas and hydrogeological zones**

Table 2.1. Hydrogeological zone and conceptual model association with unconfined aquifer GMAs

Prescribed Wells Area	Hydrogeological Conceptual Model		
	Coastal plain	*Highland transition*	*Mallee highlands*
Tintinara–Coonalpyn	Boothby, Tintinara	Coonalpyn	Sherwood
Tatiara	Stirling, Willalooka, Wirrega*	North Pendleton	Cannawigara, Shaugh, Zone 8A, Tatiara
Padthaway	Padthaway Flats	Padthaway Ranges	

*The southern part of Wirrega GMA is notably represented better by the highland transition or Mallee highland conceptual model

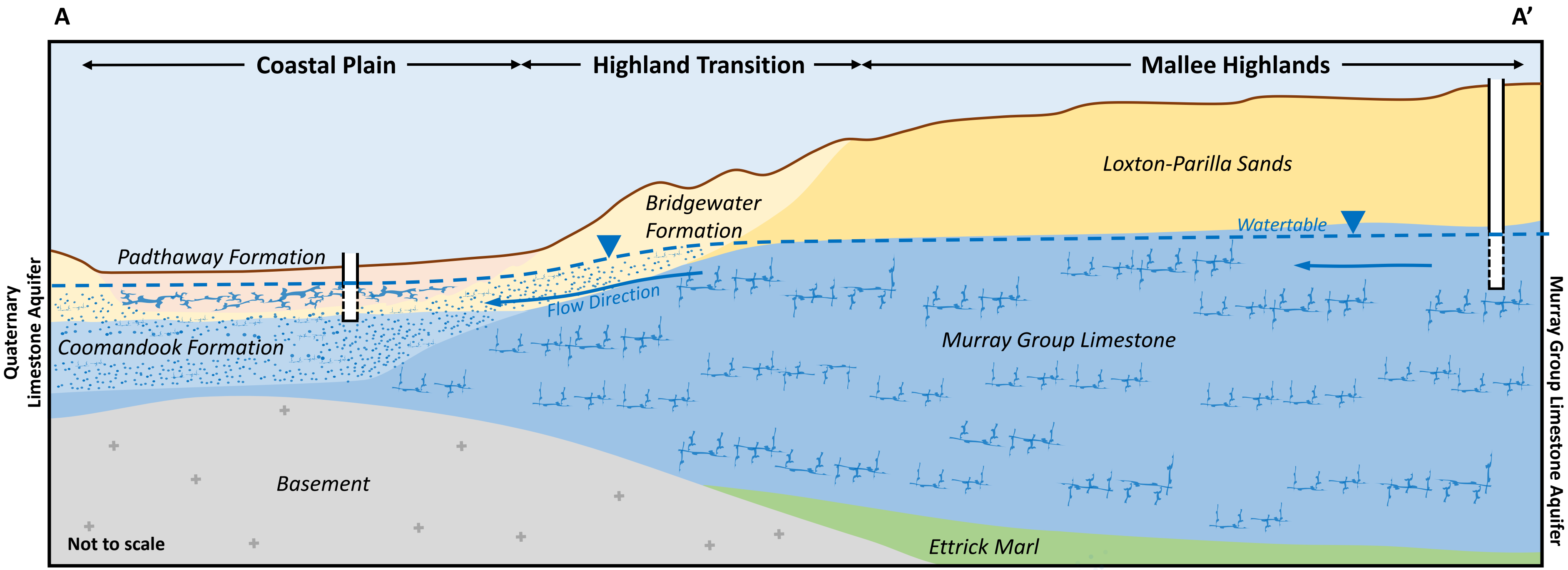


Figure 2.8. Broad hydrogeological conceptual model showing the coastal plain, highland transition and Mallee highlands for the unconfined aquifer

2.3 Coastal plain

The coastal plain is underlain by three Quaternary limestone units: the Padthaway, Bridgewater and the Coomandook Formations which can be grouped as the Quaternary limestone aquifer because there is generally a high degree of hydraulic connectivity between them (Figure 2.9).

The **Padthaway Formation** is a well-cemented, fine grained limestone with some interbeds of silts and marls but importantly, also has extensive secondary porosity. These are in the form of dissolution features that are often well connected. Where these features are intersected by irrigation wells, very large yields up to 300 L/s are possible (Stadter and Love, 1987). If these features are not intersected, the well yields are much lower as inferred by an assessment of airlift yield data (Appendix A). The Padthaway Formation is up to 20 m thick but is more commonly between 10 and 15 m thick and has a limited saturated thickness. As this formation was deposited in a lacustrine environment, some parts of the aquifer contain the basal Keppoch Clay Member which is a green-brown mottled clay that may locally confine parts of the underlying formations.

The **Bridgewater Formation** generally consists of variably cemented fine – coarse grained calcareous aeolian sands with occasional dissolution features. This formation is typically a barrier bar – coastal dune deposit which are seen as elevated and stranded dunes from previous high sea level stands. Yields from the Bridgewater Formation are generally lower than from the Padthaway Formation but can have a greater saturated thickness towards the eastern margin of the coastal plain.

The **Coomandook Formation** is a sandy and marly limestone comprised of fossiliferous sands, silts and glauconite. This formation is generally not considered to be a high yielding aquifer but in some areas may behave similarly to the adjacent and in some areas, underlying Murray Group limestone aquifer.

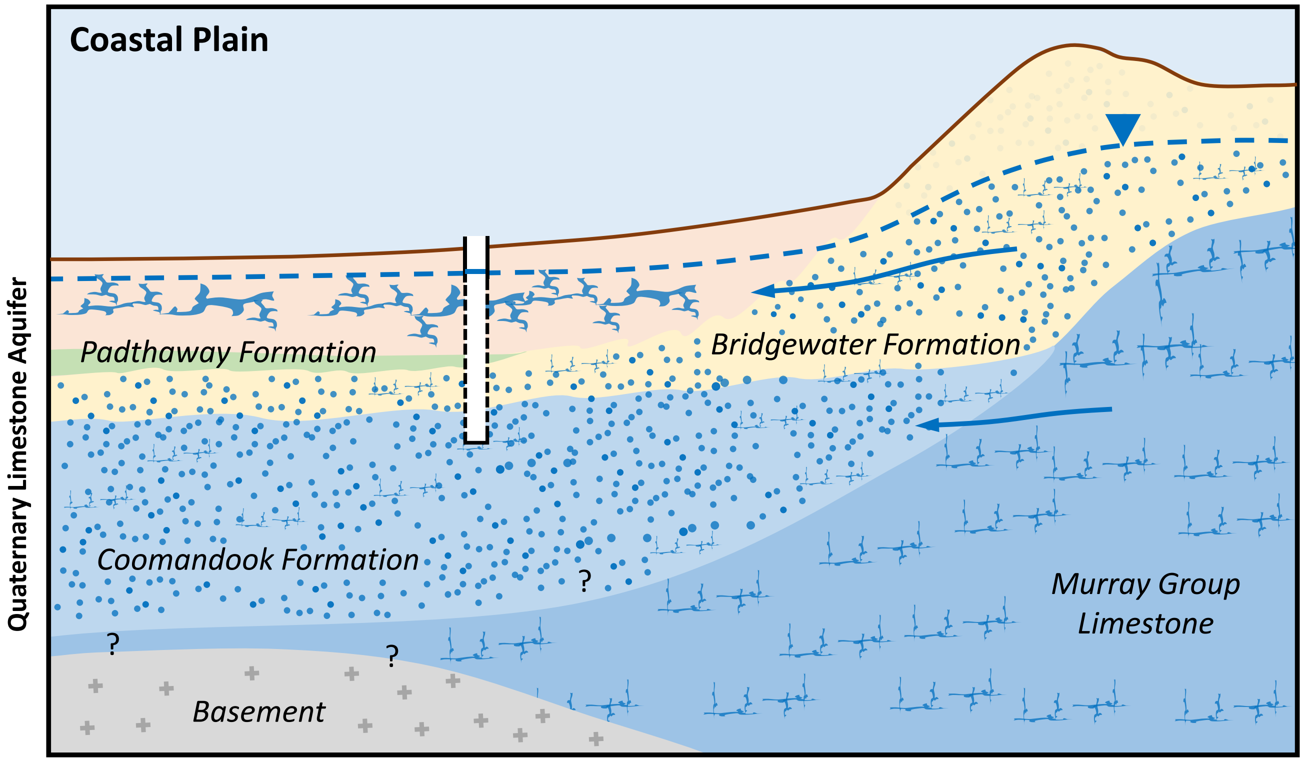


Figure 2.9. Hydrogeological conceptual model of the Quaternary limestone aquifer in the coastal plain with groundwater salinity increasing to the west

Rainfall is a major source of recharge to the Quaternary limestone aquifer which also receives considerable volumes of groundwater throughflow from the highland areas to the east. One sustainability issue is the potential dewatering of the higher yielding parts of the aquifer (i.e. the Padthaway Formation) caused by continued extraction and reduced recharge due to a drying climate. Declining groundwater levels would decease both pump efficiency and well yields which may cause current flood irrigation practices to become unviable. Well deepening may be necessary to ensure continued groundwater supplies which would be available but at lower yields. The behaviour of the aquifers is not well understood once groundwater levels fall below the historical minimum level, but it is possible for the rate of decline and seasonal drawdowns to increase even if the extraction rate does not increase above current levels (i.e. if the specific yield of the deeper part of the aquifer is lower than that of the shallower part of the aquifer). Groundwater levels have been relatively stable from the 1960s to mid-1990s, after which a steady decline has been observed.

Another risk to the sustainability of the resource is increasing groundwater salinity. This primarily occurs through two main processes; changes in the salinity of throughflow entering the coastal plain caused by vegetation clearance, and through irrigation recycling which has resulted in persistent rising salinity trends for a number of decades. A first pass assessment of the salinity trend behaviour of 277 observation wells in the USE over the last 30-40 years is presented in Appendix B, showing the spatial distribution of such behaviour (i.e. slight, moderate and major rising trends shown in Figure 6.3). The use of groundwater salinity as a resource condition indicator is discussed in more detail in the following chapters.

Reported transmissivity values from aquifer tests within the Quaternary limestone aquifer in the USE range from 1130–13 000 m^2d^{-1} (Mustafa and Lawson, 2002; Stadter and Love, 1987). As wells are often screened or completed as open hole across multiple formations, it is not possible to confidently associate a range of transmissivity values with each formation.

2.4 Highland transition

The highland transition contains unconfined aquifers within the Bridgewater Formation and underlying MGL (Figure 2.10). The MGL is a poorly to well-cemented fossiliferous limestone with interbeds of sand and marl. The saturated thickness of the Bridgewater Formation decreases to the east, while the thickness of the Murray Group limestone increases towards Victoria.

Rainfall recharge and throughflow from the east are the primary sources of groundwater recharge in the highland transition. In some areas where the top of the MGL is shallow, considerable point recharge occurs through runaway holes at the terminus of surface drainage features (e.g. Poocher and Mundulla Swamps in the Tatiara PWA). The groundwater throughflow from this area is considered to be critical for sustainable extraction from the shallow Quaternary limestone aquifer to the west. This throughflow could decrease if the hydraulic gradient towards the west is impacted by reduced recharge and/or by groundwater extractions in areas to the east.

The impact of Mallee clearance on increased recharge rates and an initial increase in salinity have been observed where the depth to watertable is relatively shallow (Wohling, 2007). Groundwater levels in these areas show rising trends from approximately the 1970 –1990s before stable or slight declining trends are observed from the beginning of the 2000s. The long term salinity trend behaviour shows similarly, a rise and then decline in response to this change in recharge rate after land clearance (see Figure 6.3 in Appendix B). Where thicker unsaturated zones are present (i.e. to the east in the Mallee highlands) these impacts have not yet been commonly observed.

Reported transmissivity values from aquifer tests within these aquifers in the Upper South East range from 190–6160 m^2d^{-1} (Mustafa and Lawson, 2002; Stadter and Love, 1987). These values are representative of a range of depth intervals within each or both aquifers.

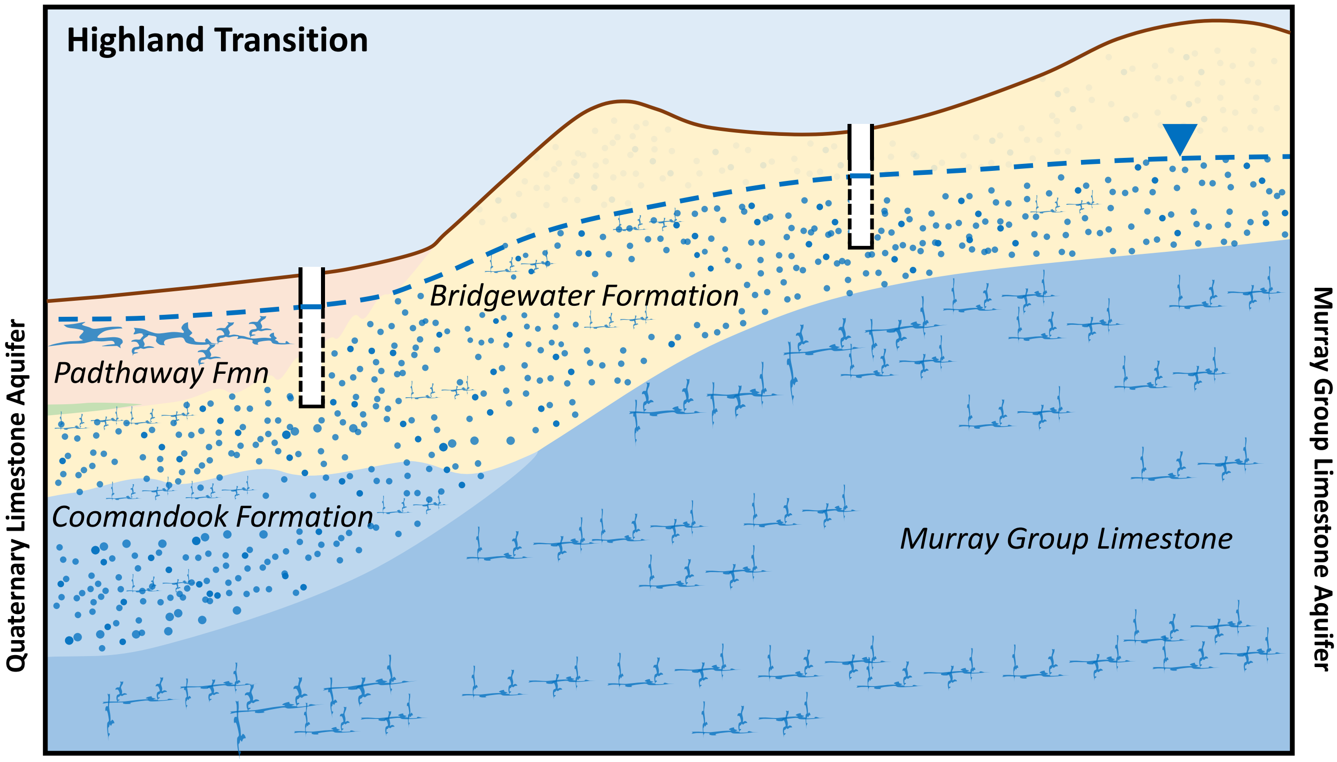


Figure 2.10. Hydrogeological conceptual model of the highland transition area

2.5 Mallee highlands

The Murray Group limestone (MGL) is the most extensive aquifer in the Mallee highlands and is overlain by the Loxton-Parilla Sands and underlain by the Ettrick Marl (Figure 2.11). The Loxton-Parilla Sands are comprised of aeolian and fluvio-lacustrine deposits but are generally unsaturated due to the deep watertables in the Mallee region. There are some sandy clays which are believed to confine the MGL aquifer in the far northeast corner of the Tatiara PWA (Stadter et al., 1995) and the Bookpurnong Formation further north into the Murray Basin. The presence of clays is thought to prevent significant rates of modern recharge from occurring in areas where they exist extensively but this has not been investigated in detail. The MGL aquifer is a poorly to well-cemented fossiliferous limestone with interbeds of sand and marl. The saturated thickness ranges from approximately 75 m in the south-east, to about 60 m in the north-west resulting in storage volumes of the order of 30 000 GL over the three PWAs.

