Science support for the Tatiara PWA WAP review: 2017–18

Volume 1

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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
DEPARTMENT FOR ENVIRONMENT AND WATER

Acknowledgements

The authors would like to thank the stakeholder advisory group members for the revision of the Tatiara PWA WAP for their valuable contributions to discussion of the hydrogeological and other challenges faced by the groups they represent. These discussions have helped shape the design of potential resource condition limits and the groundwater modelling scenarios which are developed and presented in this report. We would also like to thank Jennifer Schilling (formerly NR SE) for her dedication to the development of this and other scientific investigations which will enable informed policy decisions in future. The internal reviews by Steve Barnett (DEW) and independent external review by Glenn Harrington (Innovative Groundwater Solutions Pty. Ltd.) have also added to the clarity of the key messages found in this report and the structure of the adaptive management framework described.

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 Tatiara Prescribed Wells Area (PWA) Water Allocation Plan (WAP) is currently under review and requires a range of scientific inputs to enable Natural Resources South East (NR SE) to develop the new WAP. The most recent science support was provided as three technical reports and a series of presentations developing a recharge model and potential resource condition limits (RCLs) for the Upper South East, and a numerical groundwater flow model for the Tatiara PWA, with future climate and groundwater extraction scenarios (Morgan et al., 2017; Cranswick and Barnett, 2017; Li and Cranswick, 2017). The hydrogeological understanding added by these pieces of work is built upon in this report, and extended to develop a series of inputs intended to be directly useful for communication with the WAP Stakeholder Advisory Group (SAG), and inclusion within and development of the future WAP risk assessment by DEW. The objectives of this project are to:

- Further develop the preliminary RCLs presented in Cranswick and Barnett (2017) and applied in Li and Cranswick (2017) into a series of potential RCLs for consideration within the Tatiara PWA WAP review.
- Develop two additional future modelling scenarios, through consultation with the Tatiara PWA WAP SAG.
- Present the modelled groundwater projections (including those of Li and Cranswick, 2017) with respect to a series of potential RCLs for later use within the risk assessment process.
- Recommend extraction limits based on comparison with a series of potential RCL exceedances that can be considered acceptable from a hydrogeological perspective.
- Present a series of potential RCT options related to the integration of model projections and RCLs that could be used to inform risk treatment options (i.e. management responses).
- Develop communication products to describe a selection of these results (i.e. series of factsheets and presentations to Tatiara PWA WAP SAG).

Hydrogeological zones

A re-evaluation of the hydrogeological zones developed by Harrington and Currie (2008) show that the boundary between the coastal plain and the Mallee highland remains appropriate for the unconfined aquifer. Further delineation may be important to separate areas of differing groundwater salinity and watertable response times to contemporary rainfall, and these are outlined spatially for consideration as revised hydrogeologically-based groundwater management areas (GMAs). It would be appropriate for the timescales upon which potential management responses and WAP objectives operate to be different for the coastal plain and Mallee highland potential sub-areas, due to the timing of events along specific risk pathways.

Potential resource condition limits

A series of potential groundwater level decline RCLs were developed in consultation with the SAG to be 1, 3 and 5 m declines below a 2015 reference level with an assessment of a range of hydraulic gradients between selected pairs of observation wells in the northern, central and southern parts of the PWA. The impact on groundwater users of any such declines or changes in hydraulic gradient (with resulting changes in groundwater salinity) are intended to be a major component of socio-economic analysis conducted by the NR SE in the near future. The groundwater level projections from six groundwater extraction scenarios, combined with future climate scenarios, inform the likelihood of these potential RCLs being exceeded.

Groundwater model scenario projections

The range of future climate datasets used in the model projections is limited to six, including a dry, average and wet SA Climate Ready datasets from selected global climate models (GCMs) that simulate intermediate and high emissions climate scenarios (see more detail in Li and Cranswick (2017) and Morgan et al. (2017)). It is possible

that shorter-term rainfall variability in the future could result in declining or rising groundwater level trends, beyond the uncertainty represented by these modelled scenarios. Subsequent reduced recharge would be an important driver of changing resource condition on the coastal plain, and it may not be possible to fully manage declining groundwater level trends through reductions of groundwater extraction. Nevertheless, within the uncertainty of future climate represented in the model projections, the different aquifer responses to a range of groundwater extraction regimes are clearly presented.

The four extraction scenarios (S1–S4) reported in Li and Cranswick (2017) are combined with two additional extraction scenarios that were developed through discussion with the SAG (Keith, 22/2/2018). These explore the possible impacts of greater groundwater extraction rates from the Mallee highlands on throughflow towards the coastal plain and regional groundwater levels. S5 and S6 were derived to represent a hypothetical large scale groundwater transfer of 50 GL/y from the coastal plain to the Mallee highland and a hypothetical expansion of groundwater extraction (additional 80 GL/y) on the Mallee highland respectively. There are now six extraction scenarios, which are run from 2015 until 2045 to describe a range of possible future groundwater responses within the Tatiara PWA, each briefly outlined below:

- S1 – Full allocation extraction (129 GL/y): 2016/17 allocation data extracted from each licensed well
- S2 – Higher (periodic) extraction (91 GL/y on average): current extraction (S3) as a base rate that is increased by 25% or decreased by 25% depending on the spring-summer rainfall totals;
- S3 – Current extraction (85 GL/y): average of 2013/4, 2014/5 and 2015/6 metered extraction data
- S4 – Lower extraction (63 GL/y): current extraction (S3) reduced by 25%
- S5 – Transfer to Mallee highland (135 GL/y): additional 50 GL/y from hypothetical extraction wells distributed across the Mallee highlands while all existing wells are maintained at current extraction rates (S3)
- S6 – Expansion of Mallee highland (165 GL/y): additional 80 GL/y from hypothetical extraction wells distributed across the Mallee highlands while all existing licensed wells are maintained at current extraction rates (S3)

Hydrogeologically-based recommended extraction limits on the coastal plain

From a hydrogeological perspective, further groundwater level declines on the coastal plain should be restricted to a minimum, so that aquifer yields are not negatively impacted. The groundwater model projections over the next 30 years show that coastal plain groundwater levels are likely to stabilise or recover on average, under all but the full allocation extraction scenario. Similarly, westward groundwater throughflow on the coastal plain is currently close to the lowest on record (i.e. near the lowest westward hydraulic gradient), and is projected to stabilise or return towards historical rates in the future, under all but the full allocation extraction scenario. This recovery is largely due to the near-future rainfall projections (SA Climate Ready datasets – see Morgan et al. (2017) for further detail) being higher than the recent historical period (i.e. mid-1990s to early-2010s).

If coastal plain hydraulic gradients towards the west were to continue to decrease (e.g. as projected under the full allocation extraction scenario), there would be a greater risk of enhanced rates of increasing salinity due to irrigation recycling. It would be possible to explore additional extraction scenarios using the groundwater model to determine whether or not coastal plain extraction rates greater than the higher extraction scenario but less than full allocation extraction, could occur and still maintain westward throughflow (i.e. between on average 74 and 102 GL/y). Without further modelling however, the higher extraction scenario rates (i.e. less than 74 GL/y on average) on the coastal plain could be considered as the recommended extraction limit. The intent of this recommended extraction limit, within the uncertainty of the model projections, would be to avoid specific groundwater level declines and reduced throughflow towards the west, which would then be likely to impact aquifer yields and rates of salinity increases respectively.

Hydrogeologically-based recommended extraction limits on the Mallee highland

The projected groundwater levels on the Mallee highlands show that exceedances of the 1 m decline RCL can be expected on average under all extraction scenarios. Thus it is likely that a considerable number of stock wells may need to be deepened at some stage in the future under all scenarios, particularly within the area approximately 20 km east of the boundary between the coastal plain and Mallee highland. This is not considered to be an aquifer performance issue but a limitation to the design of historical infrastructure, given the saturated aquifer thickness of about 50 m or more below the current watertable. Over the next 30 years, exceedance of the 3 m decline RCL can be expected in the full allocation extraction, and the two scenarios where 50 and 80 GL/y of groundwater from hypothetical wells is extracted in addition to current extraction (16 GL/y) from the Mallee highland. The 5 m decline RCL is only exceeded for the latter two scenarios in the area of largest hypothetical increase in extraction (located in the central and western side of the current Zone 8A GMA).

The extraction of this additional groundwater from the Mallee highland in addition to current extraction, results in projections of westward hydraulic gradients falling close to and below the historical (1985–95) average hydraulic gradients between representative observation well pairs. However, a return to historical hydraulic gradients, or other potential hydraulic gradient RCLs presented in this report across the Mallee highland, are sufficient to maintain westward groundwater throughflow that is similar to that experienced in the past. Within the uncertainty of the groundwater model projections, Mallee highland extraction could be up to 96 GL/y with the likely impact of groundwater level declines around 5 m over 30 years that may impact stock and domestic wells in some areas. In terms of managing the groundwater resource, this could be based on an agreement through stakeholder engagement to extract water from storage at an accepted rate.

Potential resource condition triggers

For potential groundwater level decline RCLs, the potential resource condition triggers (RCTs) could be defined on the basis of a specified number or percentage of observation wells exceeding a specific groundwater level above an RCL. The current observation well network could be used for this assessment and the area of impact defined by spatial analysis of the distribution of wells exceeding the RCTs and hydrogeological interpretation. It should be noted that there may be parts of the PWA where the spatial coverage of observation wells is sparse and unable to resolve the regional or local scale influence of groundwater extraction (e.g. Shaugh GMA).

For hydraulic gradient RCLs, the representative observation well pairs would be the focus of the RCTs and should be developed based on specified hydraulic gradients greater than the RCL. The northern, central and southern observation well pairs should be used to trigger a management response in their respective areas for the hydraulic gradient RCLs. It should be noted that only the hydraulic gradient RCLs for the western side of the coastal plain are considered critical from a hydrogeological perspective. These should not be allowed to reach a flat hydraulic gradient (i.e. 0) and ideally stay above 0.0001 so that increasing groundwater salinity trends due to irrigation recycling are not further enhanced.

Risk assessment

This analysis is intended to help form the basis of consequence categories within the risk assessment and gauge the range of attitudes towards risk and the nature of potential management responses within the WAP. Selecting appropriate RCLs within this context may help enable the WAP to be adaptive over a range of relevant time scales with specific and measureable objectives for each hydrogeological zone.

1 Aims and objectives

The overall aim of this report is to provide hydrogeological and scientific support for the various components of the Tatiara WAP review including inputs into the risk assessment process. Specific objectives include:

- Further develop the preliminary RCLs presented in Cranswick and Barnett (2017) and applied in Li and Cranswick (2017) into a series of potential RCLs for consideration within the Tatiara PWA WAP review.
- Develop two additional future modelling scenarios, through consultation with the Tatiara PWA WAP SAG.
- Present the modelled groundwater projections (including those of Li and Cranswick, 2017) with respect to a series of potential RCLs for later use within the risk assessment process.
- Recommend extraction limits based on comparison with a series of potential RCL exceedances that can be considered acceptable from a hydrogeological perspective.
- Present a series of potential RCT options related to the integration of model projections and RCLs that could be used to inform risk treatment options (i.e. management responses).
- Develop communication products to describe a selection of these results (i.e. series of factsheets and presentations to Tatiara PWA WAP SAG).

It should be noted that there are a number of additional aspects (i.e. confined aquifer, stock wells, groundwater dependent ecosystems, observation network review, and risk assessment workshop inputs) that have been identified as needing further investigation and development. These are to be addressed during the 2018–19 financial year in a separate project (Cranswick, in prep.).

2 Tatiara PWA science support

2.1 Overview

The Tatiara PWA WAP is currently under review and this process has been supported by a number of technical investigations and different forms of community engagement that have been conducted since the previous WAP was adopted in 2010. There are also a number of current assessments and planned activities that will aid in the revision of the WAP and development of the risk assessment for the groundwater resources and dependent users in the Tatiara PWA. Stakeholders of the risk assessment process include; licensed and unlicensed users of the groundwater resource and dependent ecosystems (namely phreatophytic vegetation), the Tatiara PWA community and various branches of the Department for Environment and Water (DEW), all of whom will be given opportunity to help guide the revision of the WAP. Primarily, engagement will occur through the regular Stakeholder Advisory Group (SAG) meetings (approximately monthly), the DEW Working Group and a number of other community consultations. The scope and content of the risk assessment framework for the Tatiara WAP will be recorded and the science support provided in this technical report will be used to inform that process.

The current groundwater management areas are based on Hundreds and other boundaries for historic resource management and administrative reasons. There is now an option to redefine management arrangements based on the hydrogeological characteristics of the groundwater system. The Tatiara PWA could be divided into two regions – the Mallee highlands in the east and the coastal plain in the west (after Harrington and Currie, 2008). These two hydrogeological zones have different characteristics and responses to both rainfall variability and extraction, as demonstrated by Li and Cranswick (2017).

Cranswick and Barnett (2017) describe a range of resource condition indicators, which have been developed into preliminary resource condition limits (RCLs). These preliminary RCLs are intended to offer options that could represent a threshold beyond which there is an unacceptable level of risk to the economic, social and environmental values associated with the resource. These thresholds should be ultimately determined through effective stakeholder engagement and supported by socio-economic assessment, which means that they are highly relevant within the context of a risk assessment. A selection of the preliminary RCLs developed by Cranswick and Barnett (2017) have been incorporated into the groundwater scenario modelling of the Tatiara PWA by Li and Cranswick (2017). These were included in a preliminary fashion (given the final RCLs are not yet agreed for the purposes of the WAP) and are further refined in this report. In concept, they inform the likelihood of detrimental impacts on the aquifer performance, ability of users to access to groundwater, and reduction in groundwater throughflow that may have implications for the increasing groundwater salinity in parts of the PWA.

The selected observation wells used to assess these preliminary RCLs for the unconfined aquifers are shown in Table 2.1 (after Cranswick and Li, 2017). The modelling projections showed that these RCLs are unlikely to be reached at these locations under the selected climate projections and extraction rates within three scenarios (with extraction ranging from 63–97 GL/y). However with extraction of 129 GL/y (full allocation), each of the coastal plain RCLs were likely to be exceeded in the near future (as early as 2020 in some locations). These exceedances would have major negative implications for the condition of groundwater resources on the coastal plain and should be avoided. The preliminary RCL for the Mallee highlands is not exceeded in any scenario despite the continued declines in projected groundwater levels by the models. It is possible for greater rates of extraction to occur in the Mallee highlands without exceeding the preliminary hydraulic gradient RCL (Li and Cranswick, 2017).

Table 2.1. Monitoring well selections for preliminary RCLs (after Li and Cranswick, 2017)

Possible RCL	Coastal plain	Mallee highland
Aquifer performance*	STR110, STR111, WLL108, WLL105	n/a
Hydraulic gradient	STR110–LAF3, STR2–LAF6, WLL7–PRK37	CAN16–PET15, SEN3–CAN14, TAT108–WRG116

*A measure of how a reduction in groundwater level is likely to result in a reduction in well yield where the hydraulic conductivity is highest in the shallowest section of the aquifer (after Cranswick and Barnett, 2017).

These preliminary RCLs are to be further developed and replaced by potential RCLs in later stages of the WAP review process, such that they:

- describe the likelihood of specific changes in the condition of the groundwater resource in both hydrogeological zones under a range of future extraction and climate scenarios
- provide a series of metrics that could be selected as representing an unacceptable resource condition – for integration within a risk assessment process
- can be used as effective communication tools for engagement with the community and stakeholders
- can be used to determine the recommended extraction limits
- can be used as a basis for developing risk treatment options and trigger management systems.

2.2 Development of potential resource condition limits

Some adjustments would be required prior to applying the RCLs to the Tatiara PWA as they are described in both Cranswick and Barnett (2017) and Li and Cranswick (2017). Primarily this is due to the discontinuity of the Padthaway Formation sub-unit across many parts of the coastal plain and the variable nature of the aquifer performance in the shallowest section of the unconfined aquifer. The Padthaway Formation is utilised mostly by irrigators in the Stirling and Willalooka GMAs but is either absent or unsaturated in other areas, i.e. parts of Wirrega GMA. The potential RCLs developed in this report are shown in Table 2.2 and discussed below.

An alternative approach for the aquifer performance preliminary RCL could be an absolute groundwater level decline that is agreed upon through stakeholder engagement and analysis. For example, no more than a 3 m decline from the minimum historical winter level (i.e. recovered level). This could then be more easily applied to all observation wells on the coastal plain, rather than just ones that access shallow groundwater from the Padthaway Formation. Developing an RCL that can be applied to all observation wells, has the advantage of allowing more statistically significant exceedances to be the basis for adaptive management (i.e. as opposed to a smaller selection of representative observation wells).

Aquifer performance is critical for maintaining the current flood irrigation practices in the coastal plain, which require high yielding production wells and would still be the focus of this RCL. Discussion at the SAG meeting in Keith (22/2/2018) resulted in interest for RCLs of 1, 3, and 5 m below the 2015 winter levels, to be assessed over the next 10–15 years. It is intended that all three absolute declines be assessed in conjunction with the planned socio-economic analysis of the cost of such declines to irrigators and owners of stock and domestic wells. A series of potential groundwater level decline RCLs are presented in this report and are applied to all observation wells used in the Tatiara groundwater model. In practice, the number of observation wells available for this analysis would be reduced to the currently monitored observation wells in the network.