The MGL primarily receives rainfall recharge which prior to land clearance, occurred at low rates of roughly < 1 mm/y (Leaney and Herczeg, 1995). These are likely to have increased by approximately an order of magnitude after the removal of deep rooted vegetation, depending on soil type (Walker *et al.,* 1990). Considerable throughflow also enters the aquifer from the east which originates as rainfall recharge in Victoria. Observations since the earliest readings in the 1960s to present have shown very stable groundwater levels with only localised minor declines due to nearby extraction.

The impact of Mallee clearance on increased recharge rates and an initial increase in salinity have not yet been observed (see locations of stable salinity trends shown in Figure 6.3 of Appendix B). This is due to the deep watertables in the Mallee highlands and the many decades required for water to travel through the unsaturated zone before reaching the watertable (see also the orange dots representing the higher salinity recharge front in Figure 2.11). It is likely that the breakthrough of this higher salinity recharge will have a negligible impact on the overall average salinity of the MGL (since it has very large storage volumes) but may be more noticeable in wells that are screened in the shallowest parts of the aquifer. Similar to the salinity trends observed in the transition zone (in Figure 6.3 of Appendix B), an initial slight rise and then decline would be expected to be observed some time in the future (Wohling, 2008), provided well screens of observation wells are located close to the top of the watertable.

The potential decline in groundwater levels due to continued extraction and a drying climate would reduce the volume of groundwater that is available from the aquifer (i.e. as it is dewatered). Given the considerable saturated thickness of the aquifer (i.e. up to 75 m in the southeast) this may not be of concern in the short term. However, long term groundwater declines would require shallow wells to be deepened to ensure continued access groundwater supplies. Such a decline could also reduce the regional hydraulic gradient towards the coastal plain aquifers resulting in decreased throughflow which is currently critical for the replenishment of those resources.

Reported transmissivity values from aquifer tests within the MGL aquifer in the USE range from 460–8000 m^2d^{-1} (Lawrence, 1975; Mustafa and Lawson, 2002; Stadter, 1989; Stewart, 1990).

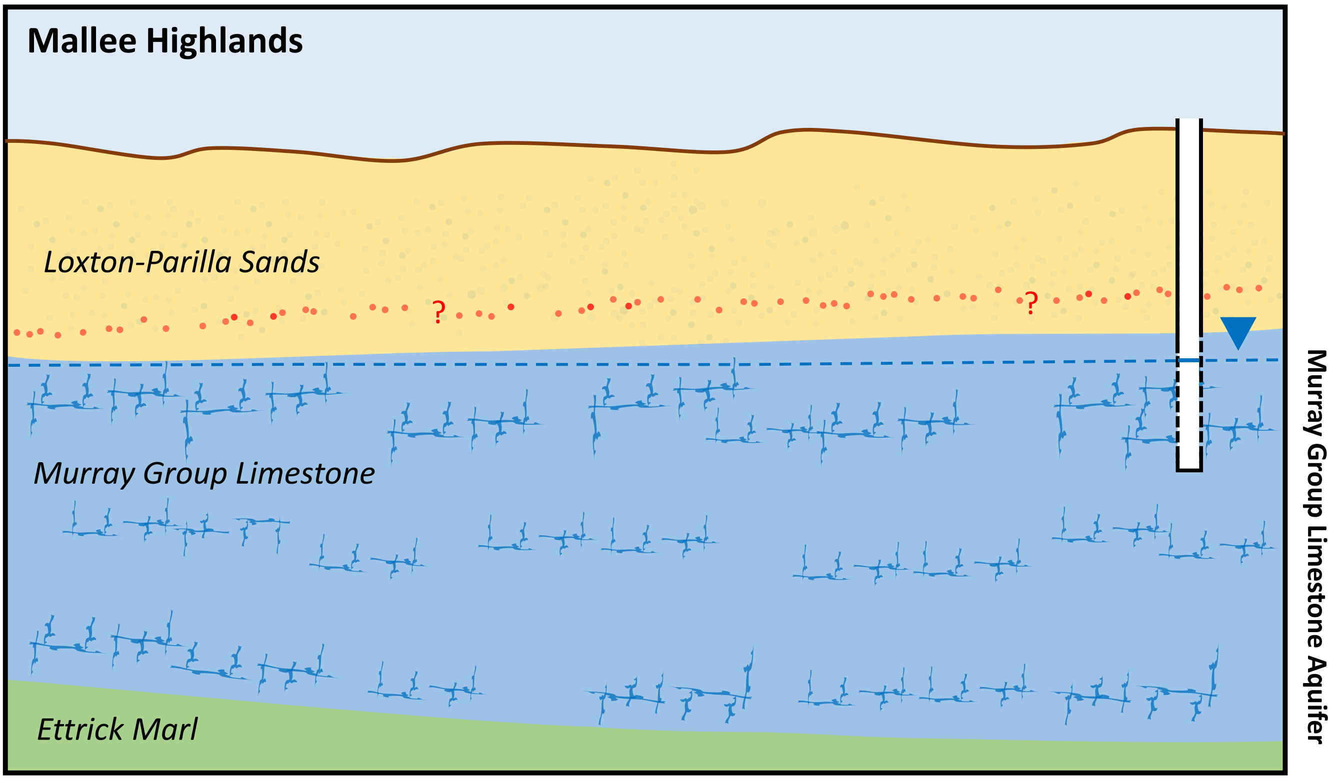


Figure 2.11. Hydrogeological conceptual model of the Mallee highlands

2.6 Confined aquifer system

The confined aquifer system is generally absent or thin within the coastal plain areas of the Padthaway and Tatiara PWAs due to bedrock highs, but is present and used more extensively in the Tintinara–Coonalpyn PWA. In the Murray Basin the unconfined MGL aquifer is underlain by the Ettrick Marl aquitard and in some areas the Buccleuch Formation, and then the Renmark Group before reaching the hydraulic basement at depth (Figure 2.12). The Ettrick Marl is comprised of glauconitic marl, interbedded clays and thin sands and acts as a confining layer. The Buccleuch Formation is comprised of interbedded clays, limestones and sands and contains the first of the confined sub-aquifers in parts of the Tintinara–Coonalpyn PWA. The underlying Renmark Group is comprised primarily of carbonaceous clays and silts with some sandy clays and sand units which are targeted as the second and third confined sub-aquifers. In the Otway Basin to the south, the equivalent to the Renmark Group is the Dilwyn Formation which is comprised of thick clay sequences with thin sandy units which are also considered as separate sub-aquifers.

The distribution of observation wells and information describing the confined aquifer is sparse in the southern PWAs but is more widespread in the Tintinara–Coonalpyn PWA. Due to the low permeability of the confining layers, the vertical movement of groundwater between the unconfined and confined aquifers is thought to be limited in the USE where data is available. Recharge to the confined aquifer is thought to occur primarily in the vicinity of the Dundas Plateau in south-west Victoria where regional flow originates (Brown and Kellett, 1989) and further south in the Nangwarry area (Brown et al., 2001).

Love et al. (1992) reported transmissivity values for the Dilwyn Formation confined aquifer in the Otway Basin from 200–1600 m^2d^{-1} based on aquifer tests from a range of investigations. There are no aquifer parameters available for the Renmark group in the Murray Basin portion of the study area.

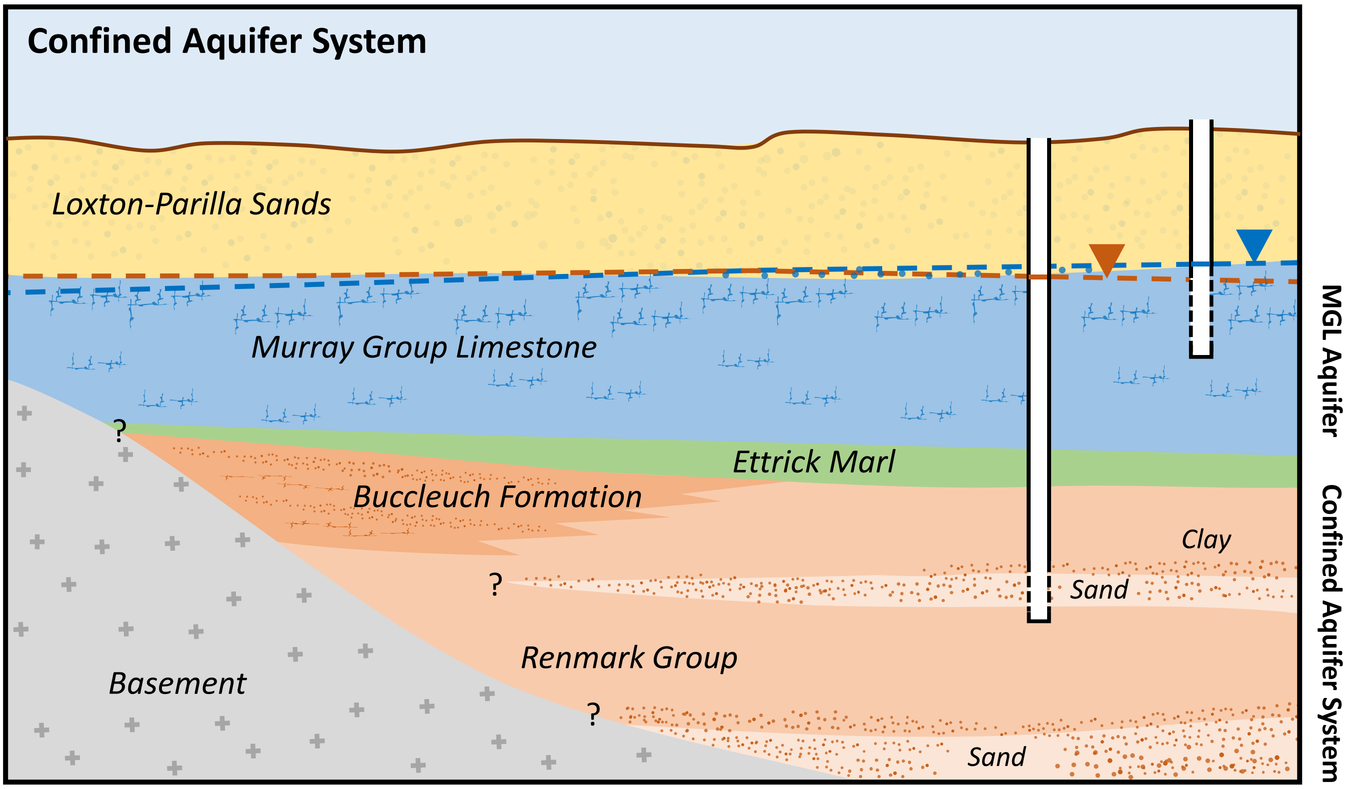


Figure 2.12. Hydrogeological conceptual model of the confined aquifer system (Murray Basin)

3 Resource condition indicators

An extensive groundwater level and salinity monitoring network exists in the USE region, particularly for the unconfined aquifers which include some continuous records from prior to the 1960s. In recent decades, the number of observation wells and monitoring frequencies have been reduced but remain – for most but not all GMAs – adequate for management purposes. One of the most important uses of this network is to enable any change in the behaviour or condition of the aquifer to be relatively well characterised. This can be done by observing the trends in groundwater levels and salinity and relating them to the various drivers that may change the water balance components (inputs and outputs) for each aquifer. An understanding of these linkages and their influence on the resource condition is essential to develop appropriate adaptive management strategies. The suitability of key resource condition indicators that could be applied in the USE region are described in the following sections. Two of these resource condition indicators (vertical hydraulic gradients and fluxes calculated based on groundwater levels adjacent to aquatic GDEs) are not currently considered relevant to the USE PWAs but may be applicable to other regions.

3.1 Groundwater levels

3.1.1 Existing groundwater level triggers

The trends in groundwater levels have been commonly used as an indicator of the condition of the aquifer and rates of decline have been set as "triggers" within WAPs, for example an average of 0.1 m/y over the past five years. The exceedance of such triggers are most meaningfully applied when they are linked to a specific risk to or condition of the resource which then limits how long such a trend can acceptably continue (e.g., a limit could be a specific percentage of total saturated thickness, a relative depth below a reference groundwater level, or until the aquifer is significantly dewatered). The critical factors which should be considered when setting should include:

- the implications or consequences of triggers being exceeded
- an appreciation of what volumetric changes in storage these triggers represent
- the requirement to determine the cause(s) of the water level decline and whether or not they are manageable through the relevant WAP
- what an acceptable rate of water level decline due to extraction in specific hydrogeological zones or groundwater management areas would be
- the specific and/or actual management responses to triggers being exceeded.

The use of water level decline triggers in isolation are most meaningfully used when they are tied explicitly to resource condition limits and effective management responses prior to those limits being reached.

3.1.2 Groundwater level trends

In unconfined aquifers, groundwater level trends in themselves (similar to above) do not have meaningful consequences and are not considered to be reliable resource condition indicators. This is because at any point in time, it is very difficult to predict how long any trend will persist into the future due to the inability to predict future climate and rainfall trends accurately nor possible changes in extracted volumes or extraction distributions. Whilst it is possible to state that a certain condition limit may be reached if a current trend continues for 5 or 10 years, the likelihood of a trend staying constant for that length of time is highly uncertain.

Pressure levels in confined aquifers are strongly controlled by extraction because they do not receive recharge directly from modern rainfall. Strong seasonal variations have been observed in the Tintinara–Coonalpyn PWA which is the only PWA where significant extractions occur from the confined aquifer. If extraction volumes remain reasonably consistent for a number of years, any observed pressure levels trends should also remain consistent and may then stabilise at a new level after some number of years (i.e. reaching a new equilibrium).

However, some caution should be used when examining pressure level trends because of the influence of hydrostatic loading. A declining watertable results in less water being stored in the unconfined aquifer and consequently, less weight pressing down on the confining layer. This reduction in weight reduces the hydrostatic pressure on the underlying confined aquifer and causes confined pressure levels to also decline, i.e. without extraction from the confined aquifer in that area. As discussed in Harrington and Cook (2011), this relationship theoretically has a ratio of 1:1 (after Jacob, 1940) meaning that any observed variation in a confined aquifer greater than that of the unconfined aquifer must be attributed to stresses within the confined aquifer.

3.1.3 Groundwater storage

Groundwater level measurements in unconfined aquifers can be used to calculate the total storage within the aquifer when the saturated thickness is multiplied by the specific yield of the aquifer. This calculation has some uncertainty due to the spatial and vertical variations in the specific yield of any given aquifer, but usually reveals a large number; for instance the storage in the MGL aquifer in Zone 7A is on the order of 5000 GL and the current usage is approximately 5 GL/y. The groundwater storage volume may not be a useful resource condition indicator for very large aquifers because of its magnitude and uncertainty, but it can be used to gain an indication of the robustness of the resource and whether controlled depletion of storage can be sustainable over a long period of time.

Groundwater modelling could be used to determine the impacts of various extraction scenarios (volume and distribution) which could form the basis for consultation with stakeholders. Whilst maintaining reasonable access to groundwater for stock and domestic users may be a consideration, this is a separate issue from sustainable groundwater development.

3.1.4 Aquifer performance

Within the unconfined Quaternary limestone aquifer on the coastal plain, the hydraulic properties of the sedimentary layers are highly variable, ranging from very high yielding layers containing dissolution features, to lower yielding layers that contain fine grained sediments. If water levels decline due to an extended period of below average rainfall and/or increased extraction, the high yielding layers may be dewatered resulting in a significant reduction in the capacity of the aquifer to supply the volumes that have been available in recent decades. This poses a direct risk to the supply of flood irrigation in some areas where high well yields are required to achieve the necessary coverage of the lucerne which is grown on mostly permeable soils.

Aquifer performance is therefore a resource condition indicator and it can be assessed using water level measurements. Knowledge of the depths of the high yielding layers is important in order to apply this indicator. If the water level declines are mainly driven by climate, the effectiveness of a management response through the WAP may be limited, but the users themselves may have to adapt through changing crop types and irrigation methods.

3.1.5 Horizontal hydraulic gradients

Throughout the USE, groundwater generally flows from the elevated margins of the Murray Basin in Victoria westward through to the coast in South Australia. Although the flow rate of several metres to hundreds of metres per year is relatively slow, maintaining the westerly direction through the various unconfined aquifers is very important for mitigating the cumulative salinity impacts caused by major land use changes since European settlement. These include clearance of Mallee vegetation on the Mallee highlands and the recycling of irrigation drainage on the coastal plain. If throughflow is not maintained and flow stagnation or reversal occurs in either of the two regions, salt will accumulate more rapidly in the aquifers which may render them unusable. Therefore a westerly horizontal hydraulic gradient is an important RCI for both the Mallee highlands and the coastal plain (as well as between the two regions). The hydraulic gradient can be measured between paired observation wells at strategic locations within the PWAs.

The same principles apply to the confined aquifer near Tintinara where any permanent cone of depression in the pressure surface would have the potential to cause flow reversal which would draw more saline groundwater from the west towards extraction wells. A westerly horizontal hydraulic gradient needs to be maintained through the areas of irrigation during the non-irrigation season (Sept–Oct) to prevent significant flow reversal.

3.1.6 Aquitard integrity

If drawdowns due to extractions are large enough, the pressure level for the confined aquifer may fall below the confining layer, and possibly even below the top of the confined aquifer itself. This process of depressurisation can reduce the hydrostatic pressure from below supporting the confining layer against the weight of the overlying unconfined aquifer and the groundwater contained within it. This could result in fracturing of the confining layer and downward leakage from the overlying unconfined aquifer into the confined aquifer. If a confined sand aquifer is depressurised, the consolidation and compaction of the aquifer material can lead to the overlying low permeability confining sediments collapsing and blocking the screens in confined aquifer wells.

The aquitard integrity is therefore an important RCI for the confined aquifer which can be measured by comparing the pressure level with the top of the aquitard.

3.1.7 Vertical hydraulic gradients

The direction of vertical hydraulic gradients between the unconfined and confined aquifer systems determines the direction of potential vertical groundwater flow between aquifers. The vertical hydraulic conductivity of the aquitard separating the aquifers controls the rate of leakage between them. If the aquitards are thin or discontinuous the potential for leakage between these aquifers is high, however where the aquitard is thick which is the case in the Tintinara–Coonalpyn PWA where the majority of confined aquifer extractions are occurring, leakage rates would be expected to be very low. This conclusion is supported by monitoring data which has shown no changes in confined aquifer salinity in the Boothby GMA over the past 15 years even though confined aquifer pressures have been consistently up to 5 m lower than the watertable in the saline unconfined aquifer. Because of these considerations vertical hydraulic gradients are not considered to be critical RCIs in the USE.

3.1.8 Groundwater dependent ecosystems

Although GDEs are not common in the USE because of the generally deep watertables, there are a series of ephemeral saline wetlands on the coastal plain, generally toward the western boundary of the three PWAs. These wetlands which have ecological value, can be considered as potential GDEs as they have been classified by Sheldon (2009) as having a high to very high likelihood of interaction with the brackish to saline groundwater. This classification is not surprising given that the wetlands are essentially groundwater discharge areas.

Declining groundwater levels of several metres have been observed across the coastal plain of the USE since the mid-1990s which are likely to have resulted in a significant change in the nature of the groundwater connection with these GDEs. It is highly likely that these wetlands have experienced similar or even lower water levels in the last several hundred years, given the large climatic variability that has been experienced over that period. Because of the high groundwater salinities, the nearest irrigation is at least 5 km away to the east and it is therefore unlikely that extractions have had a direct influence on any water level decline in the vicinity of the wetlands.

Therefore the condition of the GDEs would not be an effective resource condition indicator because water levels in the vicinity are mostly climate driven and cannot be managed directly through changes to the level of groundwater allocated in the vicinity of the GDE.

3.2 Groundwater salinity

In the USE, there are three main processes which result in rising trends in groundwater salinity in the unconfined aquifers:

1) Clearing of native vegetation – where removal of Mallee vegetation communities allows increased recharge rates and the flushing of salts previously stored in the unsaturated zone
2) Evapotranspiration from shallow watertables – where the capillary fringe above the watertable evaporates or is removed by plants causing soil moisture and the shallow groundwater to increase in salinity
3) Irrigation recycling – where *in situ* groundwater is extracted and used for irrigation, the dissolved salts become concentrated after some evaporation and transpiration by crops, before drainage then returns to the watertable with an increased salinity.

There is little that can be done to manage rising salinity trends resulting from the first two processes, given that the management toolbox provided by a WAP is mostly limited to tools such as reducing groundwater allocations available for extraction or providing the ability to transfer allocations away from areas of high demand. This management response may also not be effective in reducing the salinity impacts of irrigation recycling because these impacts result from application of water to a crop, not the physical extraction of water from the aquifer.

The only way the impacts of irrigation recycling can be reduced would be to take large areas out of production. This would have social and economic implications that would have to be considered. Managing salinity will be complicated by climate change, given the projected reductions to rainfall and increases in potential evapotranspiration (Charles and Fu, 2014) which may cause rainfall recharge rates to decrease and be of a higher salinity.

The management of salinity increases cannot be achieved through the WAP in isolation (e.g. by altering allocation with the intent of reducing extraction) without being accopmanied by measures such as changes to crop types, irrigation methods and the inclusion of alternative water sources (e.g. use of groundwater from confined aquifers or the incorporation of desalination systems). Communication of groundwater salinity trends to groundwater users is therefore crucial in this process. Once the salinity of local groundwater becomes too high for flood irrigation it may be possible to switch to dryland agriculture. However following irrigation with groundwater of ~7000 mg/L, it is likely that the remnant soil salinity would be initially to be too high for plant growth. Rainfall recharge may take a number of years to effectively flush the shallow soil salinity allowing shallow rooted crops to be grown. Other features of the soil structure and chemistry may also be limiting for successful dryland agriculture.

3.2.1 Groundwater salinity distribution

For confined aquifer systems, the risk of flow reversal occurring due to cones of depression as discussed previously is dependent on the salinity of the groundwater that would flow toward the extraction wells. The groundwater salinity distribution within each confined sub-aquifer is therefore a useful resource condition indicator to warn of potential movement of groundwater salinity. An assessment of the adequacy of the groundwater salinity monitoring networks may be required in order to confidently identify the risk of salinity impacts. Numerical modelling can be used to predict the rates of change in groundwater salinity due to flow reversals towards the extraction centers (e.g. Barnett and Yan, 2008).

3.2.2 Groundwater salinity trajectories

The salinity of groundwater is an important factor in determining how it can be used because there are specific salinity tolerances for each irrigated crop type in the region. Wine grapes and potatoes for example require a salinity of less than 1500 mg/L while lucerne can be produced with irrigation water of up to 3000 mg/L using center pivots or in other areas lucerne for seed production can be flood irrigated with groundwater up to 7000 mg/L. As such, groundwater salinity trajectories towards these thresholds should be a useful resource condition indicator, which would act as a warning for irrigators of how many years are likely to remain until such threshold values are reached. An example of this is shown for a monitoring well in the Stirling GMA (Figure 3.1). If the recent trend (from 2000–present) continues at the same rate, the salinity threshold will be reached in approximately 12 years from 2016.

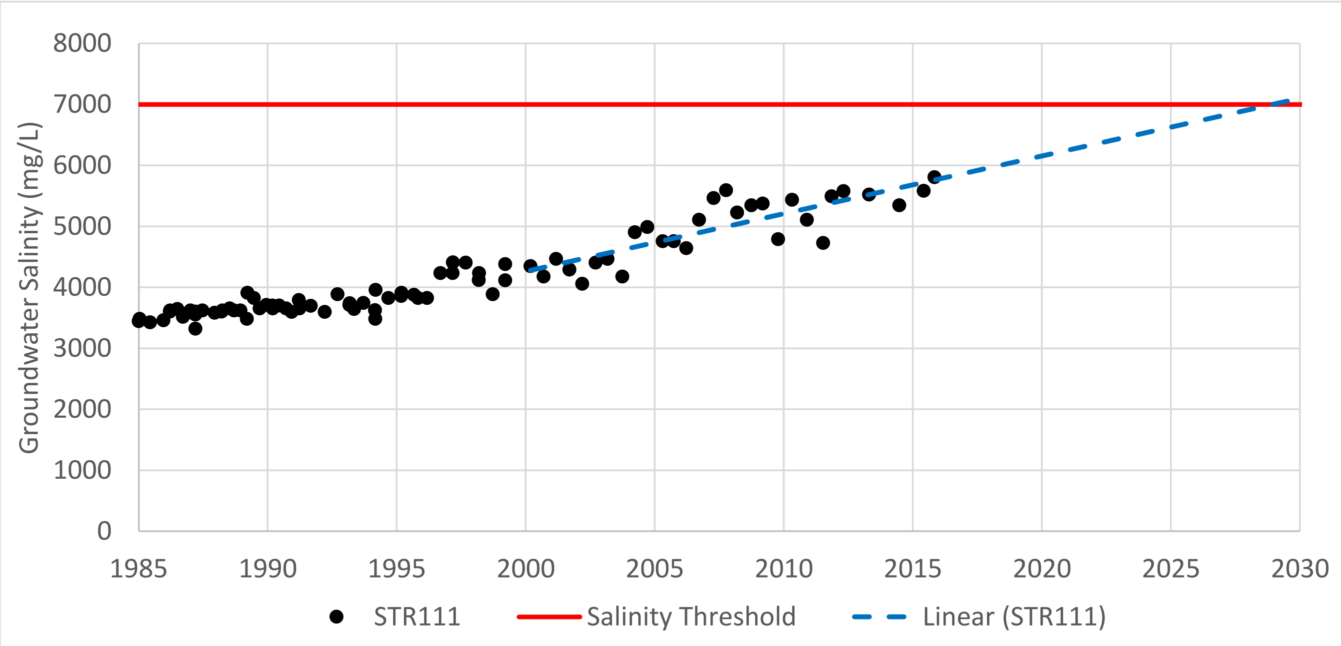


Figure 3.1. Recent groundwater salinity trend (2000–present) trajectory for STR111 on the coastal plain

3.2.3 Low salinity groundwater recharge sources

Point recharge through runaway holes and recharge from losing ephemeral creeks are important processes for local groundwater supplies where this type of recharge occurs. The most notable recharge features within the USE are the Poocher and Mundulla Swamps located at the terminus of Tatiara and Nalang Creeks respectively, as well as the length of Morambro Creek before it discharges into Cockatoo Lake. When these creeks flow, they lose water to the underlying unconfined aquifer (because the watertable is below the base of the creeks). This provides the aquifer with low salinity recharge, a plume of which extends some distance downgradient in the regional aquifer from the location where it is recharged (Figure 3.2). This low salinity groundwater is important for the groundwater users in the area influenced by these recharge processes as it is in contrast to the somewhat higher salinity of the regional groundwater. Thus the creek flow (i.e. magnitude and duration), and recharge occurring as a result, can be considered as resource condition indicators for localised fresher groundwater sources.