The potential coastal plain hydraulic gradient RCL is an indicator of the likelihood of there being a slowing or reversal of the regional groundwater flow along the western boundary of the PWA. If the groundwater throughflow to the west were to slow, there would be a higher likelihood of salinity impacts from enhanced irrigation recycling. If a reversal of the hydraulic gradient were to occur, more saline groundwater would eventually (i.e. perhaps over tens of years) be drawn from the western part of the aquifer towards irrigation areas, resulting in a step change in salinity beyond the tolerance of existing crops. A hydraulic gradient of 0 or 0.0001 should therefore be avoided to mitigate this risk. For the coastal plain observation well pairs (Table 2.3), the first potential RCL is based on the winter 2015 hydraulic gradient, which is close to the lowest westward hydraulic gradient on record. The second and third RCLs in the analysis below are defined as 0.0001 and 0.0002 lower than the first RCL. This represents a relative decline of 1 and 2 m over 10 000 m between the observation well pairs.

Table 2.2. Potential RCLs

Hydrogeological zone (RCL type)	Potential RCL to be tested	Equivalent groundwater level decline
Coastal Plain (groundwater level decline)*	1 m below 2015 winter level 3 m below 2015 winter level 5 m below 2015 winter level	As potential RCL
Mallee Highland (groundwater level decline)	1 m below 2015 winter level 3 m below 2015 winter level 5 m below 2015 winter level	As potential RCL
Coastal Plain (hydraulic gradient)	Winter 2015 hydraulic gradient of selected observation well pairs	Variable between selected observation well pairs
	0.0001 m/m below 1st potential RCL	1 m over 10 000 m
	0.0002 m/m below 1st potential RCL	2 m over 10 000 m
Mallee Highland (hydraulic gradient)	1985–94 average hydraulic gradient of selected observation well pairs	Variable between selected observation well pairs
	0.0001 m/m below 1st potential RCL	1 m over 10 000 m
	0.0002 m/m below 1st potential RCL	2 m over 10 000 m

* Note that the development of potential RCLs related to the environmental water requirements of groundwater dependent ecosystems have not been developed in this report. The groundwater level decline RCLs may however be relevant metrics for consideration.

Cranswick and Barnett (2017) also note that there is very little that can be done with regard to the rising salinity trends caused by irrigation recycling, unless an alternative (fresher) irrigation source is applied. The authors suggest communication of the salinity trend trajectories relative to crop specific thresholds as a way of managing this risk. For example, in the north-western part of the Tatiara PWA, flood irrigation of lucerne for seed production has an approximate upper salinity threshold of 7000 mg/L. Assuming landuse practices and climate remain relatively similar to the conditions between 2000 and 2016, the 7000 mg/L threshold will be reached in approximately 10–15 years in this particular location (Figure 2.1). Other parts of the coastal plain do not experience rising trends due to irrigation recycling to the same degree and the impact of clearing native vegetation has largely stabilised. There may be more options for the management of these lower salinity areas which are experiencing slower, if any, recent changes in groundwater salinity.

It should be noted that the groundwater model developed by Li and Cranswick (2017) is a groundwater flow model and does not simulate solute transport. Therefore the model cannot directly inform on the potential changes to groundwater salinity across the Tatiara PWA in the future. It indirectly uses the projected changes in the westward hydraulic gradient to describe the relative changes in fresher groundwater throughflow from the east.

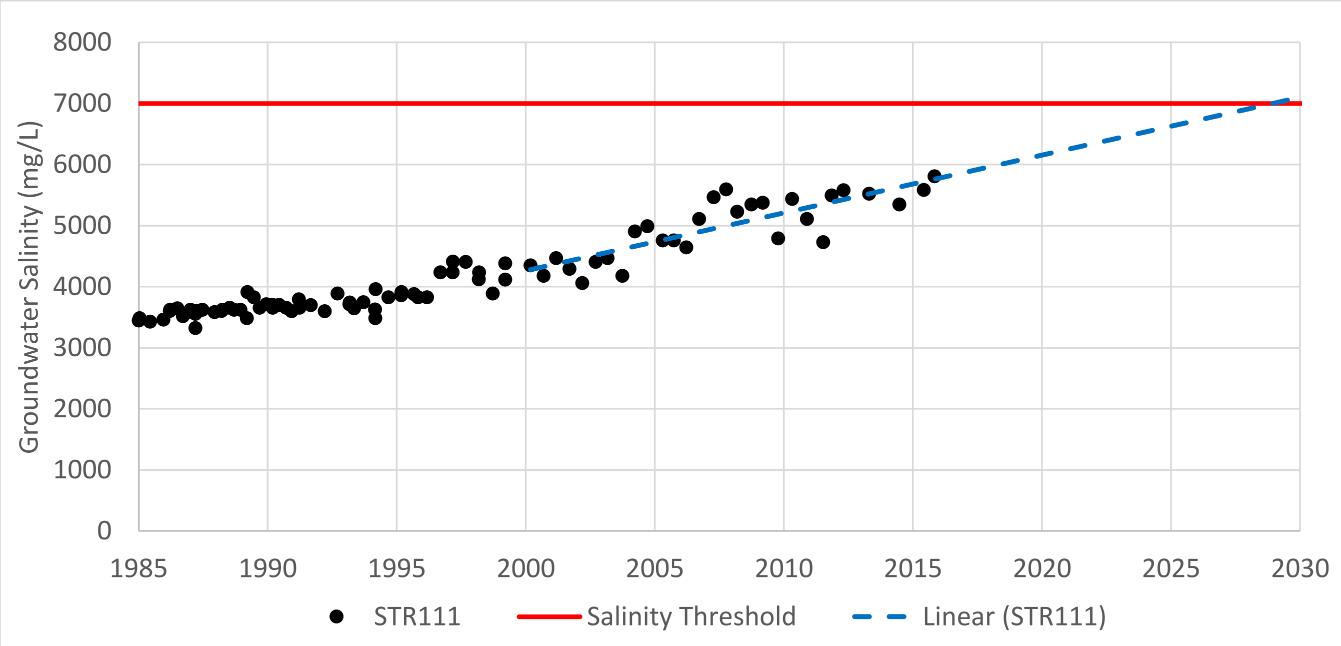

Figure 2.1. Groundwater salinity trend (2000–16) trajectory for STR111 on the coastal plain (Cranswick and Barnett, 2017)

As noted in Cranswick and Barnett (2017) and also Li and Cranswick (2017), it is challenging to define a resource condition limit for the Mallee highlands without having an idea of how the aquifer will behave when stressed with much higher levels of groundwater extraction (i.e. it has not been stressed historically and current full allocation extraction does not represent a significant stress from a hydrogeological perspective). This is particularly the case in the north-east where the only potential impact of any drawdown would be to the users, with wells intersecting only the top few metres of the deep and considerably thick aquifer. This is not an issue of the resource's capacity to supply groundwater, but of the infrastructure that has been accessing it historically (i.e. wells can be deepened or drilled, provided the cost of doing so and extracting groundwater in future is not prohibitive).

The recent hydraulic gradient from the Mallee highlands towards the coastal plain provides greater rates of throughflow than those occurring historically. It may not be possible, using a realistic scenario, for groundwater development in the Mallee highlands to reduce throughflow to rates significantly lower than those experienced in the past. However, the influence of greater rates of extraction have not yet been tested prior to this study. Two additional scenarios have been derived through consultation with the SAG (Keith, 22/2/2018) after discussion of what the likely impact of greater rates of extraction in the Mallee highlands would be on throughflow towards the coastal plain and regional groundwater level declines (see discussion in Section 2.6).

It should be noted that a reduction of the hydraulic gradient towards or below the historical gradients are unlikely to have a significant impact on the rates of throughflow from the Mallee highland to the coastal plain, without considerable regional lowering of the aquifer (which could be prevented using the potential groundwater level decline RCLs). The potential hydraulic gradient RCLs presented in this report are therefore more usefully considered as resource condition indicators rather than limits as related to the Mallee highland hydrogeological zone.

The potential hydraulic gradient RCL for the Mallee highland itself, and for the Mallee highland to coastal plain observation well pairs uses the average winter historical hydraulic gradient during the 1985–95 period as the first RCL. This is representative of the average conditions prior to the period of declining groundwater levels began in the mid-1990s. The second and third RCLs are defined as 0.0001 and 0.0002 lower than the first RCL. This represents a relative decline of 1 and 2 m over 10 000 m between the observation well pairs. It is possible for the increasing groundwater salinity trends currently observed across the coastal plain to increase further in the eastern margins of the coastal plains only, if groundwater throughflow was to occur in the future at lower rates than observed in the past. The groundwater salinity dynamics is not directly simulated by the model however, and so the indirect measure of hydraulic gradient projections can only be considered in terms of risk.

A summary of the series of potential RCLs referred to in this report are shown in Table 2.3 below and the location of observation well pairs and observation wells is shown in Figure 2.2. The likelihood of future exceedance for all potential RCLs under six groundwater extraction scenarios are assessed in Section 2.7.

Table 2.3. Observation wells and well pairs for potential groundwater level decline and hydraulic gradient RCLs

Potential RCL type	Coastal plain	Mallee highlands	Mallee highlands to coastal plain
Groundwater level decline (replaces aquifer performance on coastal plain)	All observation wells	All observation wells	All observation wells
Hydraulic gradient	STR110–LAF3, STR114–LAF6, WLL7–PRK37	CAN16–PET105, SEN3–CAN14, TAT108–WRG116	CAN16–STR116, SEN3–PET103, TAT108–WRG112

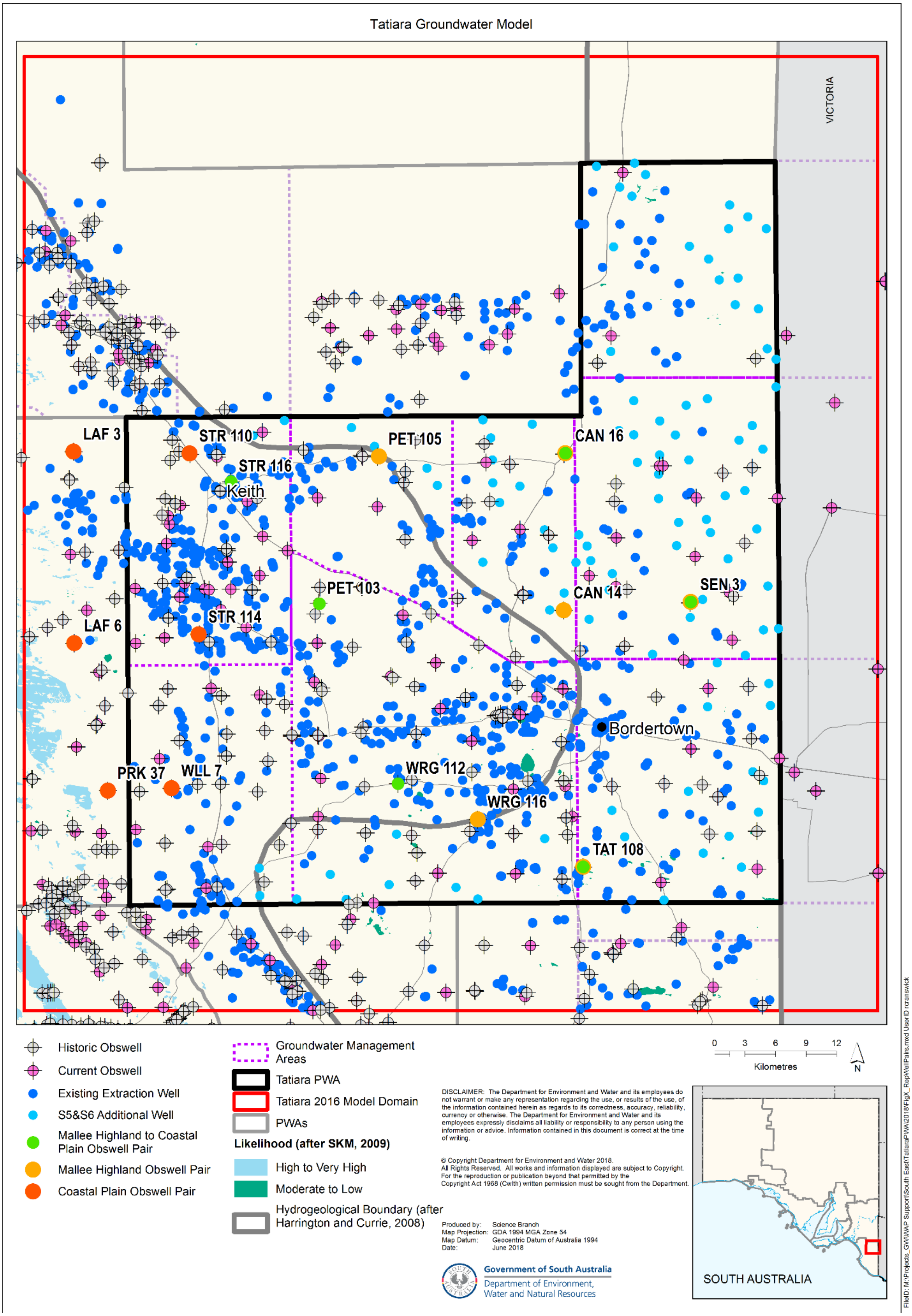

Figure 2.2. Location of observation well pairs describing the hydraulic gradient RCLs for the northern, central and southern parts of the coastal plain and Mallee highland hydrogeological zones

2.3 Potential groundwater management areas

The two hydrogeological zones (HZs) defined by Harrington and Currie (2008) appropriately divide the Tatiara PWA into areas which would benefit from distinctive adaptive management approaches. In reviewing the criteria used by Harrington and Currie (2008) to delineate the coastal plain (HZ2) from the Mallee highlands (HZ3), the approach is considered to be valid at the present time. The primary differences between these zones are the declining trends and large seasonal fluctuation of groundwater levels observed in the west, but relatively stable groundwater level trends and lack of seasonality to the east of the boundary. Largely these remain true in terms of seasonality of groundwater level trends. However there are some observation wells in the area to the east of the coastal plain that now show declining trends in the intervening years since 2007 (e.g. CAN11, CAN12, CAN13, CAN 104, SEN8, TAT9, TAT10 (and replacement TAT29), TAT26 (and replacement TAT111), WRG018 and WRG027 within around 5 km east of the original boundary). As shown by Li and Cranswick (2017), this declining trend is most likely a result of induced throughflow caused by the reduction of groundwater levels over the last 20 years on the coastal plain (i.e. the groundwater system responding to increased westward hydraulic gradients) rather than due to a combination of local high rates of groundwater extraction and reduced recharge following below average rainfall years. If a greater number of observation wells were used to delineate the boundary, it is possible that there would be more accuracy in the exact location of the delineation – however these are not currently available with adequate historical records for analysis. Applying this hydrogeological boundary within a management and policy context may require some alteration for practical, communication and administrative reasons. Discussion at the SAG meeting in Keith (22/2/2018) showed there was some developing rationale as to how this could be converted to align with road and property boundaries in the future.

There may be further cause for sub-division of these areas based on the significant spatial variation in the groundwater salinity, which is driven by a number of processes (i.e. historical recharge and evapotranspiration rates, changes in recharge rates after land clearance and various rates of irrigation recycling). It would follow that the resource could be managed differently where salinity issues are more critical, depending on the crops irrigated and the intended use of the groundwater resource. For example, the town water supply for Bordertown is derived from the very fresh groundwater that is recharged by Tatiara Creek in the vicinity of Poocher Swamp. Similarly, the irrigators adjacent to the terminus of Nalang Creek near Mundulla Swamp access very fresh groundwater supplies. These areas have been developed differently to those to the west and north-west, where groundwater of a much higher salinity is utilised (i.e. up to approximately 7000 mg/L). Delineation of the coastal plain based on groundwater salinity should be discussed amongst the relevant stakeholders with supporting technical advice. A proposed divide has been initially presented based on the 3000 mg/L salinity contour for example (red dashed line in Figure 2.3) following discussion at the SAG meeting in Keith on 22/2/2018. It is likely that the accuracy of this boundary could be improved by including additional groundwater salinity data (i.e. from irrigator, stock or additional observation wells currently not being monitored).

If required, the Mallee highlands could also be sub-divided based on the likely time lag between rainfall and recharge, approximated by historical or current depth to water measurements. For example, if there is a lag between rainfall and recharge that is on the order of 100 years, then management based on estimates of recharge (i.e. current approach) could limit current levels of acceptable extraction without the relationship between extraction and risk to the resource being clear. For example, a depth to water of 50 m below ground level could be applied as indicative of the boundary between the renewable and relatively non-renewable resources (see middle blue line in Figure 2.3).

The existing management zones present a number of challenges since the groundwater resource responds differently within some individual GMAs (i.e. Wirrega, North Pendleton and Cannawigara GMAs), potentially leading to limitations in the appropriateness of management approaches. This uncertainty of policy development is not directly considered in this report, rather a pragmatic assessment from a hydrogeological perspective is presented.