There are a number of surface water monitoring gauges (e.g. A2390534 Tatiara Creek at Bordertown, A2390562 Nalang Creek @ Allendale and A2390531 Morambro Creek @ Bordertown-Naracoorte Road Bridge) which can be used to approximate the volumes (and also quality) of the water recharging the aquifer. Additional water quality monitoring at the location of point recharge locations and along the length of the creeks would be more useful for determining the risk of water quality issues associated with runoff (i.e. contaminants). Other runaway holes exist in the region, but are not known to be fed by significant surface water flows. Any such surface water inflows are currently without gauges, making it challenging to approximate the magnitude or frequency of point recharge or creek loss. Similarly, the volumes of runoff infiltrating through drainage wells is difficult to quantify given the absence of flow meters. Some analysis could be done for wells with high frequency water level monitoring in order to develop rough estimates of drained volumes.

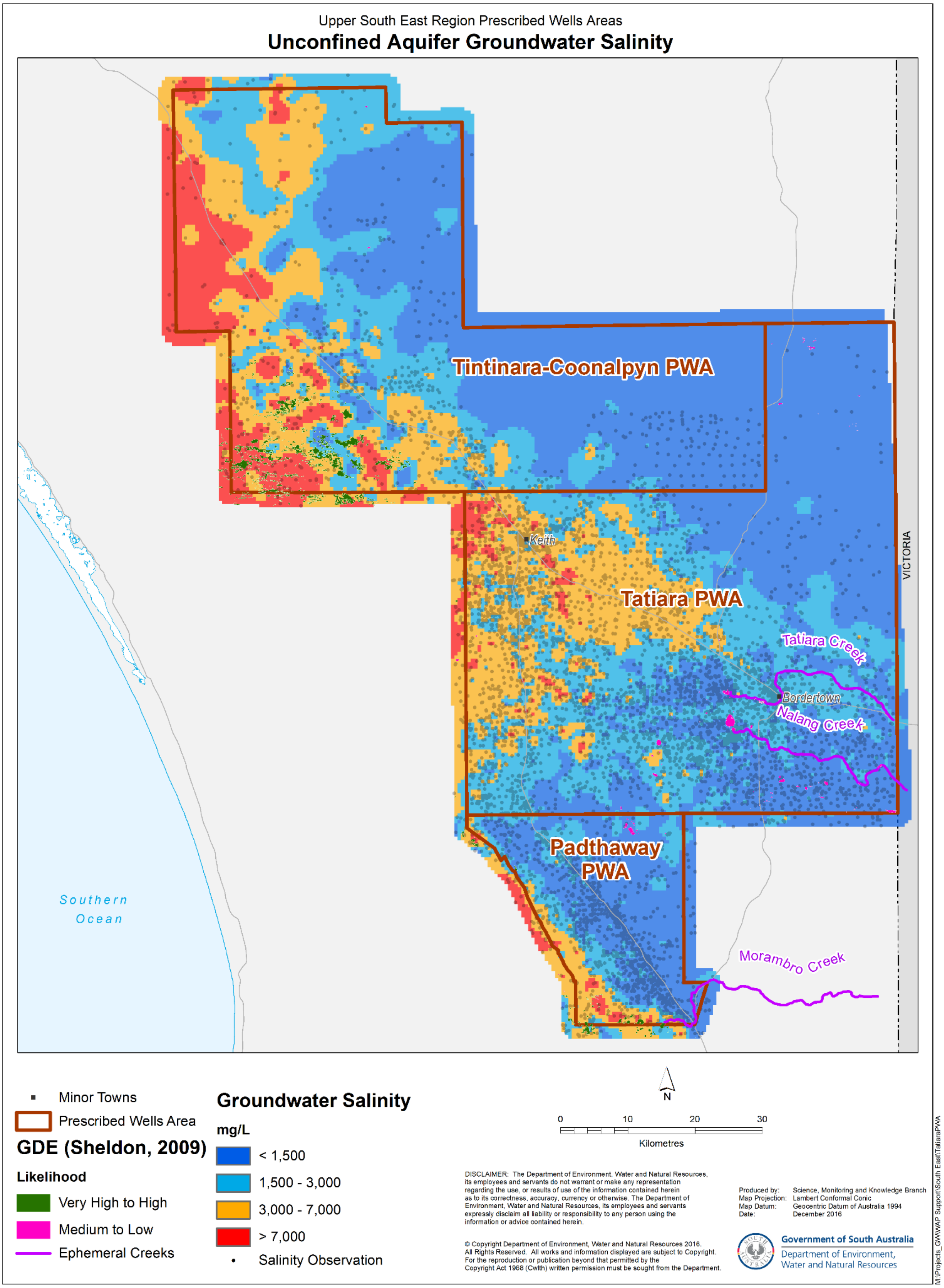


Figure 3.2. Unconfined aquifer groundwater salinity

4 Resource condition limits

RCLs should be specific to the local behaviour and condition of the aquifer and also be measureable, so that monitoring of the appropriate resource condition indicators can trigger management actions that will aim to prevent the RCL from being exceeded. These principles have been described in general by Richardson et al. (2011) and Anderson et al. (2014), but have been presented specifically for the South East NRM region by Harrington and Currie (2008). A number of management objectives (MOs) stated in the USE WAPs intend to define RCLs but are incomplete to varying degrees because they do not meet each of the above criteria (i.e. specific, measureable, and linked directly to adaptive management responses). This is discussed below and a number of new RCLs are proposed for specific hydrogeological zones, which could be easily incorporated into future revisions of the WAPs.

4.1 Existing management objectives similar to RCLs

4.1.1 Padthaway PWA

The Padthaway WAP (DEWNR, 2009) contains management objectives that could be interpreted as RCLs (i.e. that are specific and measurable) but these have not been fully developed. These include a lower watertable limit of June 2004 levels, no increases in underground water salinity beyond the values at date of adoption and maintenance of lateral throughflow). A numerical groundwater modelling exercise (Wallis and Middlemis, 2007) produced a series of future scenario projections for some of these management objectives. Based on a combination of these scenario results, an acceptable extraction limit of 48 000 ML was adopted by the WAP. These management objectives were related to the model predictions and do not explicitly incorporate ongoing adaptive management of the resource. For example, there are no clear adaptive management responses or measures to prevent the management objectives from being reached apart from the extraction limit. Agreed resource condition triggers were adopted (i.e. 1% change in salinity over 5 years, 0.1 m/y decline in waterlevels) to assess new allocations and transfers but these are not linked with specific management responses to the triggers being exceeded more broadly.

4.1.2 Tatiara PWA

The Tatiara WAP (DEWNR, 2010) contains no management objectives that could be interpreted as RCLs, but agreed resource condition triggers are used to assess new allocations and transfers (similarly to the Padthaway PWA). However, McIntyre and Wood (2011) reported on a series of community consultation workshops which were undertaken after the approval of the WAP aimed at developing resource condition limits for the Tatiara PWA. There were four proposed management objectives (MOs) described, which were related to groundwater levels and salinity as outlined below:

- MO1 – Maintain groundwater levels in the more productive layers of the aquifer in the western low-lying areas, while preventing water levels from declining more than 2 m from current levels in other areas
- MO2 – Where possible, restore water levels to pre-2003 levels
- MO3 – Manage salinity by maintaining an east to west hydraulic gradient
- MO4 – Manage salinity to tolerable thresholds for particular crop types.

MO1 contains specific and potentially measureable conditions that could be tested and adopted (see later discussion), while MO3 has been discussed earlier as an acceptable RCI by measuring the hydraulic gradient between pairs of observation wells. The remaining MOs are more aspirational and difficult to achieve with the current management approaches available through WAPs. MO2 could only be achieved if several years of above average rainfall occurred, while MO4 might be achieved if large irrigation areas were taken out of production.

4.1.3 Tintinara–Coonalpyn PWA

The Tintinara–Coonalpyn PWA WAP and technical reports by Barnett (2002; 2008) discuss the management approaches taken in this PWA for the confined and unconfined aquifers. The resource condition triggers are related to residual and peak drawdown (confined aquifers) and groundwater level and salinity trends (unconfined aquifers). If these adopted triggers are exceeded, further investigation into the causes and impacts of the trends should be done to determine whether any management intervention is warranted. The Tintinara–Coonalpyn WAP does not to contain specific or measureable RCLs that would give the resource condition triggers some context.

4.2 Coastal plain RCLs

4.2.1 Aquifer performance

The unconfined Quaternary limestone aquifer on the coastal plain in each of the PWAs, primarily provides groundwater from the highly transmissive Padthaway Formation. Underlying this formation are less permeable units with lower yields and possibly lower storage (i.e. specific yield). Thus in order to maintain aquifer performance with respect to high yields, the Padthaway Formation should always have a saturated thickness that does not significantly impact aquifer yields. A potential RCL could be the maintenance of at least 3 m of saturated thickness within the Padthaway Formation at the end of each winter monitoring round (to allow for reasonable drawdown in the subsequent summer period). The elevation of this RCL would be calculated on a well by well basis and could be incorporated into any future projections made by numerical or other groundwater models. Four examples are shown in Figure 4.1 for observation wells in the Hundreds of Stirling and Willalooka. It appears that WLL108 has already exceeded the above proposed RCL while the other three wells have approximately 1.5 m of further decline before the RCL is reached. The location of these wells is shown in Figure 4.6.

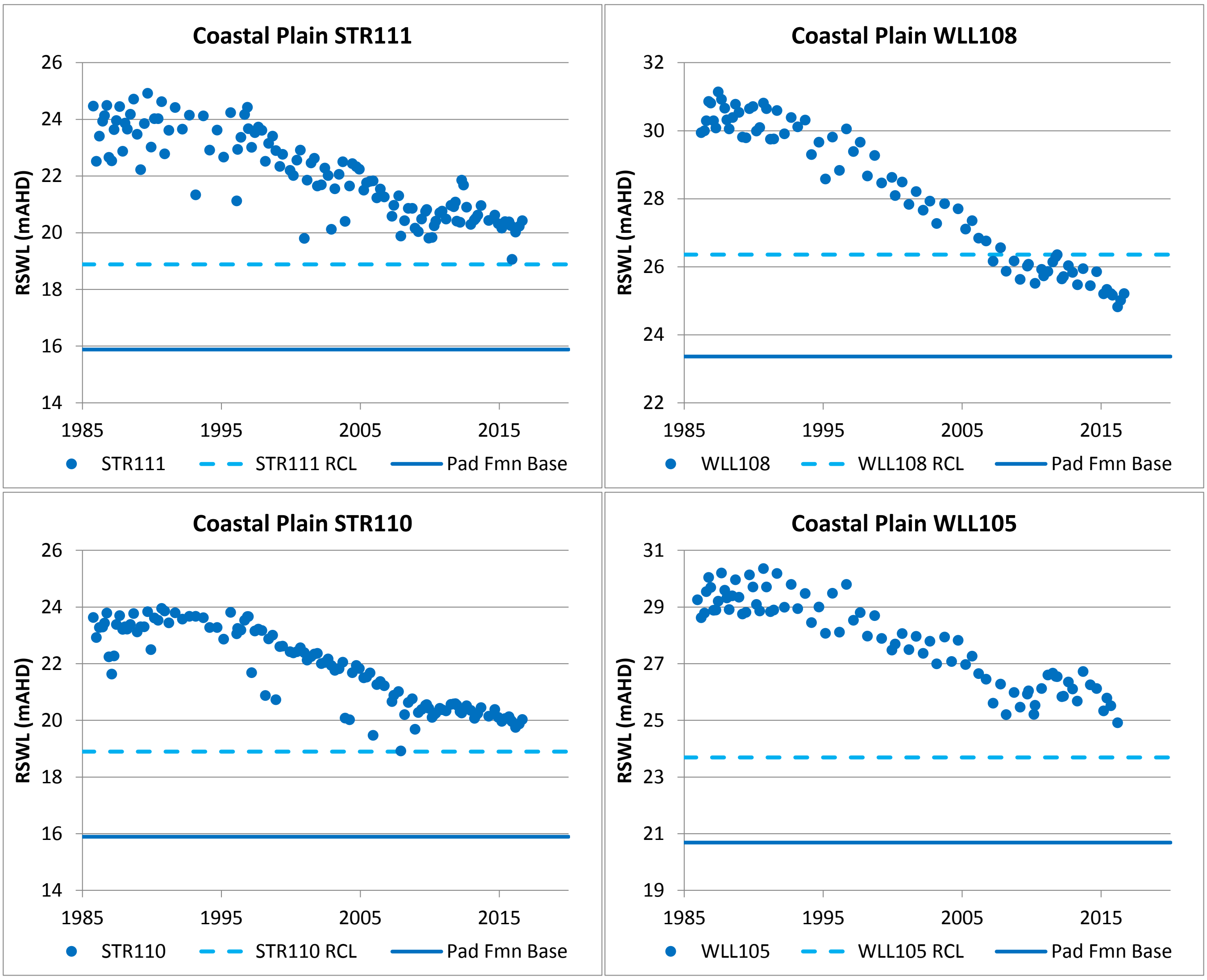


Figure 4.1. Observation wells for potential aquifer performance RCL on the coastal plain

4.2.2 Hydraulic gradient

Because of the salinity risk presented by irrigation recycling, it is essential for throughflow to be maintained in order to mitigate the risk of greater rates of already increasing groundwater salinity beneath the irrigated areas. Groundwater flow reversal, which would lead to lateral inflows of more saline groundwater from the west into the irrigation areas will also be prevented by maintaining westward groundwater flow. The hydraulic gradient can be determined by measuring water levels at paired observation wells, and should be positive at all times (i.e. always flowing westward). Maintaining a 1 m difference between paired observation wells less than 10 km apart (i.e. a hydraulic gradient of > 0.0001) would ensure that the hydraulic gradient remained positive towards the west.

This hydraulic gradient is indicated by the red error bars for three pairs of observation wells within the Tatiara PWA in Figure 4.2 (locations of wells are shown in Figure 4.6). It is clear that the upgradient wells (blue symbols) located to the east remain higher than the downgradient wells (orange symbols) located in the west for each pair. However the groundwater levels in the central Tatiara PWA observation pair are within 1 m from the late 2000s to present. This indicates that there is an increased risk of greater salinity accumulation rates and flow reversal resulting in potential eastward movement of more saline groundwater into the area between these wells. Exceedance of a 1 m difference could trigger a localised management response in future WAPs (see possible RCTs in Section 4.7).

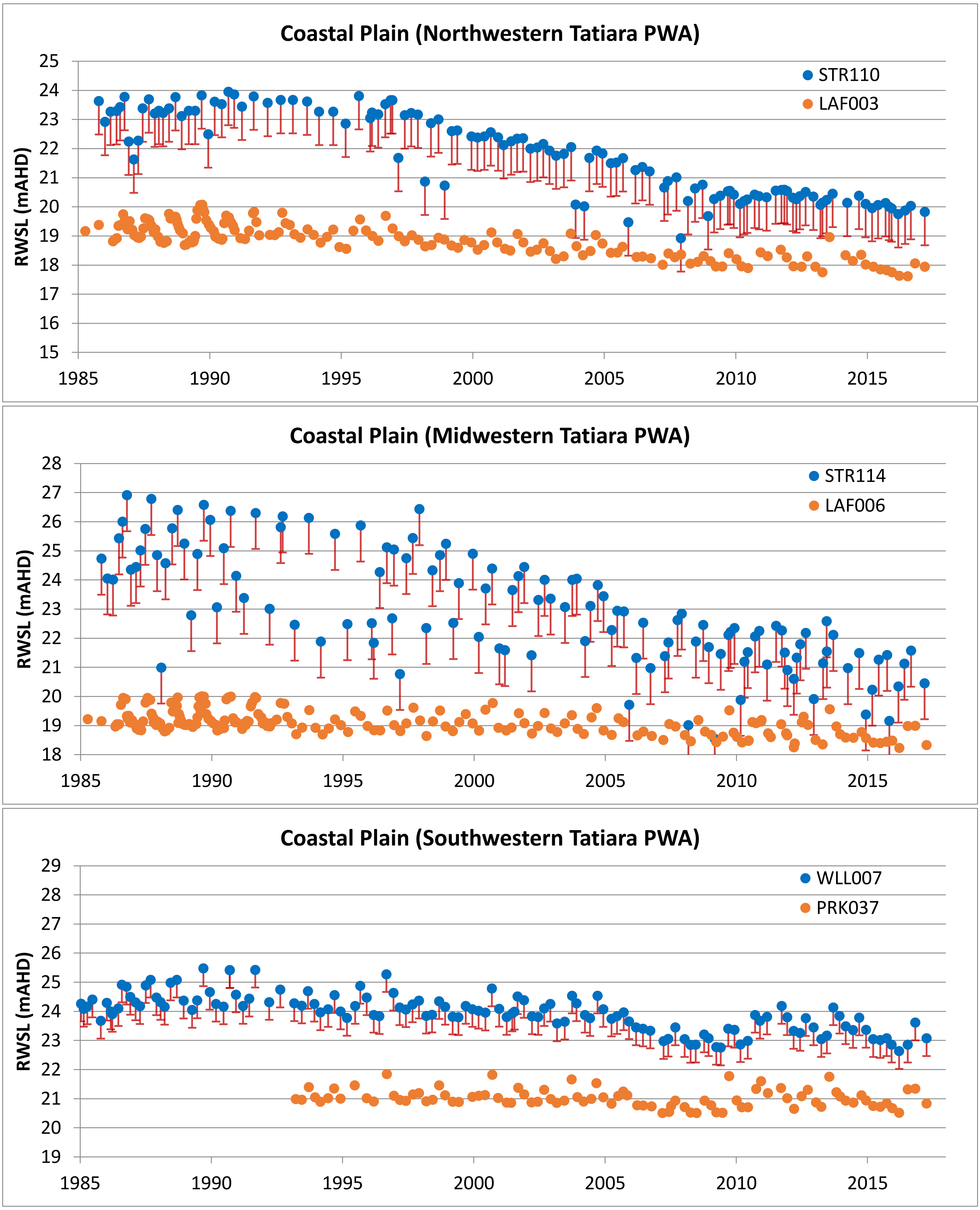


Figure 4.2. Potential hydraulic gradient RCLs for coastal plain noting that red error bars represent the difference in water level for which the 0.0001 RCL would be exceeded

4.3 Highland transition RCLs

4.3.1 Aquifer performance

Because the main aquifers (Bridgewater Formation and MGL) in the highland transition do not have the same characteristics as the Quaternary limestone on the coastal plains (i.e. multiple formations with significant vertical differences in hydraulic properties), there is no critical saturated thickness required to maintain the aquifer performance. However if intensive extraction led to significant water level declines, some wells may have to be deepened to maintain supply.

4.3.2 Hydraulic gradient

There are several salinity risks in the highland transition that can be ameliorated by maintaining throughflow across the zone. These risks include increasing salinity caused by irrigation recycling, flushing of the unsaturated zone following land clearance and flow stagnation or reversal if groundwater levels were to decline below those of the coastal plain. The hydraulic gradient can be determined by measuring water levels at paired observation wells, and should be positive at all times (i.e. always flowing westward). There is no evidence at present that would suggest what an optimum westward gradient would be, however using the relatively stable period from 1985–1995 as a reference may be appropriate (as would some other agreed reference hydraulic gradient). This is demonstrated in Figure 4.3, where the current differences between upgradient and down gradient observation wells are greater than experienced previously (i.e. greater rates of throughflow are now occurring). Groundwater modelling investigations could indicate what extraction volumes (and the distribution of any such extraction) would lead to decreased rates of throughflow.

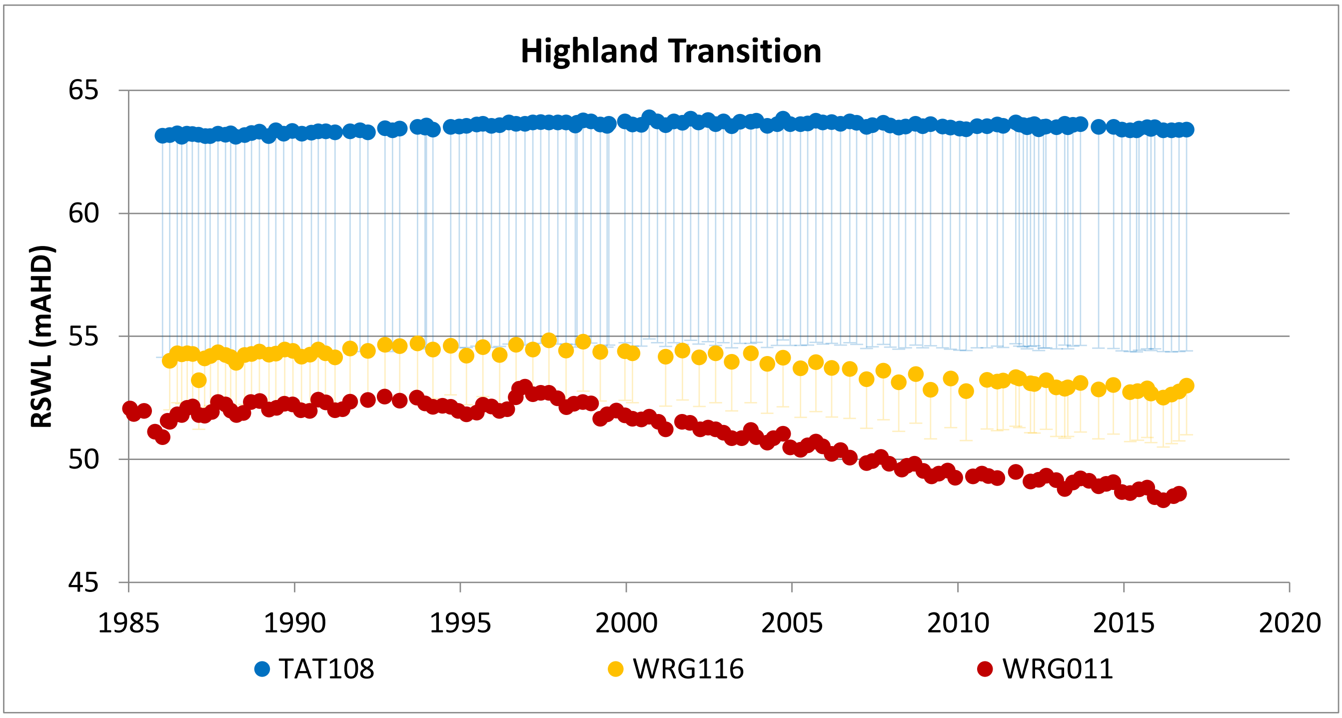


Figure 4.3. Approximation of historical differences in groundwater levels for selected observation wells in the highland transition

4.4 Mallee highlands RCLs

4.4.1 Aquifer performance

Because the MGL aquifer in the Mallee highlands does not have the same characteristics as the Quaternary limestone on the coastal plains (i.e. multiple formations with significant vertical differences in hydraulic properties), there is no critical saturated thickness required to maintain the aquifer performance. However if intensive extraction led to significant water level declines, some wells may have to be deepened to maintain access to groundwater.

4.4.2 Hydraulic gradient

The arrival of more saline recharge through deep unsaturated zones due to historical vegetation clearance presents a risk to the groundwater salinity in the Mallee highlands. This can be ameliorated by maintaining throughflow across the zone with a westward hydraulic gradient. The hydraulic gradient can be determined by measuring water levels at paired observation wells, and should be positive at all times (i.e. always flowing westward). Additionally, this ensures continued throughflow towards the coastal plain which is reliant on this groundwater source. Historically there have been no significant declining trends in eastern observation wells and so a reversal of regional flow is considered highly unlikely. Western observation wells do however show small declining trends which will increase the westward hydraulic gradient across the Mallee highlands (Figure 4.4). This decline is likely induced by the larger declines experienced in the coastal plain. There is no evidence at present that would suggest what an optimum westward gradient would be, however groundwater modelling investigations could be used to indicate what extraction volumes (and the distribution of any such extraction) would lead to reduced throughflow.

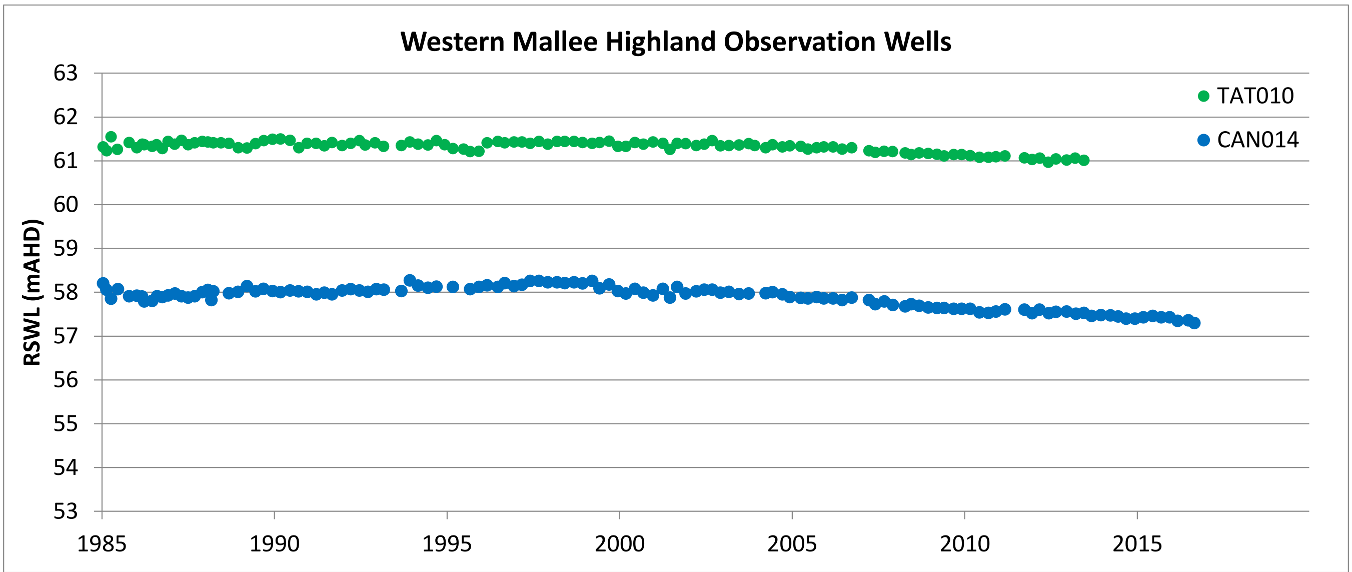
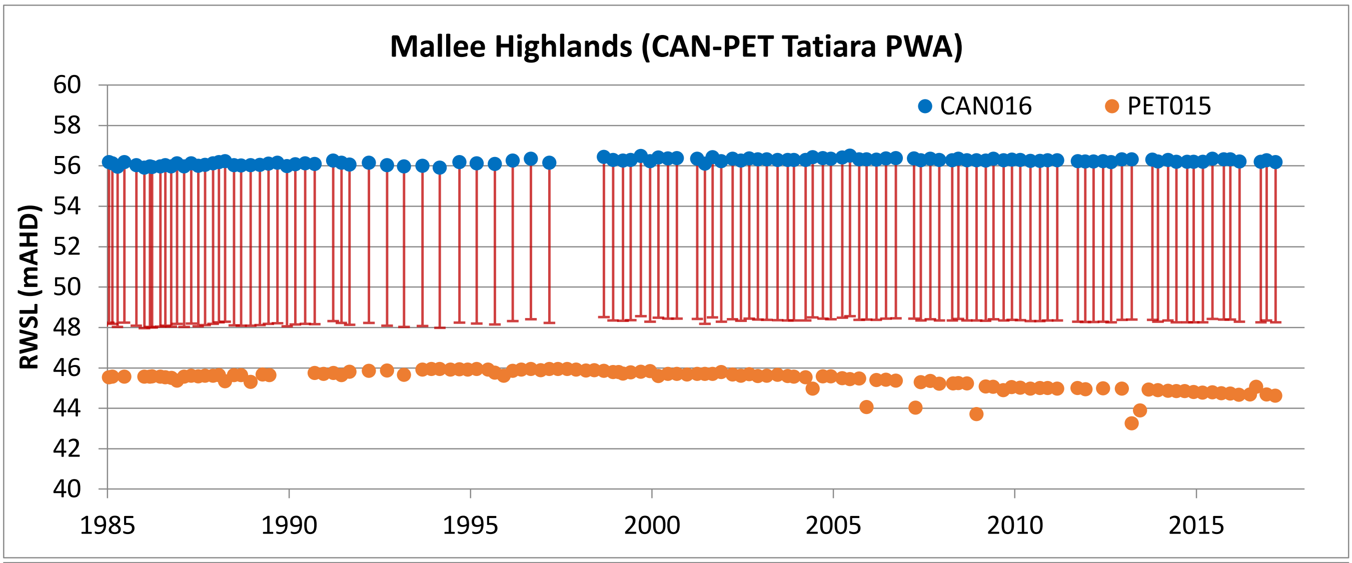
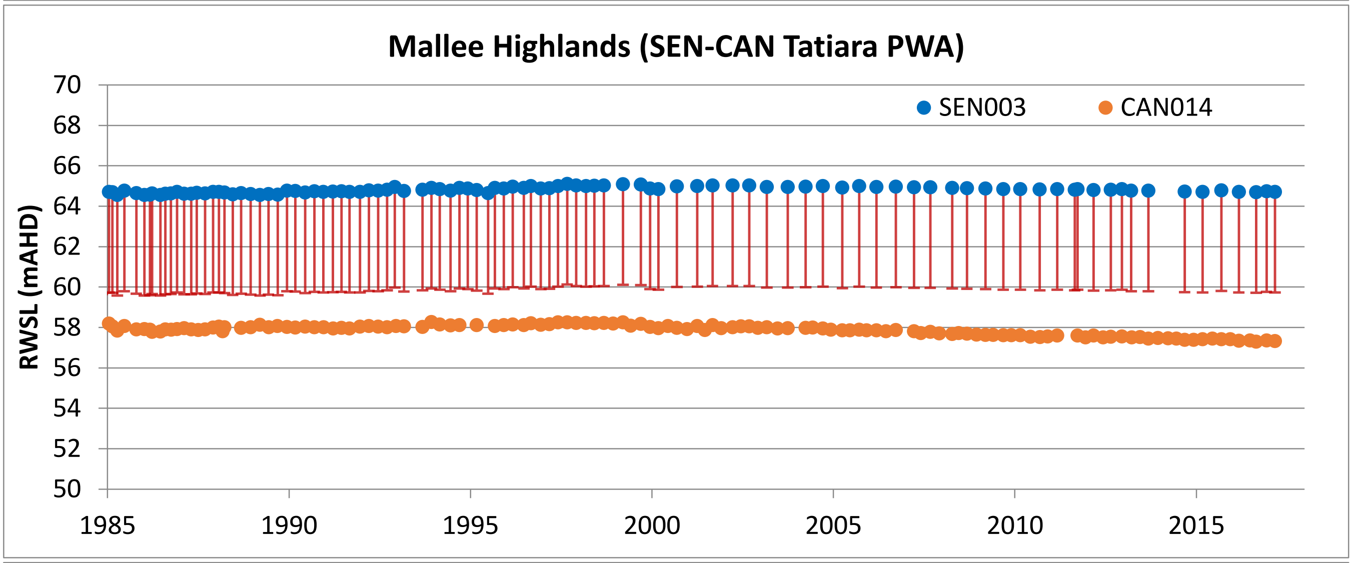