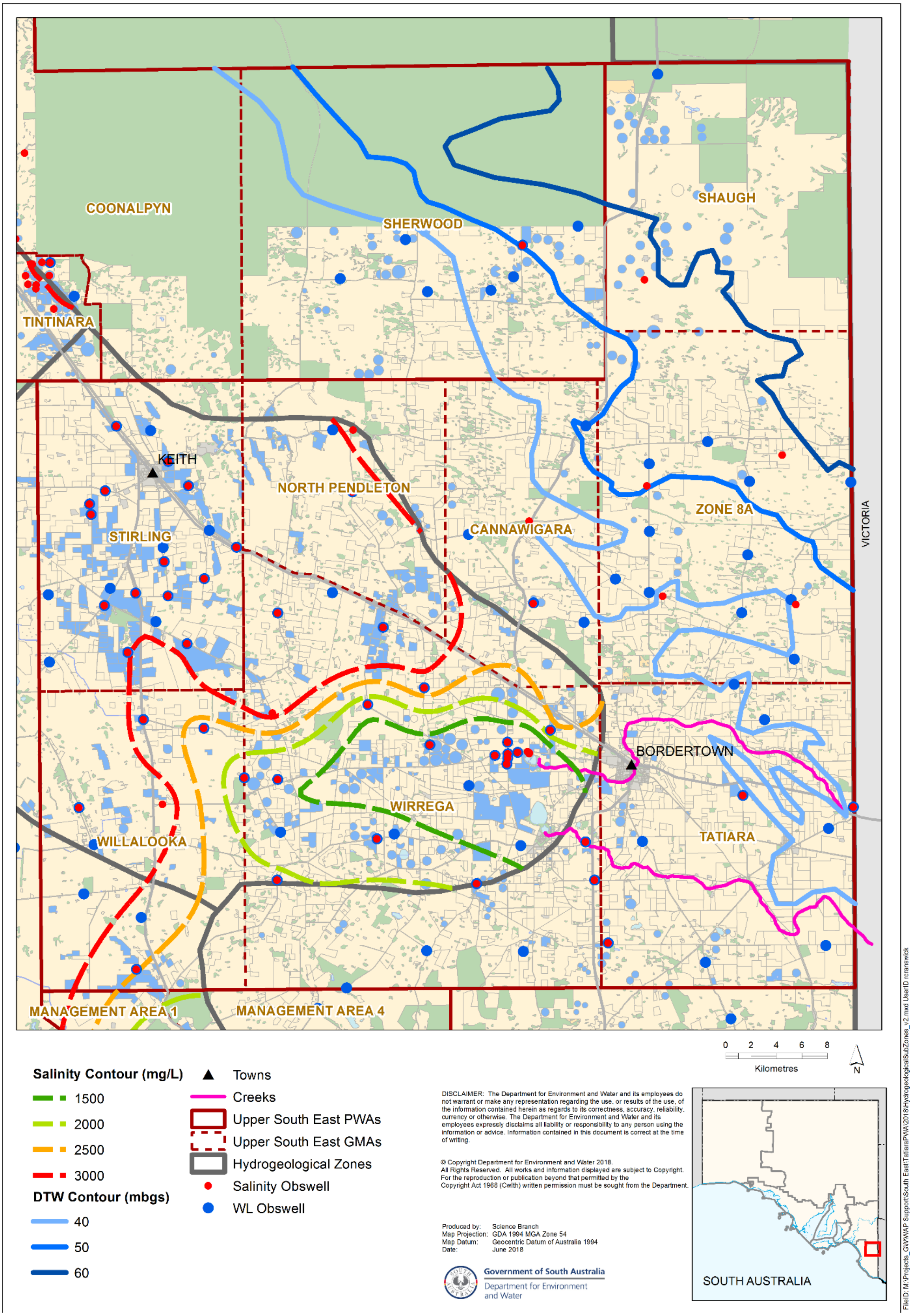

Figure 2.3. Possible groundwater management area sub-divisions based on hydrogeological zones, groundwater salinity distribution (recent 5-year average) and assessment of the relevance of contemporary recharge (using 2015–17 average depth to water as a proxy)

2.4 Temporal scale of risk assessment

The temporal scale of the risk assessment is dependent on how the objectives of the WAP and any adaptive management policy approaches are defined. Typically, WAP considerations focus on 5 or 10-year timeframes, yet this has the potential to inadequately consider future generations of users and water dependent ecosystems, in addition to the short term changes in the resource that can occur from year to year. Relevant timeframes from a hydrogeological perspective are clearly different for the Mallee highland (i.e. the recharge response to contemporary rainfall is lagging by many decades), compared to the coastal plain where groundwater levels are responsive to annual rainfall and both irrigation extraction and recharge. The coastal plain therefore, could be managed quite appropriately on an annual basis, following measurements of winter groundwater levels from the previous water year (i.e. similar to the Eyre Peninsula WAP). The Mallee highland management approaches would be more appropriately linked to agreed rates of decline (i.e. similar to the Mallee WAP) that are commensurate with an agreed measure of groundwater level decline by a specified date in the future, say 2030 or 2040. To support management on these ranging timescales, a series of potential RCLs need to be presented along with potential RCTs informing the magnitude of the management response (i.e. management should be effective in preventing long and short-term irreversible impacts whilst also recognising seasonal and inter-annual variability, see Section 2.9). The potential RCLs described previously facilitate the starting point for this decision making and should be progressed through engagement with the community stakeholder advisory and DEW working groups.

2.5 Risk assessment end points

The Tatiara PWA has a numerical groundwater model that can be used to test the response of the groundwater system to specific management settings (e.g. extraction limits or adaptive management responses) as well as different climate futures. The model projections can be tested against the potential RCLs presented above (see Section 2.7) but can also be applied to any additional RCLs later developed through consultation and engagement with community stakeholder advisory or DEW working groups. The risk assessment could be developed with a focus on RCTs (see Section 2.9) and the RCLs as end-points with clear and direct links to the associated socio-economic implications in order to define consequence categories appropriately. Some preliminary and unpublished socio-economic work has been completed in the past, which would benefit from revision. For example, the implication of groundwater levels approaching each RCL could be assessed in terms of the dollar value impact of that changing resource condition. This approach should be tailored based on the hydrogeological considerations of each GMA to include implications of:

- change in available drawdown of stock and irrigation wells
- ability of existing pump infrastructure to cope with changed condition (i.e. impact on flow rates)
- maintaining rate of extraction currently required by irrigators (i.e. diesel / electricity)
- drilling costs (well deepening, replacement, new) for different hydrogeological environments (i.e. Mallee vs coastal plain)
- approaching crop specific salinity thresholds (i.e. impact on crop yields, soil structure)
- others not listed here.

This socio-economic analysis could form the basis of the consequence categories and would be critical for guiding and informing discussions where the tolerability of specific risks related to each RCL is determined.

It is also envisaged that where risk levels are seen to be low, that there may be opportunity to expand the use of the groundwater resource within the Tatiara PWA. These potential opportunities could be incorporated into the development of policy and management approaches that account for the possibility that extraction limits may be greater than existing policy documents allow in some areas (see Section 2.8).

2.6 Future extraction and climate scenario descriptions

There are four extraction scenarios described in full within Li and Cranswick (2017), which are combined with two additional extraction scenarios that were developed through discussion with the SAG (Keith, 22/2/2018). These were developed to explore the possible impacts of larger groundwater extraction from the Mallee highlands on throughflow towards the coastal plain and regional groundwater level declines. S5 and S6 were derived to represent a large scale groundwater transfer of 50 GL/y from the coastal plain to the Mallee highland and an expansion of groundwater extraction (additional 80 GL/y) on the Mallee highland respectively. There are now six extraction scenarios, which are run until 2045 to describe a range of possible future groundwater responses within the Tatiara PWA, each briefly outlined below:

- S1 – Full allocation extraction (129 GL/y): 2016/17 allocation data extracted from each licensed well
- S2 – Higher (periodic) extraction (91 GL/y on average): current extraction (S3) as a base rate that is increased by 25% or decreased by 25% depending on the spring-summer rainfall totals;
- S3 – Current extraction (85 GL/y): average of 2013/4, 2014/5 and 2015/6 metered extraction data
- S4 – Lower extraction (63 GL/y): current extraction (S3) reduced by 25%
- S5 – Transfer to Mallee highland (135 GL/y): additional 50 GL/y from hypothetical extraction wells distributed across the Mallee highlands while all existing wells are maintained at current extraction rates (S3)
- S6 – Expansion of Mallee highland (165 GL/y): additional 80 GL/y from hypothetical extraction wells distributed across the Mallee highlands while all existing licensed wells are maintained at current extraction rates (S3)

One hundred additional wells in the Mallee highlands have been randomly placed across the hydrogeological zone in positions that are outside of a 4 km^2 circle surrounding existing licensed wells (Figure 2.5). The total extraction rates are summarised for the current GMAs and hydrogeological zones in Table 2.4 for all scenarios, while detailed groundwater balance tables are presented in Appendix A for the entire Tatiara PWA and the two hydrogeological zones. Each of the extraction scenarios are combined with six climate data sets for each of the three calibrated models as described in Li and Cranswick (2017). This results in 18 model runs for each extraction scenario to provide bounds for the uncertainty of model projections, while the average groundwater level response is also presented.

Table 2.4. Details of extraction rates (GL/y)* for each of six scenarios in each GMA and hydrogeological zone

GMA or HZ	S1 (full allocation extraction)	S2 (higher extraction)	S3 (current extraction)	S4 (lower extraction)	S5 (S3 with additional 50 GL/y on highlands)	S6 (S3 with additional 80 GL/y on highlands)
Shaugh	6.5	6.5	5.9	4.4	15.4	21.1
Zone 8A	4.9	2.0	1.9	1.4	20.9	32.3
Tatiara	8.6	5.3	4.8	3.6	11.8	16.0
Cannawigara	3.6	1.7	1.5	1.1	7.5	11.1
Wirrega	34.8	26.5	24.1	18.1	28.6	31.3
North Pendleton	8.5	5.0	4.6	3.4	6.6	7.8
Stirling	41.7	33.8	30.7	23.0	31.7	32.3
Willalooka	24.4	12.2	11.1	8.3	12.1	12.7
Mallee highland	26.6	17.5	16.2	12.1	66.2	96.2
Coastal plain	102.4	73.7	68.3	51.2	68.3	68.3

GMA or HZ	S1 (full allocation extraction)	S2 (higher extraction)	S3 (current extraction)	S4 (lower extraction)	S5 (S3 with additional 50 GL/y on highlands)	S6 (S3 with additional 80 GL/y on highlands)
Total	129.0	91.2	84.5	63.3	134.5	164.5

*Note that values for the GMA extraction rates are from the first future year of projections, while the values for the Mallee highland, coastal plain and total are the 10-year averages from 2015–24 derived from all model projections.

2.7 Potential RCL exceedances under six future extraction scenarios

2.7.1 Analysis and presentation approach

The projected groundwater levels from all model runs have been analysed in a number of ways in relation to the potential RCLs developed in Section 2.2. A series of representative hydrographs are shown on the following pages to show the important differences between scenarios while all hydrographs are available as supplementary information in Volume 2 of this report (i.e. 83 pages for each of six extraction scenarios) on the DEW Science Model Warehouse. An example is shown in Figure 2.4 below where the 1, 3 and 5 m decline RCLs from 2015 winter groundwater levels are shown in red, while the projected groundwater levels from 18 model runs occur within the blue shaded area. The average groundwater level projection is shown as the solid blue line and is the primary discussion reference. Details of the year when the first model run and average model run exceeds each potential RCL are also collated and presented in Appendix B. The location of selected representative hydrograph wells discussed below are shown in Figure 2.5 for potential groundwater level decline RCLs. These hydrographs were chosen as representative due to the high confidence placed in the calibration of the model in these locations (Li and Cranswick, 2017) and because they show the typical responses of the groundwater levels in their respective parts of the Tatiara PWA. All hydrographs are available as supplementary information in Volume 2 of this report found on the DEW Science Model Warehouse.

Additionally, the percentage of time from 2016–45 that each RCL is exceeded (includes all model runs) has been calculated for all observation wells used in model calibration (many of these are historic). These are shown spatially in maps described in Section 2.7.4 and presented in full within Appendix C. The potential hydraulic gradient RCLs and their exceedances are described in Section 2.7.5.

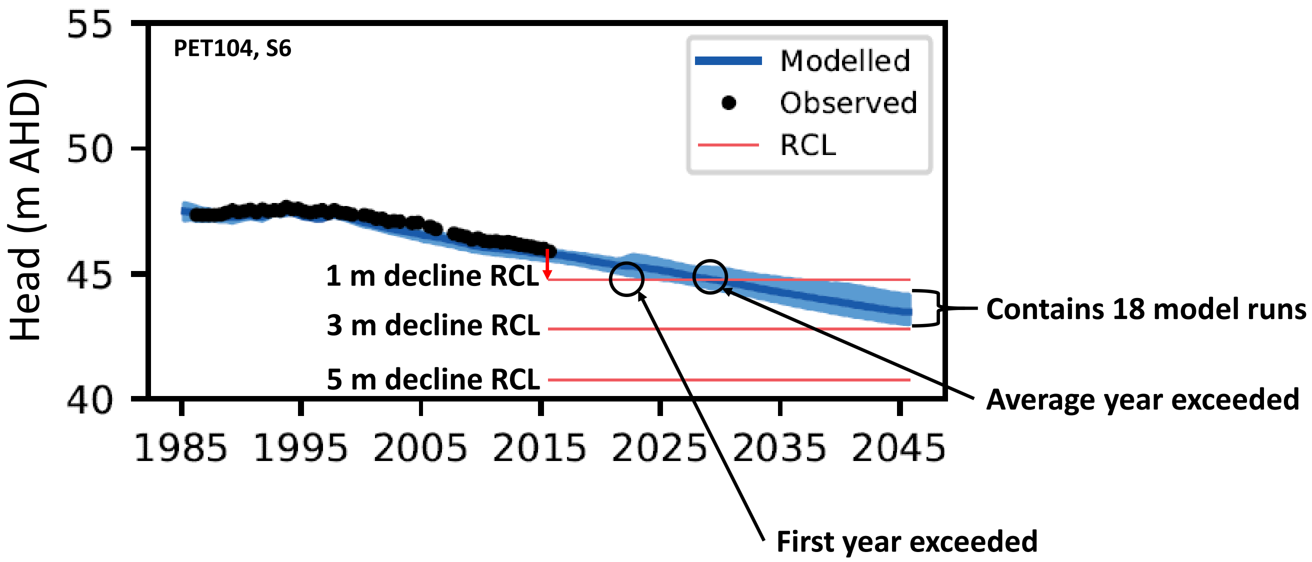

Figure 2.4. Example hydrograph projections relative to the potential groundwater level decline RCLs of 1, 3 and 5 m

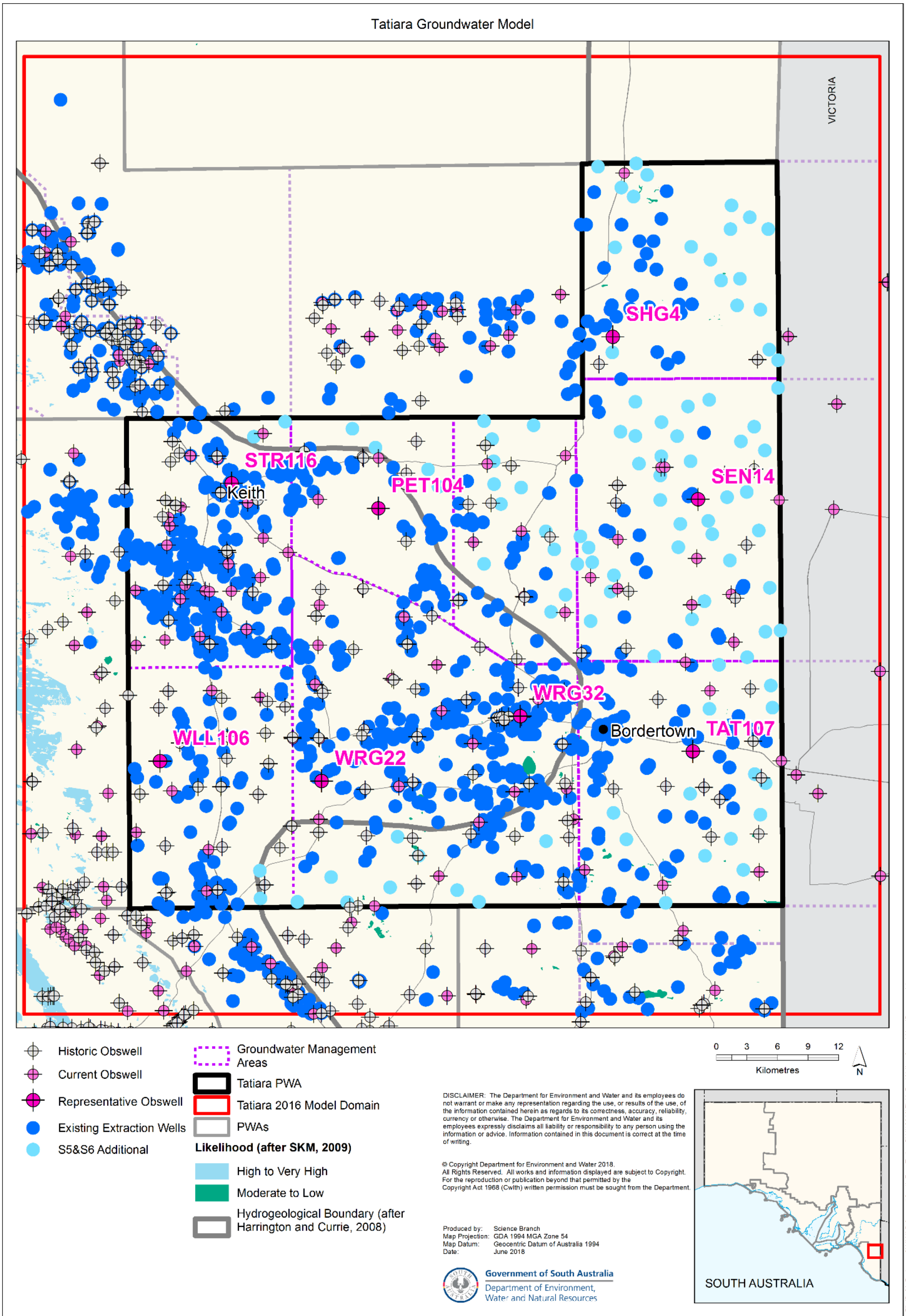

Figure 2.5. Location of representative hydrographs and additional extraction wells for S5 and S6

2.7.2 Coastal plain representative hydrographs

In the north-western part of the coastal plain, STR116 (Figure 2.6) shows the typical response for the Stirling GMA under the six future extraction scenarios. Continued declines are observed under full allocation extraction, while stable or recovering trends are observed under higher, current and lower extraction. The 1 m RCL is exceeded only under the full allocation extraction scenario, in the next few years for some model runs while the average exceeds the RCL frequently in the 2020s during summer months. The additional extraction on the Mallee highlands for S5 and S6 does not appear to have any significant influence in this part of the coastal plain.