Figure 4.4. Western observation wells in the Mallee highlands showing small declining trends since the late 1990s

Historical hydraulic gradients towards the coastal plain from the western side of the Mallee highlands are on the order of 5 m in 10 km (i.e. a hydraulic gradient of 0.0005) or more. Some examples are shown in Figure 4.5 for the Tatiara PWA where the red error bars below the upgradient observations represent the waterlevel at which a 4 m difference over 10 km would exist (i.e. a hydraulic gradient of 0.0004) which could be selected as a potential RCL. The location of these observation well pairs is shown in Figure 4.6. These pairs of observation wells demonstrate how the decline of the western wells has caused the hydraulic gradient to increase since the end of the 1990s (i.e. groundwater level difference between observation wells has increased) and hence there is a low chance of this RCL being reached without considerable groundwater development occurring in the Mallee highlands.





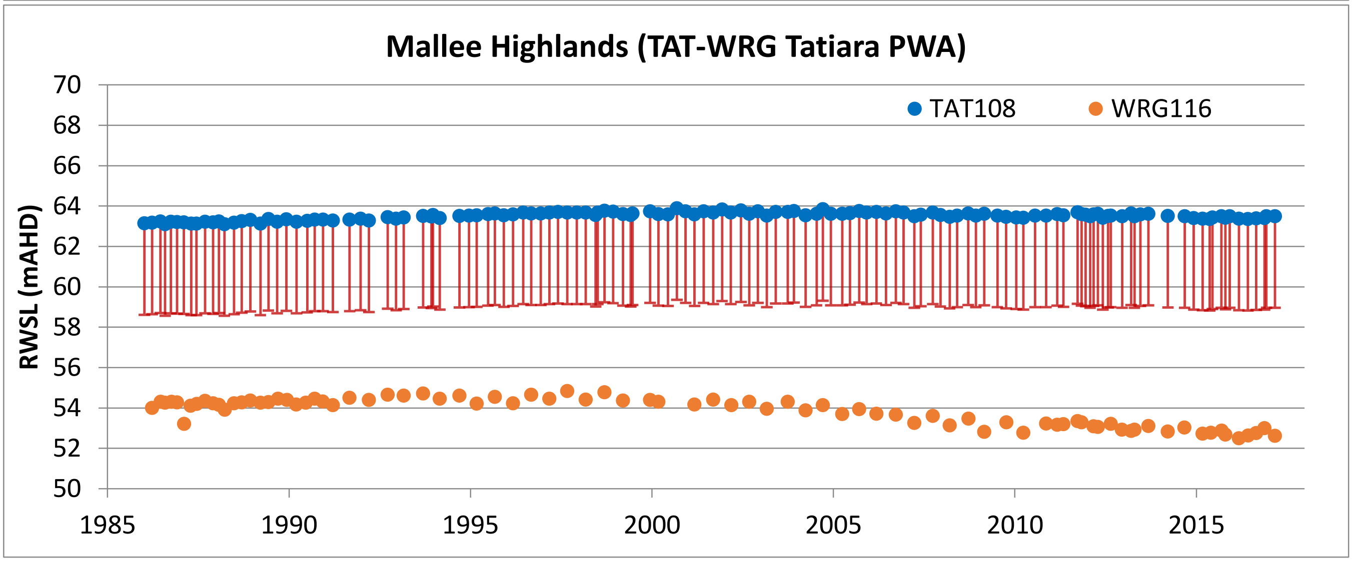


Figure 4.5. Western pairs of observation wells in the Mallee highlands noting that red error bars represent the difference in water level for which the 0.0004 RCL would be exceeded

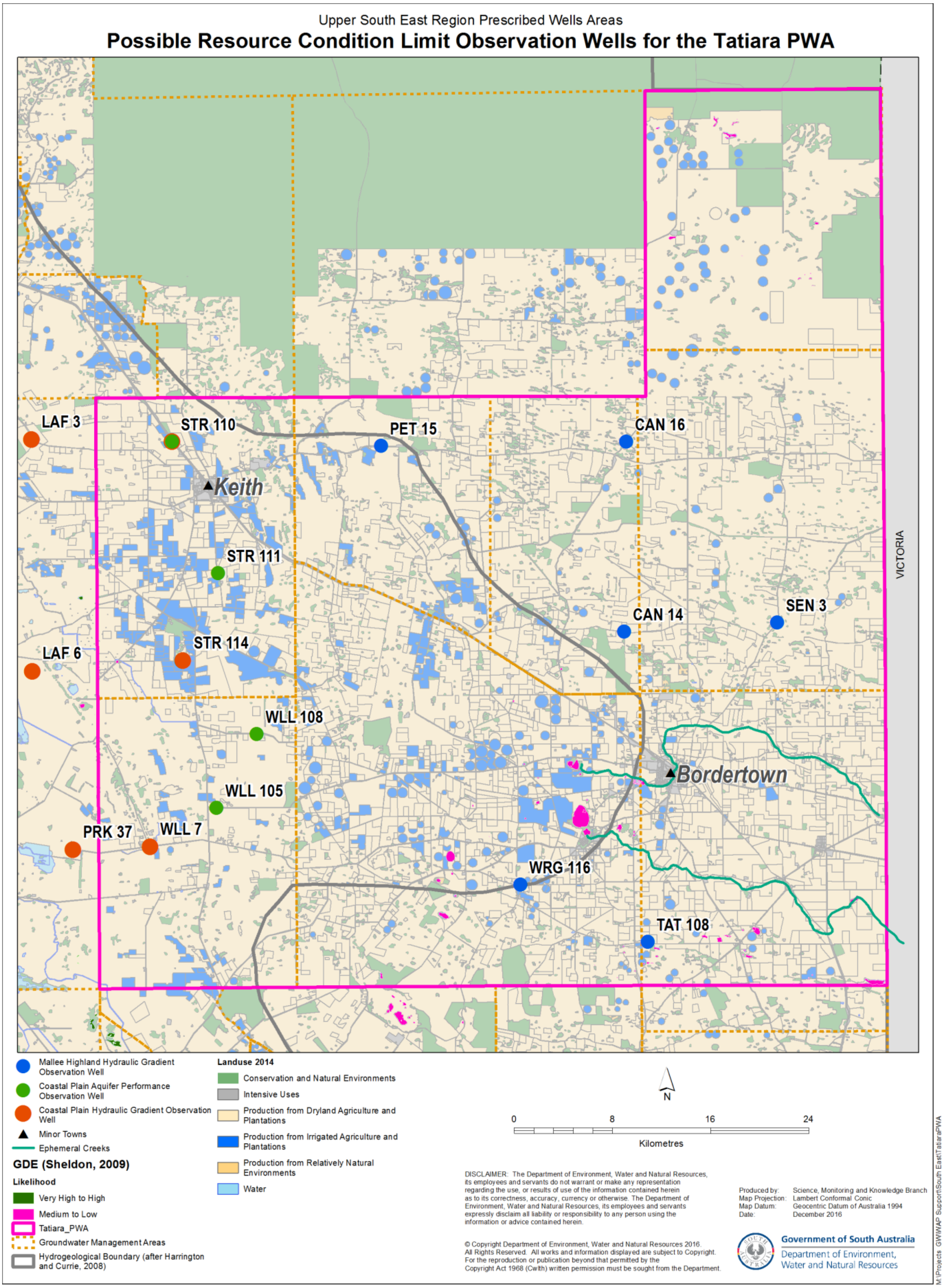


Figure 4.6. Observation wells for possible RCLs in the Tatiara PWA

4.5 Confined aquifer system RCLs

4.5.1 Aquitard integrity

An appropriate RCL for confined aquifer systems would be for the pressure level in confined observation wells to remain above the top of the aquitard at all times. This would mitigate the risk of change in the structural integrity of the aquitard. An example of this potential RCL is shown for CRC003 which is screened in the third confined aquifer in the Tauragat Management Area (Figure 4.7). It can be seen that some 40 m of additional drawdown exists until the top of the aquitard would be reached.

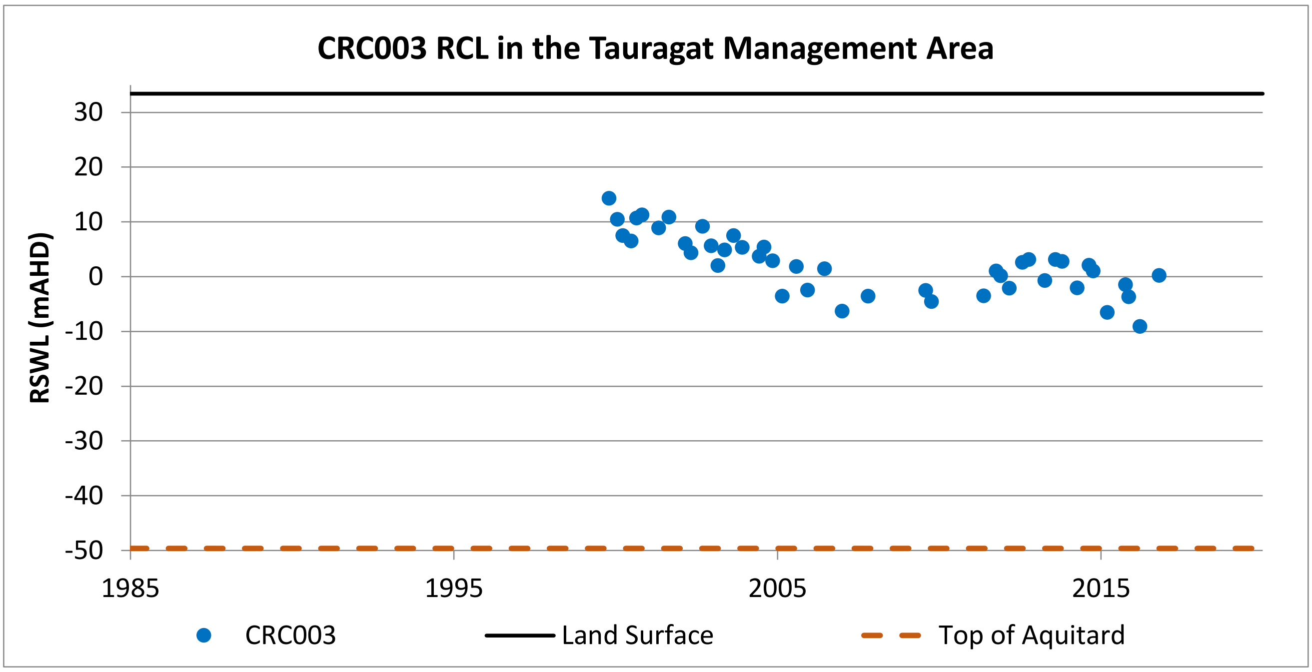


Figure 4.7. Potential RCL for selected confined aquifer system observation well

4.5.2 Hydraulic gradient

In the Boothby GMA, salinity increases due to flow reversal could occur if a permanent cone of depression was created. A water level monitoring transect through the irrigation area could determine if the westerly hydraulic gradient is maintained through the non-irrigation season. Given the very slow rates of groundwater flow within the aquifers, the permanent cone of depression would need to be in place for a number of years before any significant flow reversal could occur. It is therefore proposed that a RCL of a permanent cone of depression being present for five consecutive years be adopted. An assessment of the adequacy of the groundwater salinity monitoring networks for each confined sub-aquifer (i.e. first, second and third) may also be required in order to confidently identify the risk of salinity impacts. Numerical modelling can be used to predict the rates of change in groundwater salinity due to flow reversals towards the extraction centers (e.g. Barnett and Yan, 2008).

4.6 Summary of potential RCLs

A summary of potential RCLs for each of the hydrogeological zones is shown below (Table 4.1). These are applicable to different GMAs within each PWA as outlined in Table 2.1. Further detailed analysis may be required for each type of RCL and engagement with the PWA stakeholders prior to implementation within WAPs. For each hydrogeological area or GMA, this would include analysis of additional:

- Hydrostratigraphic and lithological logs for observation wells on the coastal plain to determine the bottom elevation of the Padthaway Formation for the aquifer performance RCL
- Groundwater hydrographs to select the most appropriate observation well pairs for hydraulic gradient and aquifer integrity RCLs
- Determination of appropriate RCTs that would allow adaptive management actions to be taken thereby clarifying or reducing the risk of an RCL being reached
- Groundwater salinity graphs to select the most appropriate wells for the projection of recent salinity trajectories toward specific salinity threshold values.