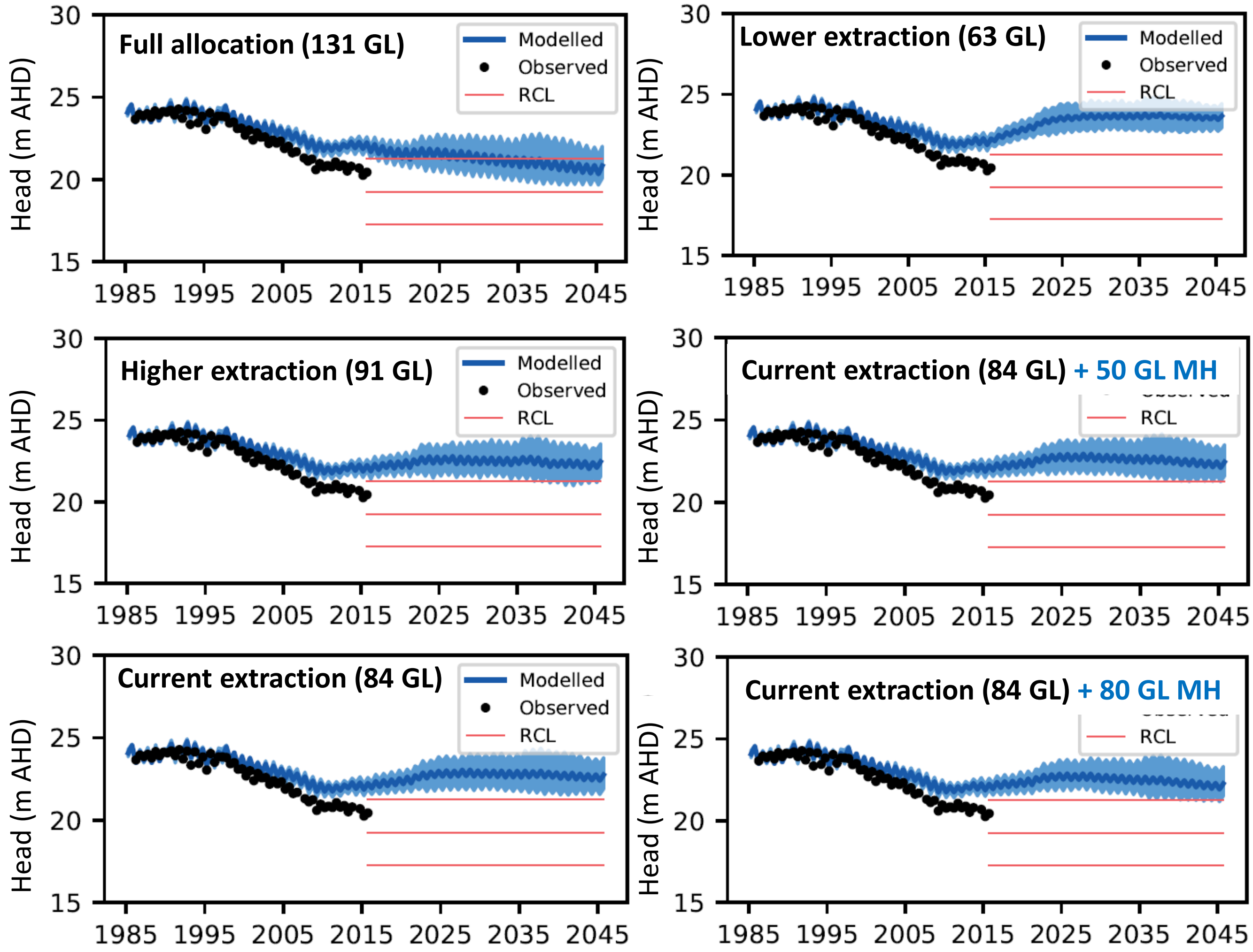

Figure 2.6. Coastal plain representative hydrographs for ST116 under six extraction scenarios

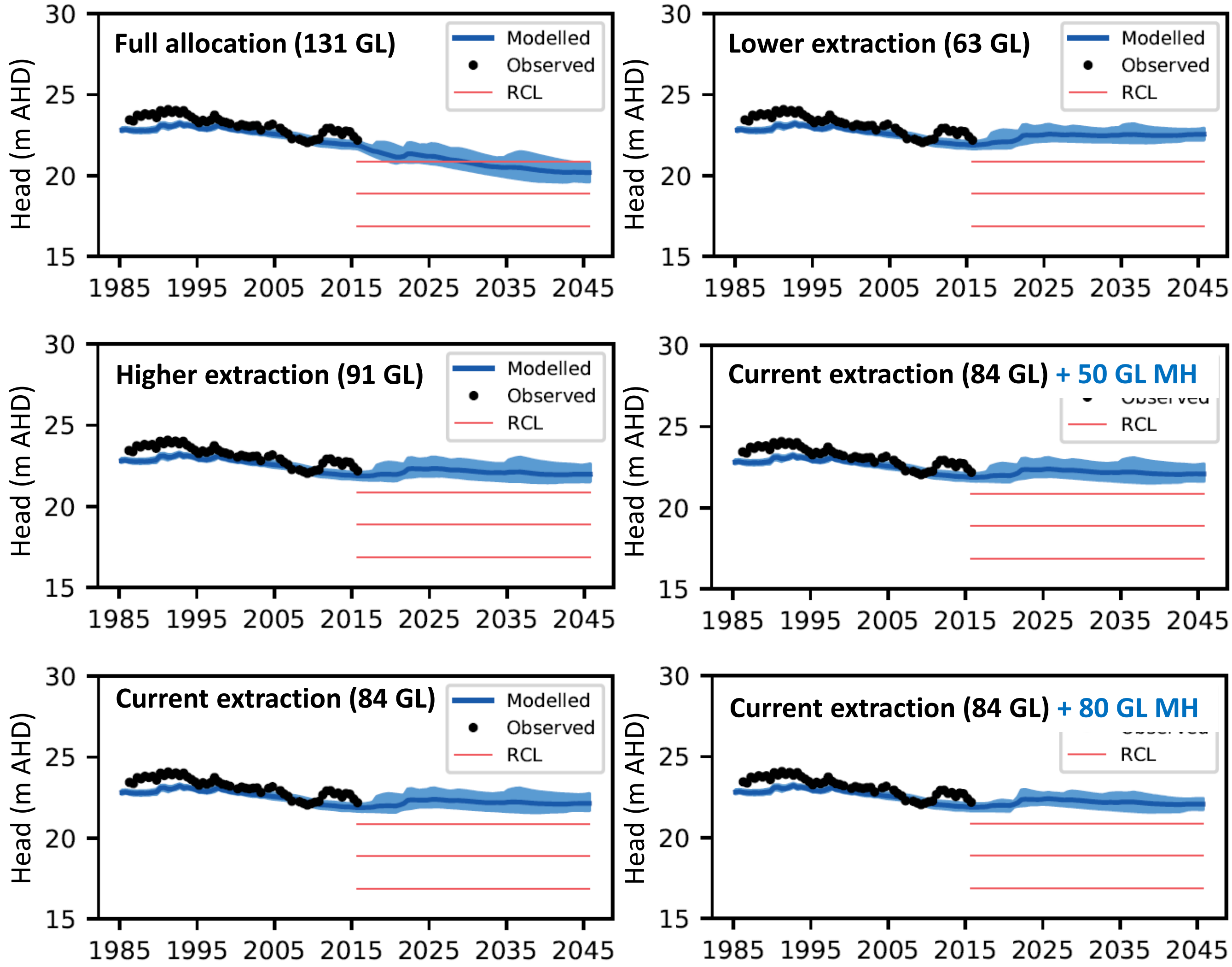

Figure 2.7. Coastal plain representative hydrographs for WLL106 under six extraction scenarios

In the south-western part of the coastal plain, WLL106 (Figure 2.7) shows the typical response for this area under the six future extraction scenarios. Continued declines are observed under full allocation extraction, while stable or recovering trends are observed under higher, current and lower extraction. The 1 m RCL is exceeded only under the full allocation extraction scenario in the next few years for some model runs, while the average exceeds the RCL permanently in around 2028. Again, the additional extraction on the Mallee highlands for S5 and S6 does not appear to have any significant influence in this part of the coastal plain.

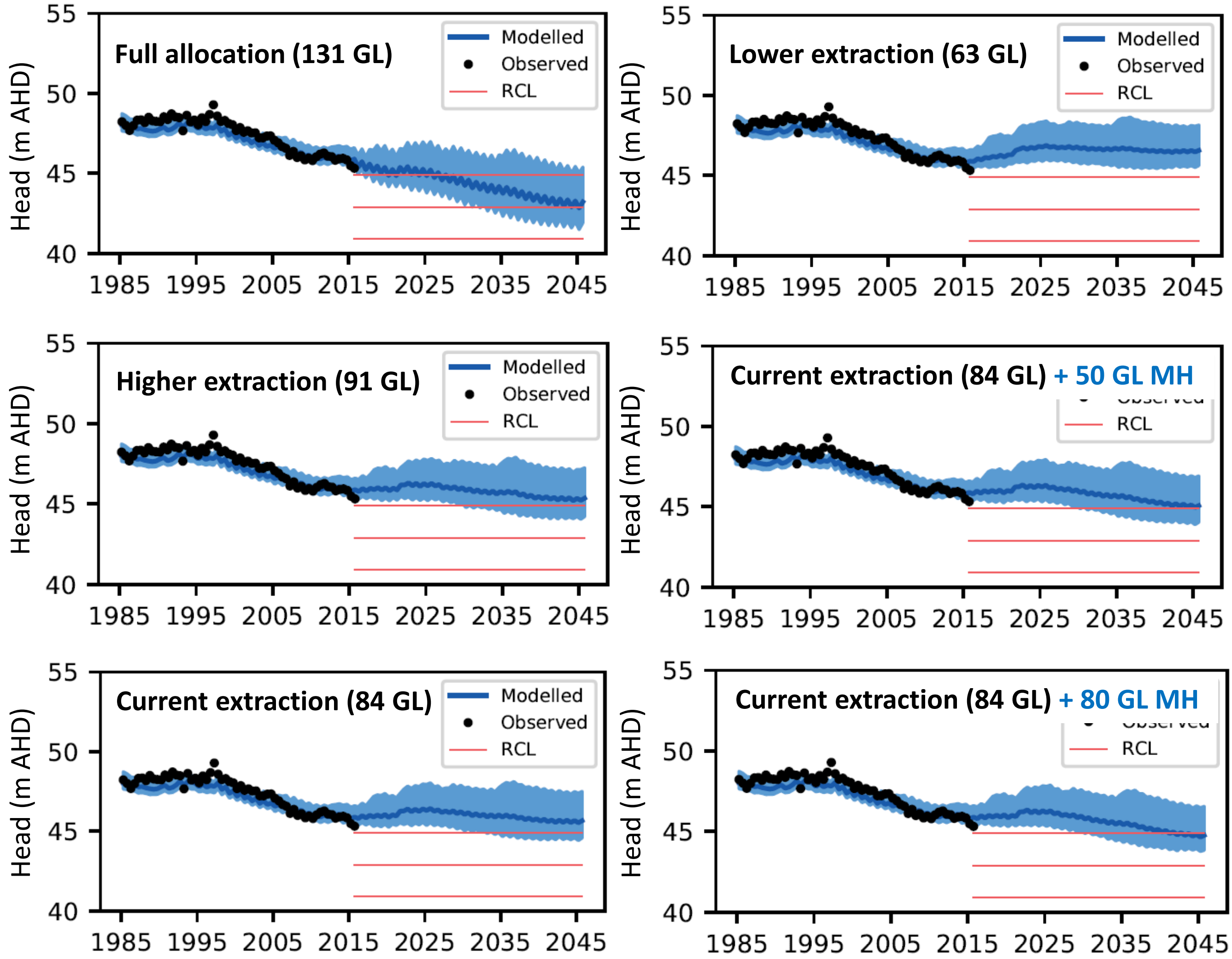

Figure 2.8. Coastal plain representative hydrographs for WRG022 under six extraction scenarios

In the southern part of the coastal plain, WRG022 (Figure 2.8) shows relatively steep declines under full allocation extraction and slightly declining to stable trends under higher, current and lower extraction scenarios. The 1 m RCL is exceeded on average in the next few years for full allocation extraction and the 3 m RCL is exceeded on average by 2042. RCLs are not reached on average for the remaining scenarios of Li and Cranswick (2017) although some model runs do exceed the 1 m RCL for higher and current extraction scenarios in the late 2030s. Current extraction with additional Mallee highland extraction of 50 and 80 GL/y (S5 and S6) is similar to S3 until approximately 2025 when the influence of additional extraction to the south and east appears to cause a slightly steeper declining trend. This results in average trigger exceedances of the potential 1 m RCL around 2040 rather than no average exceedance by 2045.

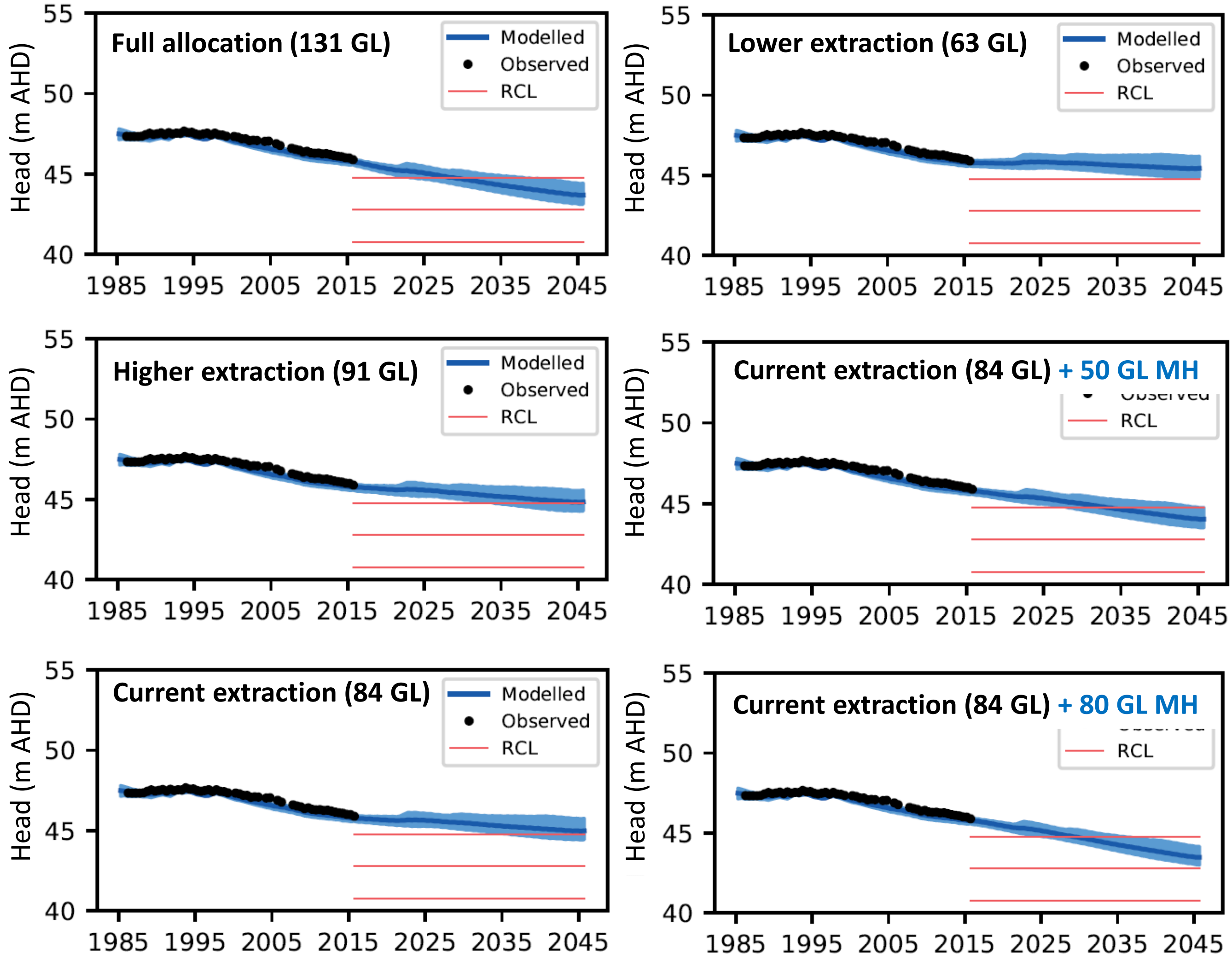

Figure 2.9. Coastal plain representative hydrographs for PET104 under six extraction scenarios

In the north-eastern part of the coastal plain (represented by PET104, Figure 2.9), continued declines are seen in the full allocation extraction scenario, with the 1 m RCL exceeded in the next 10 years and the 3 m RCL is approached towards 2045. The high extraction scenario has some model runs exceeding the 1 m RCL around 2037 while the average water level projection exceeds this RCL in approximately 2044. The current extraction scenario exceeds the 1 m RCL for only some model runs after approximately 2040. The scenarios where 50 and 80 GL/y of extraction occurs on the Mallee highland in addition to current extraction show hydrograph responses that are very similar to full allocation extraction. The 1 m RCL is exceeded on average in the next 10 to 15 years for S5 and S6 and both approach the 3 m RCL towards the end of the projection period.

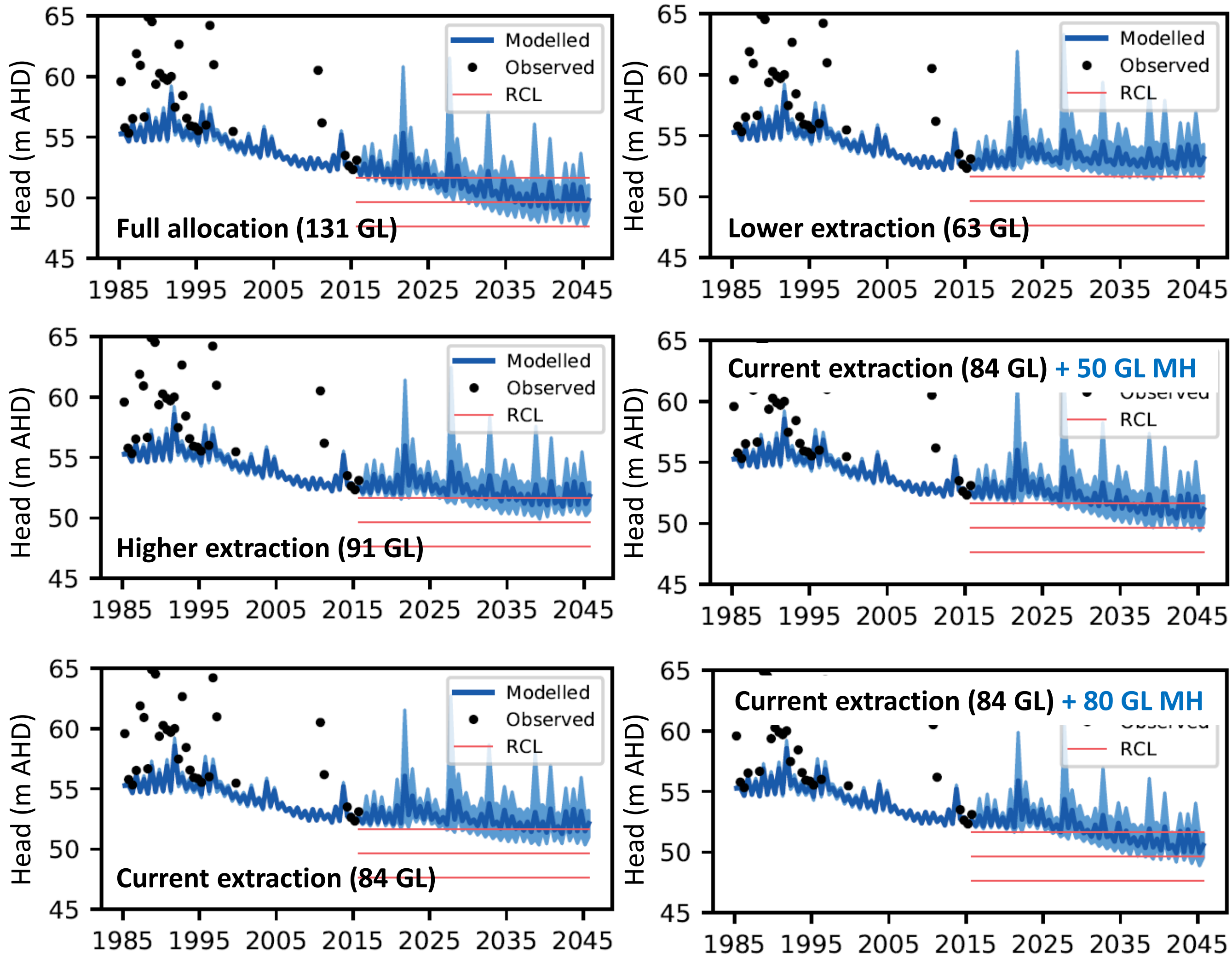

Figure 2.10. Coastal plain representative hydrographs for WRG032 under six extraction scenarios

In the eastern part of the coastal plain near Bordertown (represented by WRG032 near Poocher Swamp, Figure 2.10), continued declines are seen overall in all but the lower extraction scenario. The rate of decline increases as extraction on the coastal plain increases for current, higher and full allocation extraction scenarios, resulting in exceedances of the 1 m decline RCL by 2036, by 2031 and in the next few years respectively. The scenarios where 50 and 80 GL/y of extraction occurs on the Mallee highland in addition to current extraction show hydrograph responses that are similar to full allocation extraction, exceeding the 1 m decline RCL on average in the next 10 years (i.e. a similar overall response to PET104, despite the large point recharge fluxes occurring in nearby Poocher Swamp). The 3 m decline RCL is exceeded on average around 2035 for the full allocation extraction scenario and is approached by the scenario extracting an additional 80 GL/y from the Mallee highlands towards the end of the projection period.

2.7.3 Mallee highland representative hydrographs

In the southern part of the Mallee highlands (represented by TAT107, Figure 2.11), full allocation extraction results in almost immediate exceedance of the 1 m RCL followed by frequent exceedances of the 3 m RCL for the remainder of the projection period. The 5 m RCL is exceeded during the irrigation season after about 2038 and the large seasonality of the groundwater levels are likely due to this observation wellbeing in close proximity to two licenced wells (1–2 km to the north) with large combined allocations that have not been normally used in the recent past. The higher, current and lower extraction scenarios also show consistent average exceedances of the 1 m RCL in the next 10 years, and approach the 3 m RCL towards the end of the projection period. As described by Li and Cranswick (2017), these declines are the delayed impact of the historical groundwater level declines seen on the coastal plain over the past 20 years (as a result of below-average recharge and groundwater extraction).

Relatively steep declining trends are seen in the additional two scenarios where groundwater is extracted on the Mallee highland in addition to current extraction rates (i.e. an extra 7 and 11.2 GL/y for S5 and S6 respectively within the Tatiara GMA, in addition to the current extraction of 4.8 GL/y). The 1 m RCL is exceeded in the next few years while the 3 m RCL is exceeded in approximately 2033 and 2030 for S5 and S6 respectively. The 5 m RCL is exceeded for the current extraction plus 80 GL/y on the Mallee highlands towards the end of the projection period (2044). If the model projections were run further into the future, it is likely that a new equilibrium would be reached (i.e. groundwater levels would stabilise at a lower level) but this is not seen by 2045. It should be noted that the saturated thickness of the aquifer in this location ranges between 50 and 70 m. Thus a decline of 5 m over 30 years represents the use of approximately 7–10 % of the total storage.

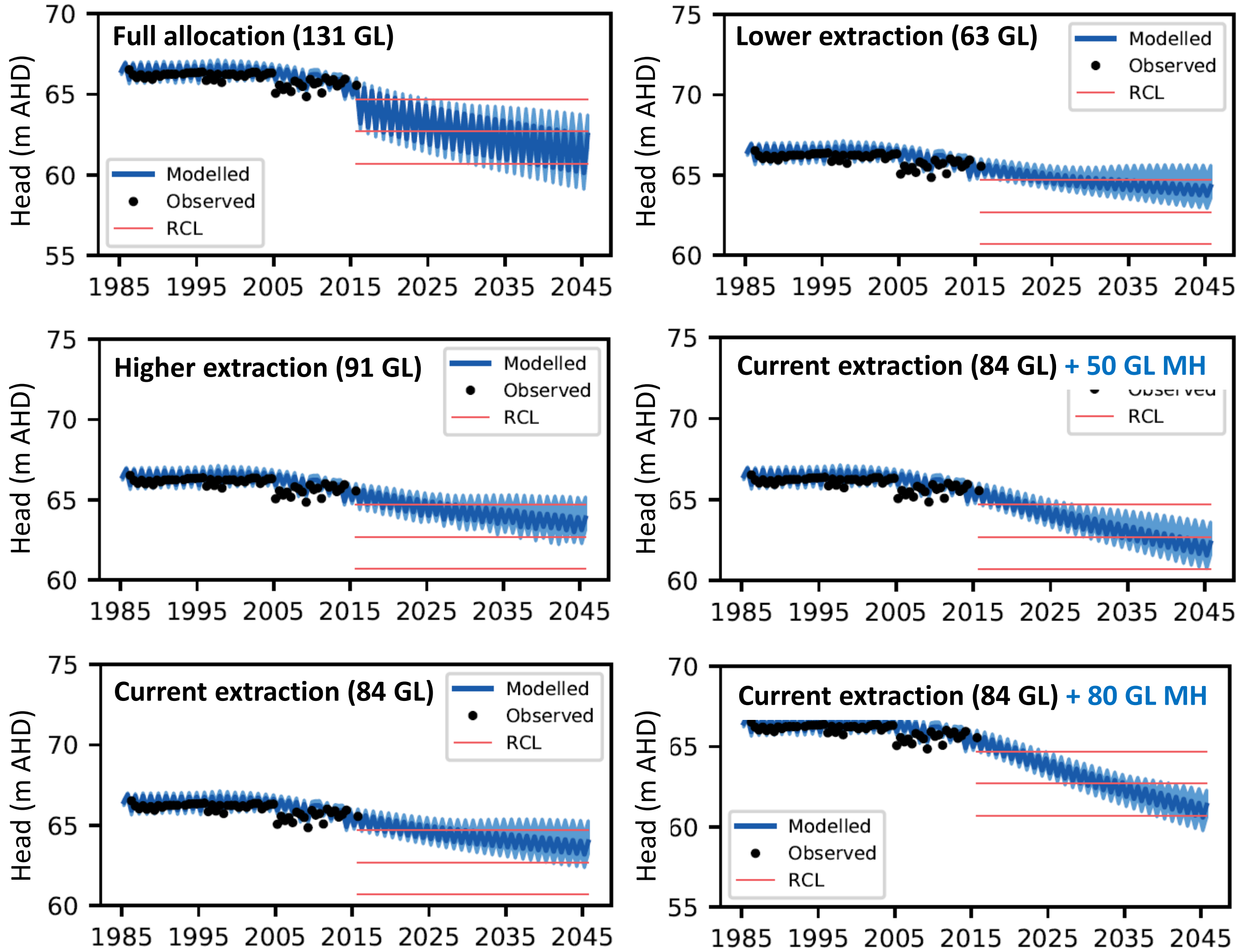

Figure 2.11. Mallee highland representative hydrographs for TAT107 under six extraction scenarios

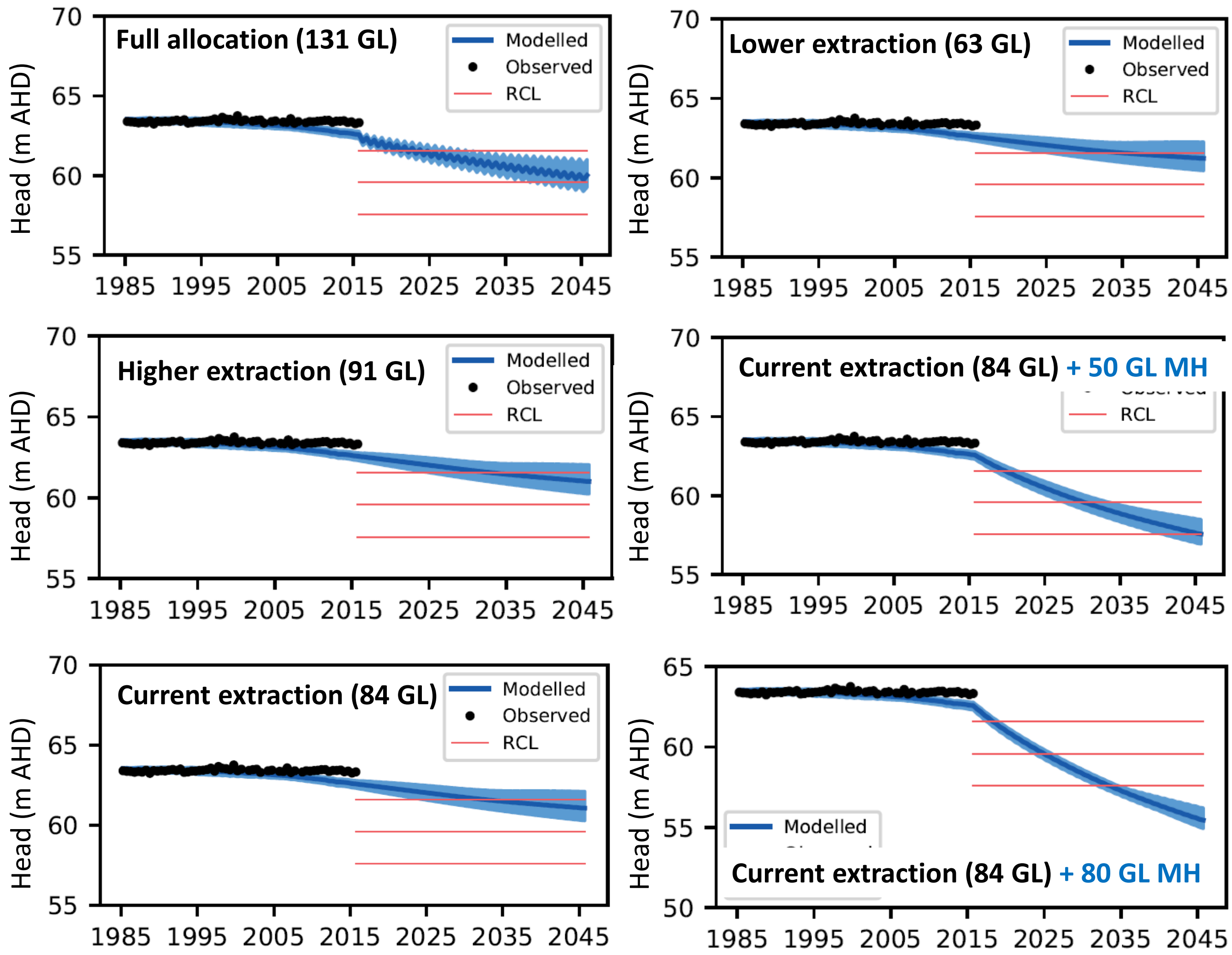

Figure 2.12. Mallee highland representative hydrographs for SEN014 under six extraction scenarios

In the central part of the Mallee highlands, SEN014 (Figure 2.12) shows a steep decline due to the scenarios extracting additional groundwater from the Mallee highlands. This equates to an extra 19.5 and 31.2 GL/y for S5 and S6 respectively within the Zone 8A GMA (in addition to the current extraction of 10.5 GL/y). Compared to the full allocation extraction scenario, which reaches the 3 m RCL by 2045, S5 and S6 reach this RCL by 2025 and 2030 respectively. S5 reaches the 5 m RCL on average by 2044 while this RCL is exceeded just prior to 2034 for S6. If the model projections were run further into the future, it is likely that a new equilibrium would be reached (i.e. groundwater levels would stabilise at a lower level) but this is not seen by 2045. It should be noted that the saturated thickness of the aquifer in this location is approximately 80 m. Thus a decline of 5 m over 30 years represents the use of approximately 6 % of the total storage.

The higher, current and lower extraction scenarios show very similar projections, exceeding on average the 1 m RCL by around 2030. As described by Li and Cranswick (2017), these declines are the delayed impact of the historical groundwater level declines observed on the coastal plain over the past 20 years (which are as a result of below average recharge and extraction during that time). The authors also note that the slight declines occurring late in the historical period across some parts of the Mallee highland, are an artificial result of the reduced recharge applied across the model domain to better match the observed groundwater levels overall. It is possible that the influence of these slight declines also carries through to the future period due to the average recharge multipliers applied (Li and Cranswick, 2017), which may result in a more conservative estimate of future projected declines (i.e. they may be slightly exaggerated).