Table 4.1. Potential Resource Condition Limits

Hydrogeological zone	Potential resource condition limit
Coastal plain	*Aquifer performance* – maintain a saturated thickness within the Padthaway Formation of greater than 3 m at the end of each winter monitoring round.
	Hydraulic gradient – maintain a westward hydraulic gradient of >0.0001 at all times between paired monitoring wells along the western boundary of the PWAs.
Highland transition	*Hydraulic gradient* – maintain a minimum hydraulic gradient (i.e. greater than the 1985–95 gradient) at all times between paired monitoring wells from the Mallee highlands to the coastal plain.
Mallee highlands	*Hydraulic gradient* – maintain a westward hydraulic gradient of > 0.0004 at all times between paired monitoring wells along the western boundary of the Mallee highlands.
Confined aquifer systems	*Aquitard integrity* – maintain hydraulic head above the top of the aquitard at all times in all confined observation wells.
	Hydraulic gradient – observing a permanent cone of depression for five consecutive years in the Boothby GMA.

It should also be noted that it is critical to continue salinity monitoring in the unconfined aquifer to flag the trajectory of trends breaching specific crop salinity thresholds to enable adaptive management actions by stakeholders, i.e.1500 mg/L for grapes and potatoes, 3000 mg/L for spray irrigation of lucerne and 7000 mg/L for flood irrigation of lucerne. Similarly it is considered critical to continue monitoring of the salinity distributions in confined aquifer systems noting any movement of more saline groundwater relative to cones of depression caused by extraction.

4.7 Possible resource condition triggers

As a starting point for discussions on policy development, a series of possible resource condition triggers are outlined below and summarized in Table 4.2. The triggers take into account the rate of change of the processes that each RCL applies to, as well as the effectiveness of any management response. For instance, if those RCLs designed to mitigate salinity risk (e.g. by maintaining hydraulic gradients) are exceeded, the potential for salinity increases is created but the actual changes in salinity probably would not occur for some time (possibly decades) due to the slow rates of groundwater flow. The investigation RCTs are intended to clarify the risk of a RCL being exceeded in the near but not imminent future and investigations may be conducted using historical data in combination with more targeted data collection specific to the hydrogeological processes involved. It would be prudent to have a number of RCTs for each RCL to allow for staged adaptive management approaches. These should be developed with stakeholder engagement and may be aided by a series of groundwater level or other projections from numerical groundwater models. The swift action RCTs are intended to initiate a management response of reducing allocations for a period of time that will result in an improvement of the resource condition, such that the RCT will no longer be exceeded after several years.

Table 4.2. Possible resource condition triggers for RCLs

Hydrogeological zone	Potential RCL	Investigation RCT	Possible investigation	Swift action RCT	Possible management response
Coastal plain	Aquifer performance	Groundwater level at the end of winter is within 1 m of the RCL	Investigate temporal dynamics of water levels including larger selection of observation wells and whether yields have changed in the area.	N/A	N/A
	Hydraulic gradient	Hydraulic gradient between paired wells becomes less than 0.00015	Investigate temporal dynamics of hydraulic gradient including larger selection of observation wells and salinity monitoring in high risk areas	N/A	N/A
Highland transition	Hydraulic gradient	N/A	N/A	N/A	N/A
Mallee highlands	Hydraulic gradient	Hydraulic gradient between paired wells becomes less than 0.0006	Investigate temporal dynamics of hydraulic gradient including larger selection of observation wells and the influence of surrounding groundwater users	N/A	N/A
Confined aquifer systems	Aquifer integrity	Hydraulic head in confined aquifer falls within 5 m of the top of the aquitard during irrigation season	Investigate the spatial distribution of cone of depression including a larger selection of observation wells and the influence of surrounding groundwater users	Hydraulic head in confined aquifer falls below the top of the aquitard during two consecutive irrigation seasons	Reduce allocations for a period of time until levels recover above RCTs
	Hydraulic gradient	A permanent cone of depression for more than two consecutive years in the Boothby MA	Investigate the spatial distribution of cone of depression including a larger selection of observation wells and salinity monitoring in high risk areas	A permanent cone of depression for more than five consecutive years in the Boothby MA	Reduce allocations for a period of time until levels recover above RCTs

N/A: not assessed – should be developed through stakeholder engagement, perhaps with the aid of numerical model scenarios or other projections

5 Conclusions

The Tintinara–Coonalpyn, Tatiara and Padthaway PWAs in the USE region contain significant groundwater resources. To ensure that these resources remain viable in the future, it is important to establish the limits that exist within the different hydrogeological zones of each PWA and effective management responses to mitigate the risk of these limits being reached. As a starting point, the hydrogeological conceptual models of the groundwater resources in the region have been revised based on the latest understanding of their hydrogeological responses and structure. Distinct hydrogeological conceptual models have been developed for the coastal plain, the highland transition, the Mallee highlands and confined aquifer systems. These are each relevant for different GMAs within each of the PWAs and are an improvement on previous conceptual models as they can be applied simply across the hydrogeological zones of the USE region.

The development of the hydrogeological conceptual models allows a clearer communication of the potential limits that exist for each of the resources. These can be described using resource condition indicators (RCIs) derived from the high quality groundwater level and salinity monitoring network that exists in the South East NRM region. These RCIs include: aquifer performance, horizontal hydraulic gradients and both the trends and spatial distribution of groundwater salinity within the USE. Other RCIs such as condition of aquatic GDEs and vertical hydraulic gradients between unconfined and confined aquifers were not considered relevant for the USE. The selected RCIs, when combined with the revised hydrogeological conceptual models, are useful for the development of potential resource condition limits (RCLs) for adoption within future WAPs. These RCLs are intended to represent a threshold beyond which there is an unacceptable level of risk to the economic, social and environmental values associated with the resource when developed in consultation with the community and other stakeholders.

The RCLs developed in this report are designed to be specific to either local or regional hydrogeological behaviour, giving them relevance to groundwater users. They are also designed to be measureable, allowing easier links to be made with appropriate management responses which should be initiated by resource condition triggers (RCTs) which warn of an increased risk of an RCL being reached. These management responses could be in the form of further investigations as to the causes and extent of the change in resource condition or more swift actions such as reductions in allocation (which effectively reduce extraction) for a period of time.

The RCLs proposed in this report for the USE PWAs include the following:

Coastal plain

- Aquifer performance – maintain a saturated thickness within the Padthaway Formation of greater than 3 m at the end of each winter monitoring round.
- Hydraulic gradient – maintain a westward hydraulic gradient of > 0.0001 at all times between paired monitoring wells across the western boundary of each PWA.

Highland transition

- Hydraulic gradient – maintain a minimum hydraulic gradient (i.e. greater than the 1985–95 gradient) at all times between paired monitoring wells from the Mallee highlands to the coastal plain.

Mallee highlands

- Hydraulic gradient – maintain a westward hydraulic gradient of > 0.0004 at all times between paired monitoring wells across the western boundary of the Mallee highlands.

Confined aquifer systems

- Aquitard integrity – maintain hydraulic heads above the top of the aquitard at all times in all confined observation wells.

- Hydraulic gradient – observing a permanent cone of depression for five consecutive years in the Boothby GMA

It is considered critical to continue salinity monitoring in the unconfined aquifer in all areas to flag the trajectory of salinity trends that may breaching specific crop salinity thresholds, i.e. 1500 mg/L for grapes and potatoes, 3000 mg/L for spray irrigation of lucerne and 7000 mg/L for flood irrigation of lucerne. In relation to confined aquifer systems, it is also considered critical to continue monitoring of the salinity distributions noting any movement of more saline groundwater relative to cones of depression caused by extraction.

It is intended that the RCLs listed above be tested and incorporated within the development of any future assessments of groundwater resource condition in the region. The Tatiara PWA Groundwater Model (Li and Cranswick, 2017) will be the first to apply these specific RCLs where relevant in early 2017. Possible RCTs are intended to be used in preliminary discussions related to the development of adaptive management policy designed to mitigate the risk of RCLs being exceeded.

6 Appendices

A. Analysis of airlift yield data for the Tatiara PWA region

Airlift yield information is usually recorded during the development of newly drilled wells. The development of a well typically involves injecting air from a compressor into the well to generate groundwater flow through the screen or open hole thereby flushing it and the aquifer of any drilling fluid or fines remaining after drilling. The rate of groundwater flowing out of the well during this process is recorded (either measured using a bucket or estimated by eye). Hence there is some variability in the accuracy of such estimates, which are also dependent on the capacity of the compressor and the construction of the screen or open hole well. Nevertheless, this is a commonly recorded piece of information which can be used to infer the relative transmissivity of the aquifer intersected by a groundwater well.

A total of 2961 airlift yield values were downloaded from SA Geodata in the Tatiara PWA region. These were split into two areas, east and west of the transition zone where a steep hydraulic gradient exists in the unconfined aquifer (see Li and Cranswick, 2017 for details). This resulted in 1662 values in the west and 1299 values from the east. The western dataset can be thought of as representative of the unconfined Quaternary limestone formations (i.e. Padthaway, Bridgewater and Coomandook). The eastern dataset can be thought of as representative of the Murray Group limestone and overlying formations where they are saturated (i.e. some Padthaway and Bridgwater Formations).

The histogram below (Figure 6.1) shows that the distribution of the western dataset is skewed towards values ranging from 0.1–1 and 1–10 L/s rather than the very large yields that are usually associated with, for example, the Padthaway Formation. This suggests that the majority of the aquifer may have lower transmissivities than those of the high yielding wells (i.e. >100 L/s wells) that are generally the focus in this region. The eastern dataset shows a more even distribution between the ranges of 0.1–1, 1–10 and 10–100 L/s and has far fewer of the very large yielding wells. Interestingly the eastern dataset has a larger proportion of 10–100 L/s wells than the western dataset, which may be a result of larger open intervals within the generally thicker aquifer in the east.

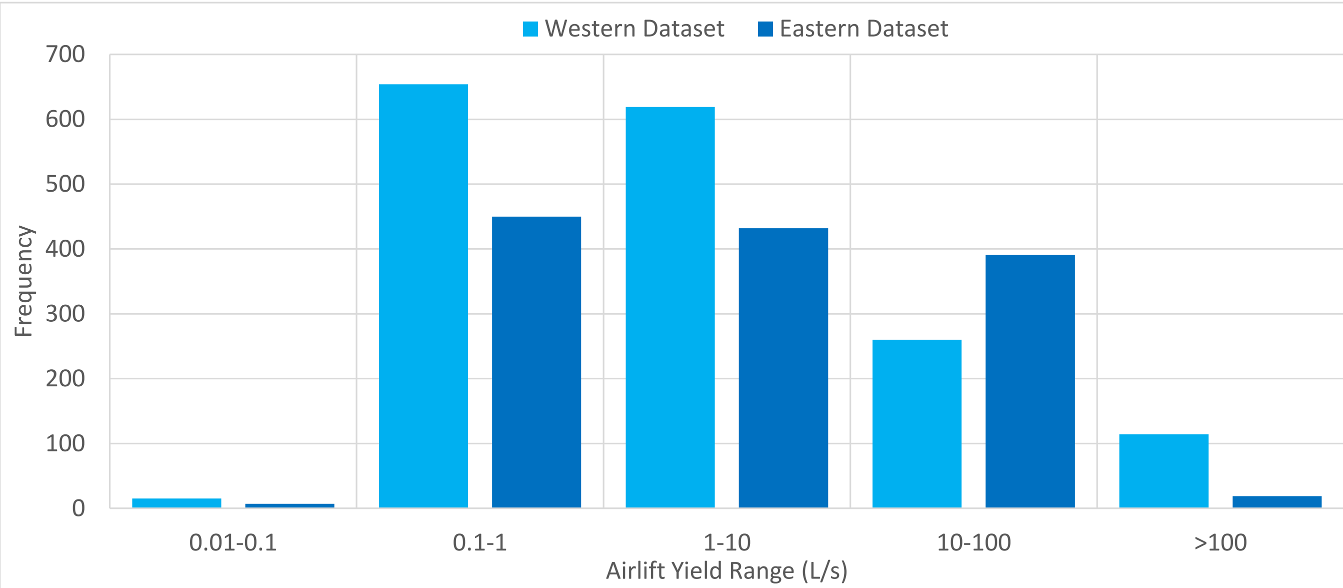


Figure 6.1. Histogram of airlift yield data from the Tatiara PWA region

A comparison between airlift yield data and the depth of each well below the watertable has also been made for both the eastern and western datasets (Figure 6.2). Although the deeper depth intervals contain fewer values and are not as statistically significant, it appears that there is a reduction in median airlift yield below depths of

40 mbWT for the western dataset. This is likely due to these deeper wells being screened specifically within the formations underlying the Quaternary limestone (i.e. deeper aquifers). Meanwhile, the eastern dataset shows a general increase in median airlift yield with depth which suggests that the hydraulic conductivity of the Murray Group limestone aquifer could be relatively constant with depth (i.e. since transmissivity would be expected to increase as the saturated thickness increases under a constant hydraulic conductivity). It is also clear that the median and mean values for each depth interval vary, with the mean being biased towards the larger airlift yield data. The maximum average airlift yields are found at depth intervals 15–20 and 30–40 mbWT for the western and eastern datasets respectively. The 25th and 75th percentile values are also plotted from the median value from each depth interval and show the relative variability of that sub-set of airlift yield data.