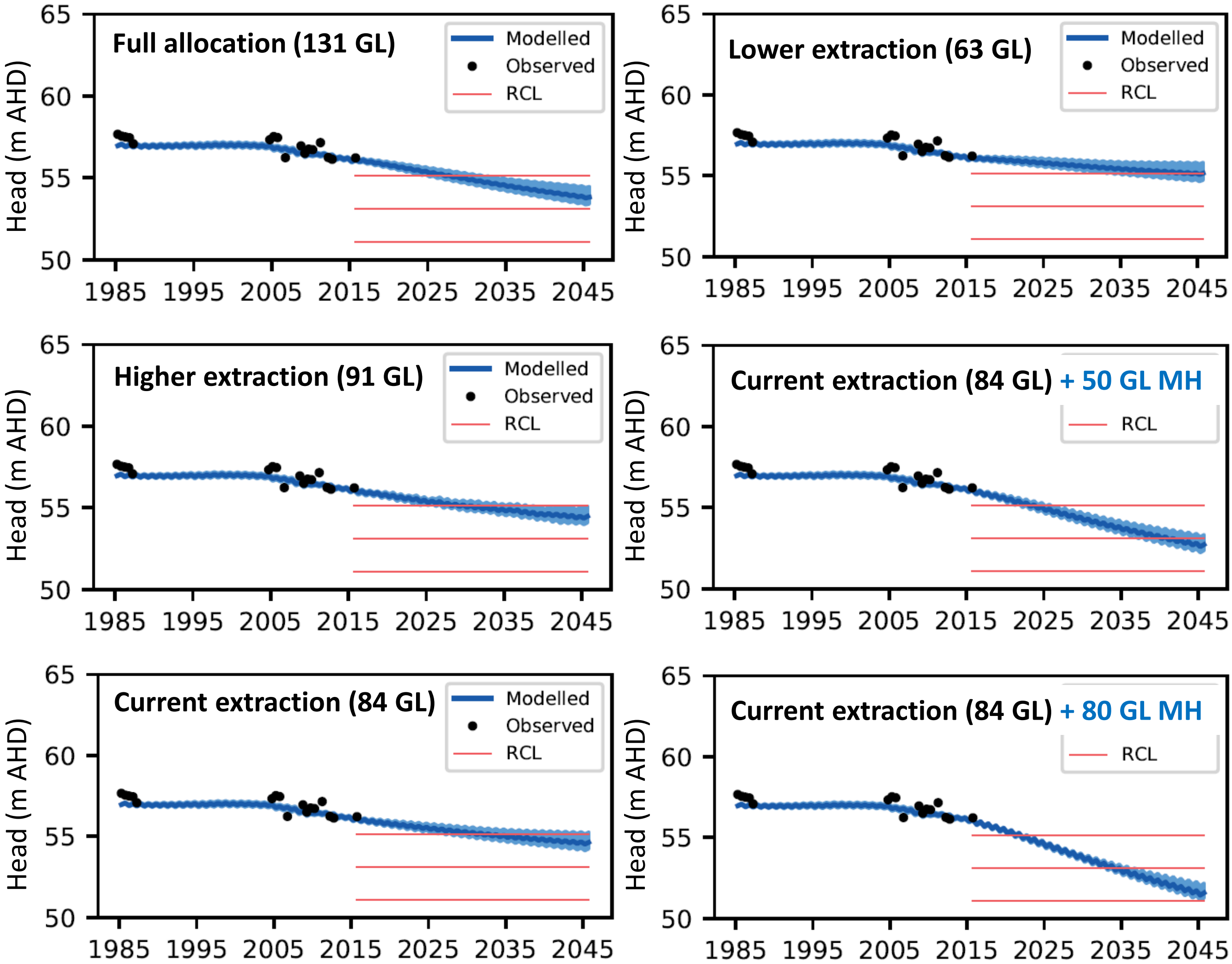

Figure 2.13. Mallee highland representative hydrographs for SHG004 under six extraction scenarios

In the northern part of the Mallee highlands, the SHG004 hydrographs (Figure 2.13) show a range of responses to each of the six extraction scenarios. Continued declines are seen in all scenarios, with the 1 m RCL being exceeded on average in approximately the next 9, 10, 13 and 23 years for the full allocation, higher, current and lower extraction scenarios respectively. The scenarios with additional extraction in the Mallee highlands (i.e. an extra 9.5 and 15.2 GL/y for S5 and S6 respectively within the Shaugh GMA, in addition to the current extraction of 6 GL/y) show exceedances of the 3 m RCL on average around 2040 and 2033 respectively. It should be noted that the saturated thickness of the aquifer in this location ranges between 85 and 100 m. Thus a decline of 5 m over 30 years represents the use of approximately 5–6 % of the total storage.

It should be noted that a 5 m decline in 30 years represents a groundwater level decline rate of 0.17 m/y, which is allowable in the current South Australian–Victorian Border Groundwaters Agreement (0.25 m/y) and slightly steeper than the current WAP groundwater level decline trigger of 0.1 m/y. That is, declining groundwater levels at these rates are not of concern from a hydrogeological perspective, especially given the saturated thickness of the aquifer in the Mallee highland.

2.7.4 Spatial distribution of potential groundwater level decline RCL exceedances

The average percentage of time each of the 1, 3, and 5 m groundwater level decline RCLs is exceeded is presented for each of the six scenarios in the series of maps shown in Appendix C (Figure 4.1–Figure 4.17). A summary figure is also presented below for each of the potential 1, 3 and 5 m decline RCLs (Figure 2.14, Figure 2.15 and Figure 2.16 respectively). The average percentage of time that the potential RCL is exceeded can alternatively be thought of with respect to the average year the RCL is reached. For example, an average percentage of time exceeded of 50 % represents reaching the potential RCL in 15 years on average (33 % of the time is 10 years, 100 % of time is 0 years, etc.).

The 1 m decline RCL (Figure 2.14) is commonly exceeded for > 50% of the time across the majority of the Tatiara PWA under the full allocation extraction scenario, meaning that this is likely to be commonly exceeded within the next 5–15 years. In the higher, current and lower extraction scenarios the 1 m RCL decline is most likely exceeded between 30 and 60 % of the time at the worst, but only within the area approximately 20 km east of the coastal plain on the Mallee highlands. This is the result of the historical groundwater level declines observed in the west over the last two decades (i.e. as a result of below-average recharge and groundwater extraction, see Li and Cranswick, 2017). It appears that 1 m RCL exceedances are highly likely on the Mallee highlands under these three reasonable scenarios within the next 15 years. In contrast, the 1 m decline RCL is only exceeded significantly on the western side of the Tatiara PWA (i.e. on the coastal plain) less than 30–40% of the time for the higher extraction scenario (and less or not at all for current and lower extraction scenarios).

For the scenarios where further groundwater is extracted on the Mallee highlands in addition to current extraction rates, the exceedance of the 1 m decline RCL is likely to occur in the near future (Figure 2.14). However, compared to the full allocation extraction scenario, the influence of this additional 50 or 80 GL/y does not intrude significantly onto the coastal plain. For example, the observations wells in the coastal plain portion of the Wirrega GMA generally exceed the 1 m decline RCL on average 0–10% of the time in the west, and 50–60% of the time in the east towards Bordertown. The influence of these two scenarios (S5 and S6) on the observation wells in the Sherwood GMA (within the Tintinara–Coonalpyn PWA) is similar to the impact of the higher extraction scenario.

The 3 m decline RCL (Figure 2.15) is generally not exceeded for the higher, current and lower extraction scenarios across the entire Tatiara PWA. Full allocation extraction shows 10–30 % exceedances in the areas adjacent to the boundary between the coastal plain and Mallee highlands, in addition to greater exceedances in the Sherwood GMA and the Padthaway PWA. For scenarios where additional extraction occurs on the Mallee highland, there are exceedances of the 3 m decline RCL of up to 60% (S5) and 80% (S6) of the time in the area covered by part of the North Pendleton and Zone 8A GMAs, which is where the majority of additional wells are located (see also Table 2.4). This is expected since the increase in extraction is large compared to the extraction historically occurring in this area.

The 5 m decline RCL (Figure 2.16) is likely to be exceeded up to 50% of the time within only six observation wells under the scenario where an additional 80 GL/y is extracted from the Mallee highlands on top of current extraction rates (S6). These are located in the area of greatest change in extraction in the central and western part of the Zone 8A GMA (and one location in the southern part of the Wirrega GMA, WRG26 whose calibration was found by Li and Cranswick (2017) to have a low level of confidence). The 5 m decline RCL is only rarely exceeded for all other scenarios.

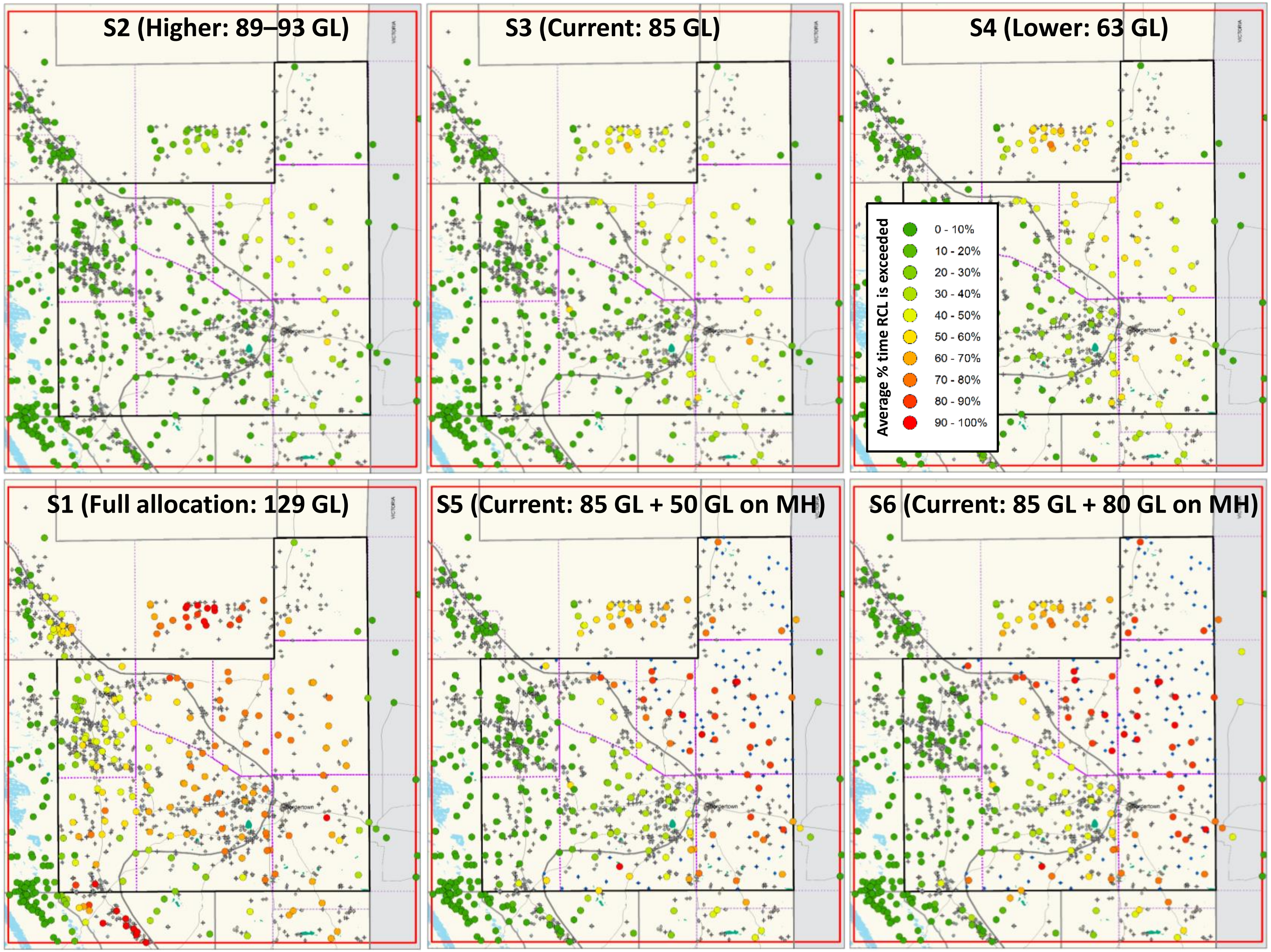

Figure 2.14. Maps showing the average percentage of time the 1 m decline RCL is exceeded (2016–45) under all extraction scenarios

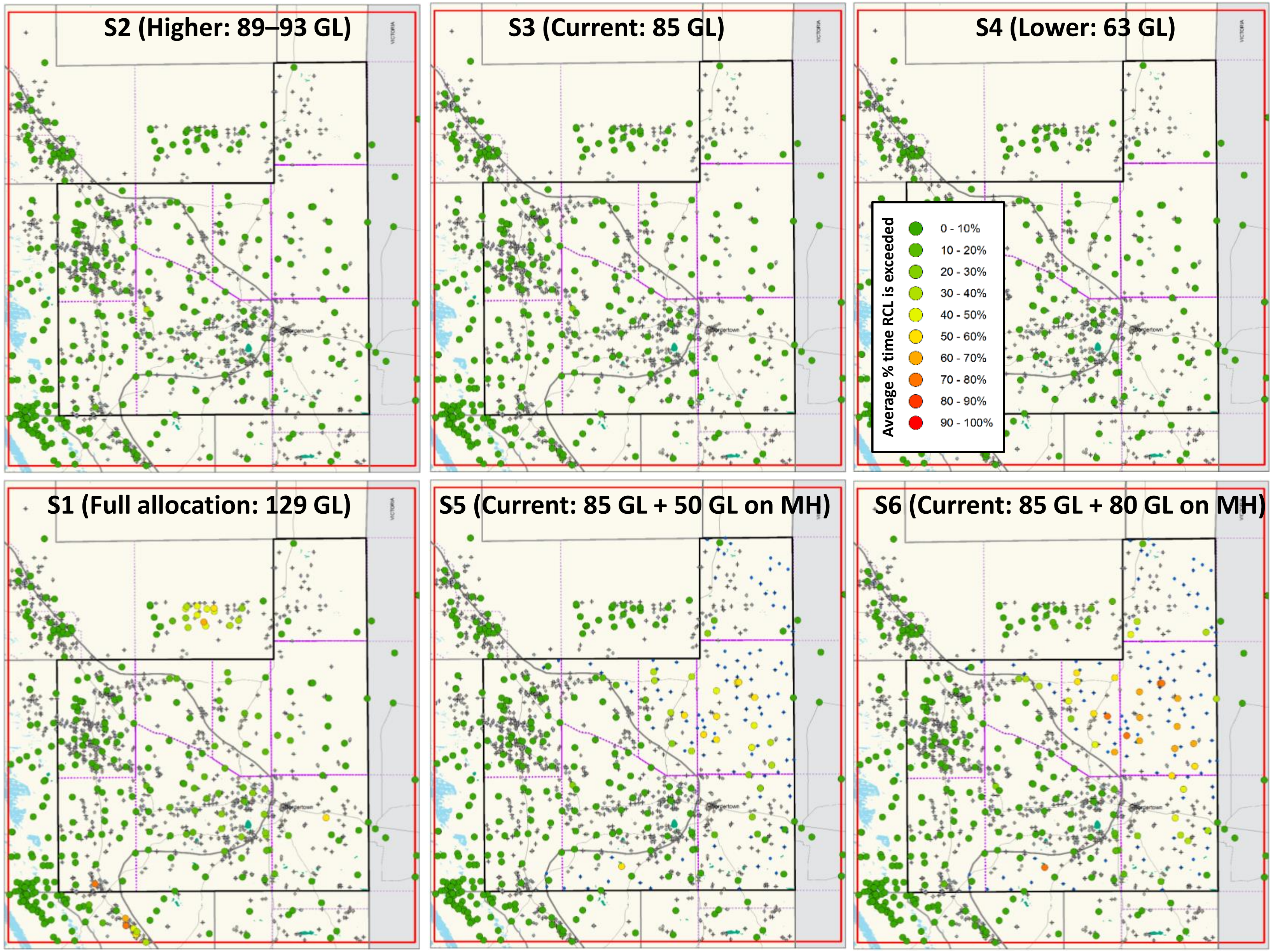

Figure 2.15. Maps showing the average percentage of time the 3 m decline RCL is exceeded (2016–45) under all extraction scenarios