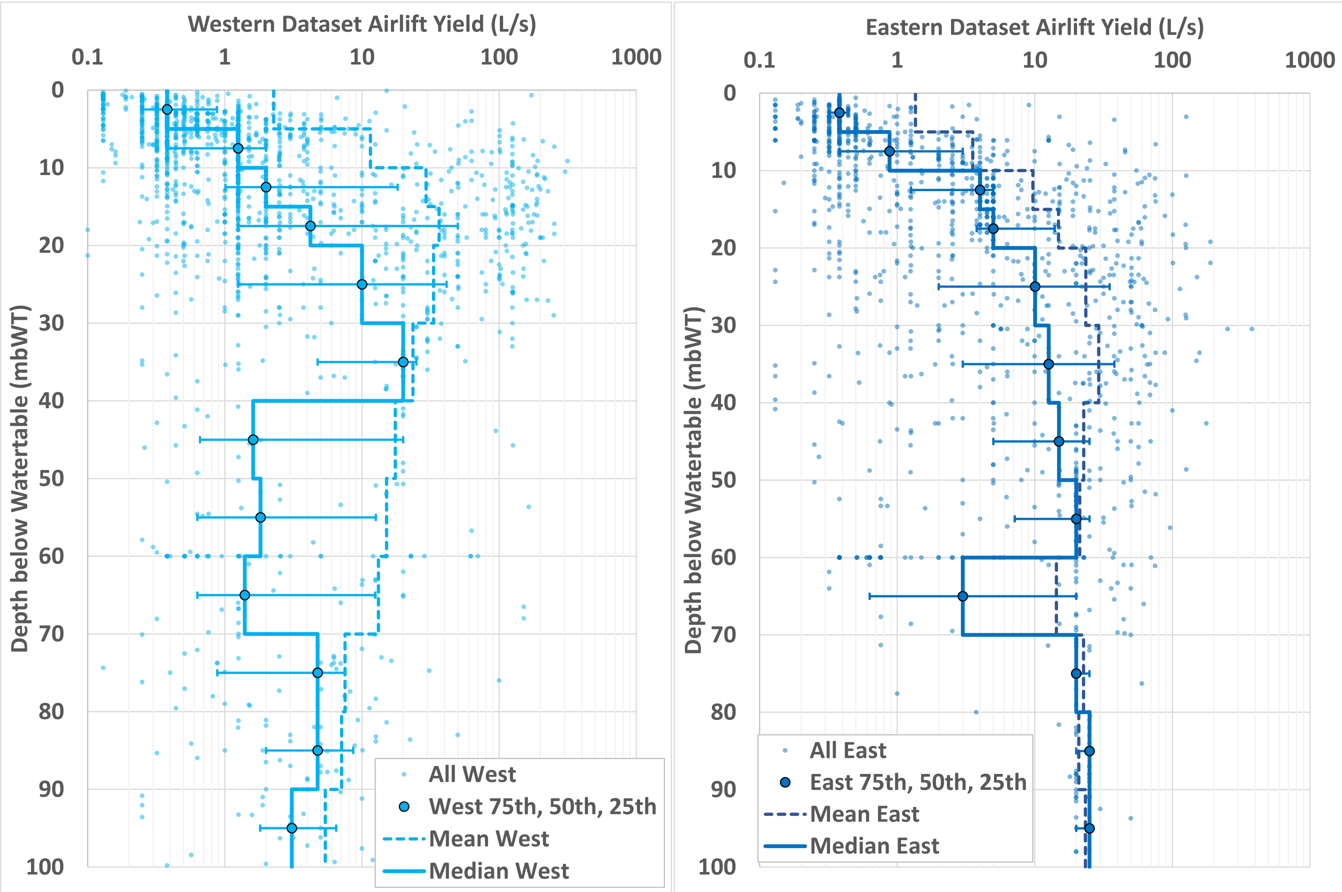


Figure 6.2. Plot of the airlift yield vs total well depth below watertable for the western and eastern datasets

B. Brief assessment of groundwater salinity trends in the USE

The groundwater salinity in the unconfined aquifer can be influenced by a number of local and regional scale processes as described earlier in this report. A preliminary analysis of the groundwater salinity trends has been conducted to develop an understanding of the spatial distribution of such processes. This first pass assessment was made for 267 salinity observation wells with 10 or more data records and is presented in Figure 6.3 and Table 6.1.

The areas that are most influenced by irrigation recycling show consistent moderate to major rises in groundwater salinity and primarily include the Stirling GMA and parts of the Tintinara and Padthaway Flats GMAs.

The changing recharge salinity and recharge rates due to mallee clearance are thought to have been observed in the Padthaway highlands, parts of the Padthaway flats, Wirrega, Willalooka, Tatiara, Zone 7A, Cannawigara, North Pendleton, Stirling, Coonalpyn and Tintinara GMAs. These influences present as initial stable to rising trends followed by stable to declining trends and are symbolized as blue circles or in earlier stages, pale orange and light orange triangles (Figure 6.3). These observation wells are generally located within the highland transition zone where the depth to watertable shallows between the Mallee highlands and the coastal plain.

Stable salinity trends indicate that it is unlikely that the influence of mallee clearance has reached the screens of observation wells, which are not necessarily located across the watertable (i.e. if screens are deeper they will not immediately detect any change in salinity at the watertable surface). The areas where stable salinity trends are observed include parts of the Tintinara, Coonalpyn, Sherwood, Shaugh, Zone 7A, Tatiara, Wirrega, Willalooka and Stirling GMAs. It is to be expected that rising salinity trends will be observed at some stage in the future in these areas. The timing of this impact, would depend on the depth to watertable, hydraulic properties of the unsaturated zone and the recent post-clearance recharge rates, while the detection of such changes depends on the location and length of the observation well screens relative to the watertable. There are also a number of wells showing slight declines within the highland transition that have relatively short and recent data records. It is expected that the previously accumulated unsaturated zone salts have been flushed in the vicinity of these locations after the increase in recharge rate (following the clearing of native vegetation).

Table 6.1. Summary of groundwater salinity behaviour classifications

Salinity trend classification	Number of wells
Flat to very slight change	73
Slight rise	47
Insufficient data	32
Moderate rise	28
Slight rise to flat or decline	21
Insufficient but flat	17
Major rise	12
Very slight rise	11
Very slight decline	11
Moderate to major rise to flat	7
Insufficient but rising	5
Jump to decline or breakthrough	2
Rise decline rise	1

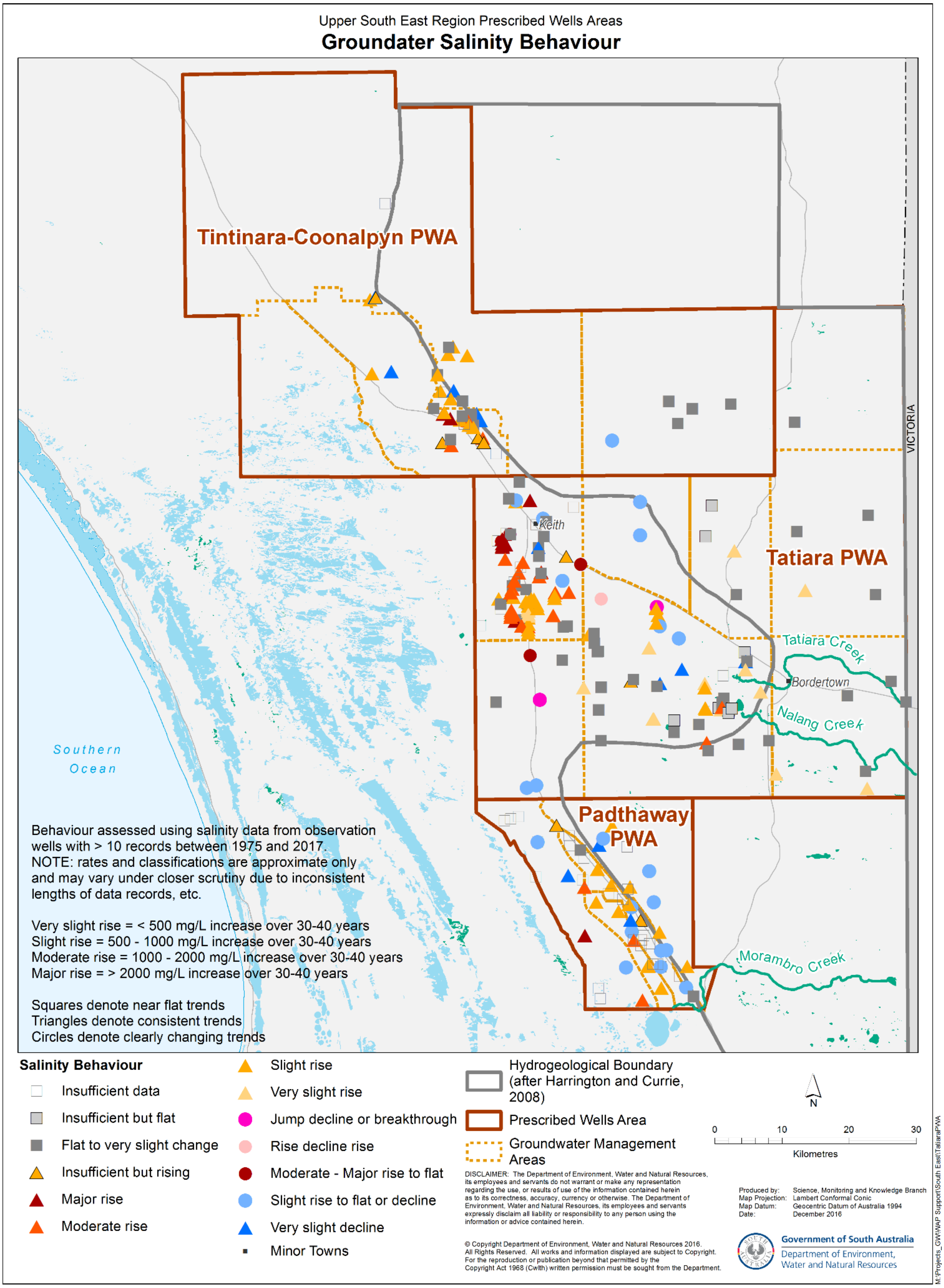


Figure 6.3. Assessment of changes in groundwater salinity trends in the USE

7 Units of measurement

7.1 Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microliter	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

7.2 Shortened forms

m AHD metres above Australian Height Datum

mbWT meters below watertable

mg/L milligrams per litre

8 Glossary

Adaptive management — A management approach often used in natural resource management where there is little information and/or a lot of complexity, and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

Aquifer — An underground layer of rock or sediment that both stores and transmits water

Aquifer, confined — An aquifer that is overlain in part or wholly by an aquitard (see also 'confining layer') and the water is held at greater than atmospheric pressure; water in a penetrating well will rise above the surface of the aquifer unless seriously impacted by groundwater extraction

Aquifer, unconfined — Aquifer in which the upper surface has free connection to the ground surface and the water surface is at atmospheric pressure

Aquitard — A layer in the geological profile that separates two aquifers and restricts the flow between them

Cone of depression — An inverted cone-shaped space within an aquifer caused by a rate of groundwater extraction that exceeds the rate of recharge; continuing extraction of water can extend the area and may affect the viability of adjacent wells, due to declining water levels or water quality

Confining layer — A geological unit which has low permeability that restricts the flow of water and forms the upper bound of a confined aquifer; a body of impermeable material adjacent to an aquifer; see also 'aquifer, confined'

DEWNR — Department of Environment, Water and Natural Resources (Government of South Australia)

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Evapotranspiration — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

GDE — Groundwater dependent ecosystem

GMA — Groundwater Management Area

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also 'underground water'

Hydraulic conductivity (K) — A measure of the ease of flow through aquifer material: high K indicates low resistance, or potential high flow conditions; measured in metres per day

Hydrogeology — The study of groundwater, which includes its occurrence, recharge and discharge processes, and the properties of aquifers; see also 'hydrology'

Impact — A change in the chemical, physical, or biological quality or condition of a water body caused by external sources

Irrigation — Watering land by any means for the purpose of growing plants

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams, groundwater flow or predicting ecological response to environmental change

Monitoring — (1) The repeated measurement of parameters to assess the current status and changes over time of the parameters measured (2) Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things

Natural recharge — The infiltration of water into an aquifer from the surface (rainfall, streamflow, irrigation etc). See also recharge area, artificial recharge

Observation well — A narrow well or piezometer whose sole function is to permit water level measurements

Permeability — A measure of the ease with which water flows through an aquifer or aquitard, measured in m^2/d

Potentiometric head — The potentiometric head or surface is the level to which water rises in a well due to water pressure in the aquifer, measured in metres (m); also known as piezometric surface

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed well — A well declared to be a prescribed well under the Act

PWA — Prescribed Wells Area

Recharge area — The area of land from which water from the surface (rainfall, streamflow, irrigation, etc.) infiltrates into an aquifer. See also artificial recharge, natural recharge

Recommended extraction limit (REL) — The volume of extraction for consumptive use that can be sustained over time while keeping the groundwater system from exceeding relevant resource condition limits

Resource condition indicator (RCI) — with respect to groundwater resources, a parameter that can be directly monitored such as groundwater levels or groundwater salinity which gives an indication of the state of the resource; can be derived from other field observations such as the groundwater discharge (baseflow) component of river flow or estimates of aquifer storage.

Resource condition limit (RCL) — with respect to groundwater resources, a selected resource condition indicator beyond which there is an unacceptable risk to the economic, social and environmental values associated with the resource

Resource condition trigger (RCT) — with respect to groundwater resources, a specified level or metric of a resource condition indicator that is breached warning that there is an increased risk to a resource condition limit being reached. The trigger is intended to initiate a management response which may be further investigation or more swift action related to licensed allocations.

SA Geodata — A collection of linked databases storing geological and hydrogeological data, which the public can access through the offices of PIRSA. Custodianship of data related to minerals and petroleum, and groundwater, is vested in PIRSA and DWLBC, respectively. DWLBC should be contacted for database extracts related to groundwater

Salinity — The concentration of dissolved salts in water or soil, expressed in terms of concentration (mg/L) or electrical conductivity (EC)

Spatial variability — where the value of a parameter is changes across some distance or area

TDS — Total dissolved solids, measured in milligrams per litre (mg/L); a measure of water salinity

Temporal variability — when the value of a parameter changes in time

Threshold level — See 'Resource condition threshold level'

Timelag — broadly refers to the an interval of time between two related phenomena (such as cause and its effect); more specifically for the Upper South East it may refer to the period of time between rainfall and subsequent recharge

Transmissivity (T) — A measure of the ease of flow through aquifer material: high T indicates low resistance, or potential high flow conditions; measured in metres squared per day and can calculated by multiplying the hydraulic conductivity by the saturated thickness of the aquifer or by conducting aquifer tests

Underground water (groundwater) — Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

WAP — Water Allocation Plan; a plan prepared by a water resources planning committee and adopted by the Minister in accordance with the Act

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Water quality data — Chemical, biological, and physical measurements or observations of the characteristics of surface and groundwaters, atmospheric deposition, potable water, treated effluents, and wastewater, and of the immediate environment in which the water exists

Water quality monitoring — An integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses

Well — A well (also known as a 'bore', or 'borehole') is usually a drilled hole constructed by a licensed driller for the purposes of obtaining or monitoring groundwater, but may also include an artificial excavation used for the purpose of collecting, storing or taking groundwater.

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