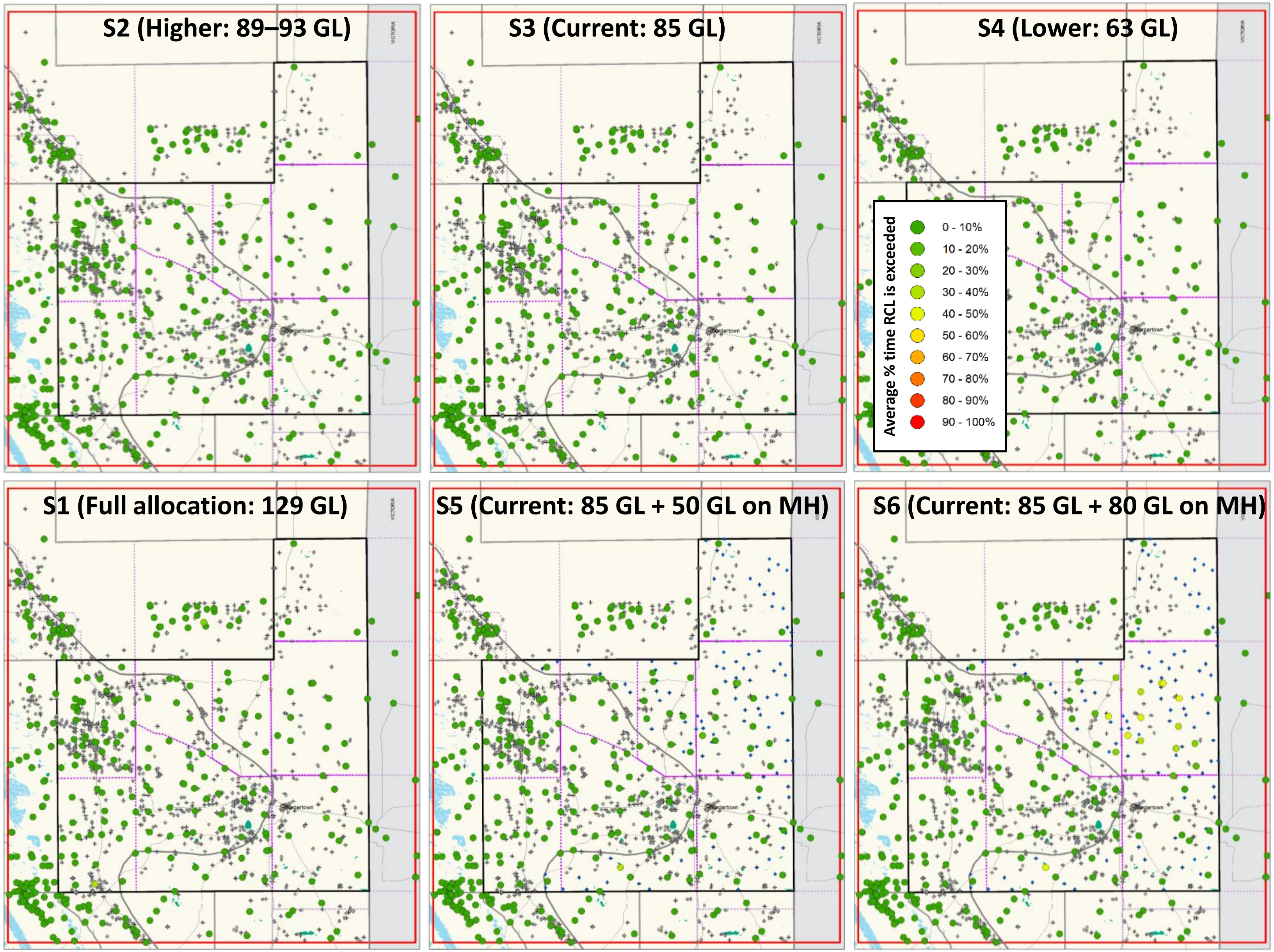

Figure 2.16. Maps showing the average percentage of time the 5 m decline RCL is exceeded (2016–45) under all extraction scenarios

2.7.5 Potential hydraulic gradient RCLs

The potential hydraulic gradient RCLs are derived using nine pairs of observation wells that are considered representative of the groundwater throughflow occurring across the western boundary of the Tatiara PWA on the coastal plain, across the Mallee highland, and between the Mallee highland and coastal plain. The locations of these observation well pairs are shown in Figure 2.2, while the observed calibration period and future projected hydraulic gradients are shown over time in Figure 2.17.

The observation well pairs on the coastal plain are designed to be representative of the likelihood of salinity impacts from either enhanced irrigation recycling, or reversal of flow direction due to reduced throughflow towards the west. These include the northern, central and southern pairs (STR110–LAF3, STR114–LAF6, and WLL7–PRK37 respectively) and are displayed for all six extraction scenarios on the left hand column of Figure 2.17. This first RCL is based on the winter 2015 hydraulic gradient, which is close to the lowest westward hydraulic gradient on record. The second and third RCLs in the analysis below are defined as 0.0001 and 0.0002 lower than the first RCL. This represents a relative decline of 1 and 2 m over 10 000 m between the observation well pairs. The northern pair shows that the first RCL is not exceeded on average for any scenarios except the full allocation extraction scenario. The first RCL is exceeded almost immediately for this scenario, and the second RCL is exceeded by some model runs towards 2040, but the average gradient does not show further RCL exceedances. The central pair again exceeds the first RCL almost immediately under full allocation extraction, and then exceeds the second RCL towards the end of the projection period. No other scenarios consistently exceed the RCLs for the central observation well pairs except the higher extraction scenario during the summer irrigation season. The southern observation well pairs exceed each of the three hydraulic gradient RCLs under the full allocation extraction scenario almost immediately, in around 2020 and just prior to 2035 respectively. This greater change under full allocation extraction is likely due to the licenses in this area having much greater allocation volumes than the recent extraction rates (i.e. going to full allocation extraction is a large change from recent rates). The higher extraction scenario exceeds the first RCL on average around 2040, while some other model runs from the other scenarios also approach or exceed the first RCL, and approach the second by the end of the projection period. The scenarios where additional extraction occurs on the Mallee highland in addition to current extraction (S5 and S6) result in essentially the same hydraulic gradients as those of the current extraction scenario.

Overall on the coastal plain, it is only the full allocation extraction scenario that threatens to increase the rates of salinity concentration, due to a flattening of the hydraulic gradient. It does not appear that regional groundwater flow reversal is a realistic possibility within the next 30 years, based on these observation well pairs and the selection of extraction scenarios investigated to date using the Li and Cranswick (2017) Tatiara PWA groundwater model.

The three observation well pairs selected on the Mallee highland are representative of the throughflow occurring across the northern (CAN16–PET105), central (SEN3–CAN14) and southern (TAT108–WRG116) areas (middle column of Figure 2.17). The first RCL represents the average winter hydraulic gradient from 1985–95, with the second and third RCLs defined by a hydraulic gradient that is 0.0001 and 0.0002 lower respectively. The northern pair of observation wells do not exceed the first RCL for the full allocation, higher, current and lower extraction scenarios. Only the scenarios where an additional 50 GL/y and 80 GL/y are extracted on top of current extraction show RCL exceedances on average in approximately 2032 and 2028 respectively. RCLs are not exceeded on average for the central observation well pair, except for the additional 80 GL/y scenario towards the end of the projection period. The southern observation well pair shows that only in the lower extraction scenario, do the average hydraulic gradients exceed the first RCL. This is caused by the recovery of the coastal plain groundwater levels, and suggests that the state of the groundwater system is likely to return to near historical conditions if the lower extraction scenario was to occur. In addition, the scenarios where an additional 50 GL/y and 80 GL/y are extracted on top of current extraction show that the first RCL is exceeded temporarily in the years around 2030. This is due to the delay in the response of the groundwater system regionally, to the much higher extraction rates on the Mallee highlands in these scenarios.

Observation well pairs have also been selected to represent the overall throughflow between the Mallee highlands and the coastal plain (see right hand column of Figure 2.17). The first RCL represents the average winter hydraulic gradient from 1985–95, with the second and third RCLs defined by a hydraulic gradient that is 0.0001 and 0.0002 lower respectively. The northern, central and southern areas are represented by CAN16–STR116, SEN3–PET103 and TAT108–WRG112 respectively. The northern pair shows that the first RCL is exceeded in approximately 2020 by the lower extraction scenario, and the two scenarios with additional extraction on the Mallee highland. The hydraulic gradient stabilises for the lower extraction scenario, while the additional 50 and 80 GL/y scenarios exceed the second RCL in approximately 2045 and 2035 respectively. These exceedances are due to the regional recovery of groundwater levels on the coastal plain and in combination with regional drawdown on the Mallee highlands for the former and latter two scenarios respectively. The current and higher extraction scenarios exceed the first RCL in approximately 2025 while the full allocation extraction scenario does not exceed the first RCL until after 2035. The central pair of observation wells (SEN3–PET103) show a very similar pattern of exceedances (Figure 2.17) to the northern pair. The southern pair of observation wells (TAT108–WRG112) show that the first RCL is likely to be exceeded by 2025 in all but the full allocation extraction scenario, which does not exceed the first RCL. The hydraulic gradient is then seen to stabilise within this part of the Tatiara PWA for all scenarios.

Overall on the Mallee highland, the first hydraulic gradient RCL is only exceeded in the northern area under the scenarios where very large volumes of groundwater are extracted, in addition to current extraction rates or under a lower extraction scenario in the southern area. This is largely due to the large increase within the Zone 8A GMA (i.e. from 1.9 GL/y to an additional 31.2 and 19.5 GL/y for S5 and S6 respectively). Smaller rates of additional extraction (i.e. perhaps reducing these rates to 10–15 GL/y within this GMA) could still result in the average hydraulic gradient remaining higher than those of the average historical (1985–95) period, noting that this scenario has not yet been modelled. The central and southern observation pairs do not consistently exceed the first RCL under these additional Mallee highland extraction scenarios. In the case of the lower extraction scenario, the first RCL exceedances in all three observation well pairs are due to the recovery of the coastal plain groundwater levels. The other scenarios (full allocation, higher and current extraction) do not exceed the first RCL.

Between the Mallee highland and coastal plain, the first RCL is exceeded for most scenarios as the groundwater system responds to the combination of historical and future stresses. Continued reductions of the westward hydraulic gradient occur only in the northern and central observation pairs for the two scenarios, with large additional extraction from the Mallee highland. All other extraction scenarios are seen to stabilise in the future projection period, particularly in the southern area. Returning to hydraulic gradients between the Mallee highland and coastal plain that are similar to the historical gradients are not considered likely to cause any significant impacts due to the reduction in groundwater throughflow. If hydraulic gradients were to be lower than those experienced in the historical period, it is possible that the rates of increasing groundwater salinity could be enhanced in the eastern margins of the coastal plains only, due to continued irrigation recycling combined with lower rates of throughflow. These potential changes in the salinity dynamics are not simulated directly in the groundwater model but projections of future hydraulic gradients could be used as indirect measures to inform risk of salinity impacts.

The potential hydraulic gradient RCLs on the Mallee highland, and also between the Mallee highland and coastal plain, are not clearly related to an unacceptable impact or adverse condition of the resource, and so should only be used as resource condition indicators in the future.

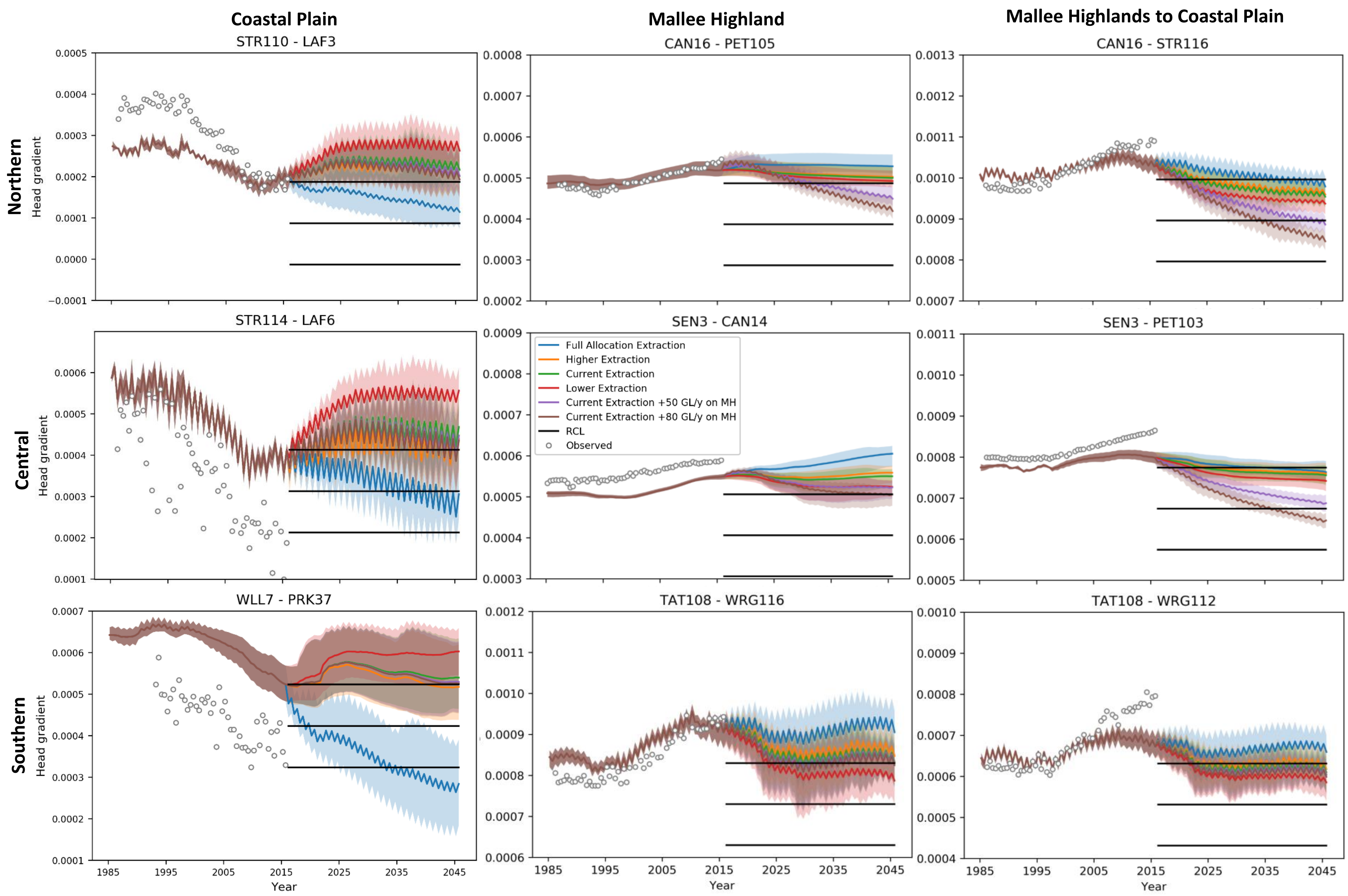

Figure 2.17. Hydraulic gradient RCLs for the northern, central and southern parts of the coastal plain, Mallee highland and from the Mallee highlands to coastal plain

2.8 Hydrogeologically-based recommended extraction limits

The range of future climate datasets used in the model projections is limited to six, including a dry, average and wet dataset from selected GCMs that simulate intermediate and high emissions climate scenarios (see more detail in Li and Cranswick (2017) and Morgan et al. (2017)). It is possible that shorter-term rainfall variability in the future could result in declining or rising groundwater level trends beyond the uncertainty represented by these modelled scenarios. Subsequent reduced recharge would be an important driver of changing resource condition on the coastal plain and it may not be possible to fully manage declining groundwater level trends through reductions of groundwater extraction. Nevertheless, within the uncertainty of future climate represented in the model projections, the different aquifer responses to a range of groundwater extraction regimes are clearly presented above.

2.8.1 Coastal plain

From a hydrogeological perspective, it is recommended that further groundwater level declines on the coastal plain be restricted to a minimum, such that aquifer yields are not negatively impacted. The groundwater model projections over the next 30 years show that coastal plain groundwater levels are likely to stabilise or recover on average, under all but the full allocation extraction scenario. Westward groundwater throughflow on the coastal plain is currently close to the lowest on record (i.e. near the lowest westward hydraulic gradient), and is projected to stabilise or return towards historical rates in the future under all but the full allocation extraction scenario. If hydraulic gradients towards the west were to continue to decrease there would be a greater risk of enhanced rates of increasing salinity, due to irrigation recycling. Thus, full allocation extraction on the coastal plain is not recommended, and there may be an acceptable extraction rate between this and the higher extraction scenario. It would be possible to run additional extraction scenarios in future to demonstrate that extraction rates greater than the higher extraction scenario (on average 74 GL/y) on the coastal plain would also be acceptable, but these have not been run. Conservatively, the higher extraction scenario rates (S2) are recommended on the coastal plain, notwithstanding any additional scenario modelling. That is, coastal plain extraction should be less than 74 GL/y on average, to avoid unacceptable groundwater level declines and reduced throughflow towards the west, which would be likely to impact aquifer yields and rates of salinity increases respectively.

2.8.2 Mallee highlands

The projected groundwater levels on the Mallee highlands show that exceedances of the 1 m decline RCL can be expected on average under all extraction scenarios. Thus it is likely that a considerable number of stock wells may need to be deepened at some stage in the future under all scenarios, particularly within the area approximately 20 km east of the boundary between the coastal plain and Mallee highland. This is not considered to be an aquifer performance issue but a limitation to the design of historical infrastructure, given the considerable saturated aquifer thickness of about 50 m or more below the current watertable. Over the next 30 years, exceedance of the 3 m decline RCL can be expected in the full allocation extraction, and the two scenarios where additional groundwater (50 and 80 GL/y) is extracted on top of current extraction (16 GL/y) from the Mallee highland. The 5 m decline RCL is only exceeded for the latter two scenarios in the area of largest hypothetical increase in extraction (located in the central and western side of the current Zone 8A GMA). The extraction of this additional groundwater from the Mallee highland in addition to current extraction, is likely to cause westwards hydraulic gradients to fall below the historical (1985–95) average hydraulic gradient between representative observation well pairs in some areas. However, a return to historical hydraulic gradients, or other potential hydraulic gradient RCLs presented in this report across the Mallee highland, result in groundwater throughflow rates that is similar to that occurring historically. Within the uncertainty of the groundwater model projections, Mallee highland extraction could be up to 96 GL/y with the likely impact of groundwater level declines around 5 m over 30 years in that may impact some stock and domestic wells in some areas.

2.9 Potential resource condition triggers

Resource condition triggers (RCTs) should be put in place at groundwater levels or hydraulic gradients above their respective RCLs, such that management responses have time to alter the trajectory of a change in the groundwater system, thereby avoiding the RCL being reached. These are distinctly different from existing "RCTs" of the current WAP i.e. water level and salinity trends, because they have a specified groundwater level or hydraulic gradient as a limit for each observation well or observation well pair respectively. The trends are still useful in identifying areas where the groundwater levels are approaching RCTs or RCLs.

Consideration should also be given to the timeframe over which RCT exceedances may be allowed to occur prior to triggering an assertive management response (i.e. percentage reductions to entitlements or allocations). This should find a balance between tolerating short-term climate variability and groundwater dynamics, and being responsive enough to recognise and act on longer-term adverse trends to mitigate risk to the resource and users. For example, it may be that an exceedance of an RCT could be tolerated for up to three successive years for example (provided the RCL is not exceeded), to account for a number of successive below-average recharge years. Note that this would only apply to areas where a seasonal response to rainfall is observed (i.e. coastal plain not Mallee highland areas). If the example three year RCT exceedance was then breached, it would be clear that a longer-term impact is occurring requiring a more assertive management response. This would be in contrast to a short-term impact resulting from, for example a compounding influence of seasonal variability of recharge, which may not require a response beyond continued monitoring. It is likely however, that if RCTs are being exceeded in an area that continued landuse and similar weather patterns would result in reaching the RCL in the near-future. Thus a spatial approach may be more appropriate for larger-scale management responses, which could also include the above consideration of timeframes.

2.9.1 Potential groundwater level decline RCTs

For groundwater level decline RCLs, the potential RCTs could be defined on the basis of a specified number or percentage of observation wells exceeding a specific groundwater level above an RCL. The RCT framework could include a series of potential RCTs with differing management responses, for example:

- RCTa: 10% of wells within X m of RCL – investigate cause of declining groundwater levels and assess the recent spatial distribution of extraction
- RCTb: 25% of wells within X m of RCL – incentivise trade away from impacted area to alter the intensity of extraction
- RCTc: 50% of wells within X m of RCL – Y % (moderate) reductions to extraction within specified area to avoid imminent RCL exceedance
- RCTd: 50% of wells within X m of RCL and some RCLs exceeded – Z % (major) reductions to extraction within specified area to avoid additional RCL exceedances

Values of X will depend on which RCL is agreed upon for implementation within the WAP for each management area or consumptive pool. For simplicity this could be a single value half way between the reference groundwater level and the final RCL (i.e. 0.5, 1.5 or 2.5 m RCT for the 1, 3, and 5 m decline RCLs respectively) – see Figure 2.18 for an example using the potential 5 m decline RCL. Alternatively, a single RCT could be set at 0.5 m above whichever RCL is selected (i.e. 0.5, 2.5 and 4.5 m RCT for the 1, 3 and 5 m RCLs respectively). Using a range of percentage exceedances of the RCT could allow a range of management responses to effectively mitigate the risk of exceeding the RCL. The values of Y and Z for the percentage of extraction reductions could be informed by the modelled extraction scenarios that show a recovery or stabilisation of groundwater levels.

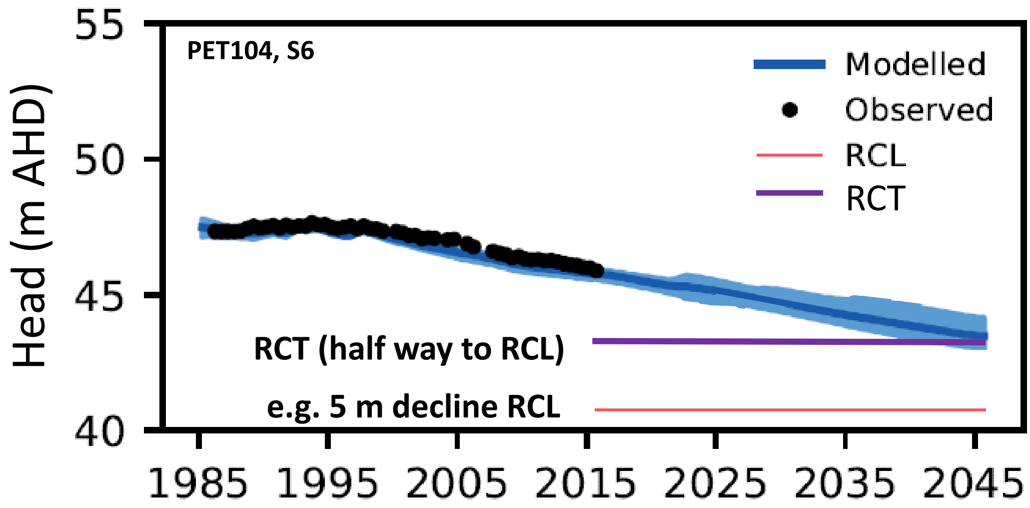

Figure 2.18. Resource condition trigger level for an example observation well with a 5 m decline RCL

In the Mallee highland, adopting the 1 and 3 m decline RCLs would likely result in a number of management responses being triggered in the near future (see Sections 2.7.3 and 2.7.4) due to the influence of 20 years of declining trends on the coastal plain rather than local extraction. These may not be manageable through reductions on the Mallee highland due to the hydrograph projections being similar between the higher, current and lower extraction scenarios. The 5 m decline RCLs however would have RCTs exceeded for the full allocation extraction and scenarios extracting an additional 50 and 80 GL/y on the Mallee highland. The risks of exceeding a decline RCL could be mitigated using the RCTs and management responses described above since there are significant differences in the groundwater response between these scenarios. Adopting the 1 and 3 m decline RCLs on the coastal plain may also trigger management responses after a few years of below average rainfall or under full allocation extraction rates.

The current observation well network could be used for this assessment, and the area of impact defined by spatial analysis of the distribution of wells exceeding the RCTs and hydrogeological interpretation. It is possible that the network may require improved spatial coverage in some areas to better represent the impact of some irrigation areas. For example, the Shaugh GMA has only one observation well currently being monitored for the Murray Group limestone aquifer (SHG7) and this is in the northern-most part of the GMA, rather than amongst or adjacent to the areas where groundwater is being extracted. All currently monitored observation wells should be used as RCT wells for the groundwater level decline RCL. To identify areas where RCTs are being exceeded, a simple calculation for each observation well would be used as a starting point (i.e. the latest winter groundwater level subtracted from the winter 2015 groundwater level). A surface would then be created from this data and the classification scheme would identify areas where different RCTs are exceeded.

An example is shown for the model projections under the full allocation extraction scenario using average winter groundwater level projections from 2030 (Figure 2.19). Similar figures of average drawdown for the other five scenarios are presented in Appendix D. It should be noted that these are the average drawdown projections, which do not represent the worst or best case model projections from the driest and wettest climate datasets respectively. Additionally, these average drawdown projections are from the six Model B runs, and do not include the projections from Model A or Model C that capture a greater range of uncertainty – see Li and Cranswick (2017) for detail on the differences between these models.

If a 5 m decline RCL was to be hypothetically adopted for 2030, there is a small area where the 2.5 m drawdown RCT (medium orange) is exceeded in the Sherwood GMA (outside of the Tatiara PWA where full allocation extraction was also applied). While the RCT is not likely to be exceeded within the Tatiara PWA by 2030, there is a north–south oriented band where the average drawdown is 1.5–2.5 m (pale orange) and is approaching the RCT.

If the 3 m decline RCL was adopted, the 1.5 m drawdown RCT is likely to be exceeded in this north-south oriented band (pale orange, 1.5–2.5 m drawdown) by 2030 and approaching the RCT in adjacent areas to the east and west (yellow, 1–1.5 m drawdown). However, if the 1 m decline RCL was adopted, the drawdown RCT of 0.5 m (light blue and greater) is likely to have been exceeded across almost the entirety of the PWA by 2030 under full allocation extraction.

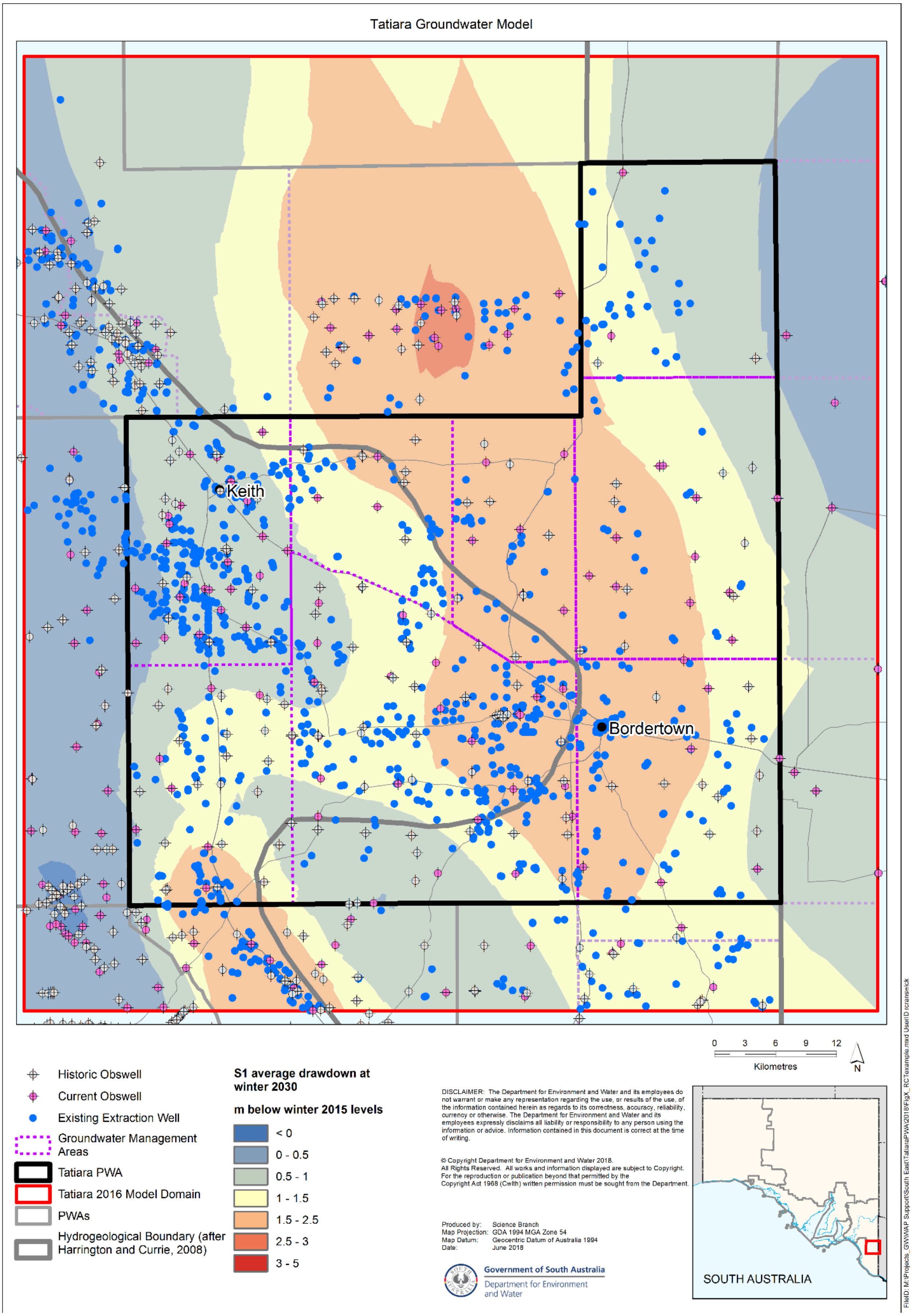

Figure 2.19. Example RCT exceedance analysis for the 5 m decline RCL, using average 2030 winter projected groundwater levels under full allocation extraction

2.9.2 Potential hydraulic gradient RCTs

For hydraulic gradient RCLs, the representative observation well pairs would be the focus of the RCTs and should be developed based on specified hydraulic gradients that are greater than the RCL. For example, if the hydraulic gradient RCL for a particular observation well pair on the Mallee highland, or between the Mallee highland and coastal plain was 0.0005, an RCT might be 0.0006. This is equivalent to a 1 m decline over 10 km change in the hydraulic gradient. The northern, central and southern observation well pairs discussed in Section 2.7.5 could be used to trigger a management response in their respective areas for the hydraulic gradient RCLs, however these are more appropriately used to monitor the condition of the resource on the Mallee highland and between the Mallee highland and the coastal plain.

It should be noted that only the hydraulic gradient RCLs for the western side of the coastal plain are considered critical from a hydrogeological perspective. These should not be allowed to reach a flat hydraulic gradient (i.e. 0) and ideally stay above 0.0001. Staged management responses should also applied to areas represented by each of the three observation well pairs:

- RCTa: hydraulic gradient below 0.0002 – investigate cause of declining groundwater levels and assess the recent spatial distribution of extraction
- RCTb: hydraulic gradient below 0.00015 – incentivise trade away from impacted area to alter the intensity of extraction
- RCTc: hydraulic gradient below 0.0001 – Y % (moderate) reductions to extraction within specified area to avoid imminent RCL exceedance
- RCTd: hydraulic gradient below 0.00005 – Z % (major) reductions to extraction within specified area to avoid additional RCL exceedances

The values of Y and Z for the percentage of extraction reductions could be informed by the groundwater extraction scenarios that show a recovery or stabilisation of groundwater levels.

3 Conclusions

A re-evaluation of the hydrogeological zones developed by Harrington and Currie (2008) show that the boundary between the coastal plain and the Mallee highland remains appropriate. Further delineation may be important to separate areas of differing groundwater salinity and watertable response times to contemporary rainfall, and these are outlined spatially for consideration of revised groundwater management areas (GMAs). The timescales upon which potential management responses and WAP objectives are appropriately different for the coastal plain and Mallee highland potential sub-areas, due to the timing of events along specific risk pathways. Development of a series of potential groundwater level decline RCLs were developed in consultation with the SAG to be 1, 3 and 5 m declines below a 2015 reference level with an assessment of a range of hydraulic gradients between selected pairs of observation wells. The impact on groundwater users of any such declines or changes in hydraulic gradient (with resulting changes in groundwater salinity) are intended to be a major component of socio-economic analysis conducted by the DEW Natural Resources South East (NR SE) in the near future. The groundwater level projections from six groundwater extraction scenarios combined with future climate scenarios inform the likelihood of these potential RCL exceedances.

The range of future climate datasets used in the model projections is limited to six, including a dry, average and wet dataset from selected GCMs that simulate intermediate and high emissions climate scenarios (see more detail in Li and Cranswick (2017) and Morgan et al. (2017)). It is possible that shorter-term rainfall variability in the future could result in declining or rising groundwater level trends beyond the uncertainty represented by these modelled scenarios. Subsequent reduced recharge would be an important driver of changing resource condition on the coastal plain and it may not be possible to fully manage declining groundwater level trends through reductions of groundwater extraction. Nevertheless, within the uncertainty of future climate represented in the model projections, the different aquifer responses to a range of groundwater extraction regimes are clearly presented.

The groundwater model projections over the next 30 years show that coastal plain groundwater levels are likely to stabilise or recover on average, under all but the full allocation extraction scenario. Similarly, westward groundwater throughflow on the coastal plain is currently close to the lowest on record (i.e. near the lowest westward hydraulic gradient), and is projected to stabilise or return towards historical rates in the future, under all but the full allocation extraction scenario. This recovery is largely due to the near-future rainfall projections (SA Climate Ready datasets – see Morgan et al. (2017) for further detail) being higher than the recent historical period (i.e. mid-1990s to early-2010s).

If coastal plain hydraulic gradients towards the west were to continue to decrease (e.g. as projected under the full allocation extraction scenario), there would be a greater risk of enhanced rates of increasing salinity due to irrigation recycling. It would be possible to explore additional extraction scenarios using the groundwater model to determine whether or not coastal plain extraction rates greater than the higher extraction scenario but less than full allocation extraction, could occur and still maintain westward throughflow (i.e. between on average 74 and 102 GL/y). Without further modelling however, the higher extraction scenario rates (i.e. less than 74 GL/y on average) on the coastal plain could be considered as the recommended extraction limit. The intent of this recommended extraction limit, within the uncertainty of the model projections, would be to avoid specific groundwater level declines and reduced throughflow towards the west, which would then be likely to impact aquifer yields and rates of salinity increases respectively.

The projected groundwater levels on the Mallee highlands show that exceedances of the 1 m decline RCL can be expected on average under all extraction scenarios. Thus it is likely that a considerable number of stock wells may need to be deepened at some stage in the future under all scenarios, particularly within the area approximately 20 km east of the boundary between the coastal plain and Mallee highland. This is not considered to be an aquifer performance issue but a limitation to the design of historical infrastructure, given the saturated aquifer thickness of about 50 m or more below the current watertable. Over the next 30 years, exceedance of the 3 m decline RCL can be expected in the full allocation extraction, and the two scenarios where 50 and 80 GL/y of groundwater from hypothetical wells is extracted in addition to current extraction (16 GL/y) from the Mallee highland. The 5 m decline RCL is only exceeded for the latter two scenarios in the area of largest hypothetical increase in extraction (located in the central and western side of the current Zone 8A GMA).

The extraction of this additional groundwater from the Mallee highland in addition to current extraction, results in projections of westward hydraulic gradients falling close to and below the historical (1985–95) average hydraulic gradients between representative observation well pairs. However, a return to historical hydraulic gradients, or other potential hydraulic gradient RCLs presented in this report across the Mallee highland, are sufficient to maintain westward groundwater throughflow that is similar to that experienced in the past. Within the uncertainty of the groundwater model projections, Mallee highland extraction could be up to 96 GL/y with the likely impact of groundwater level declines around 5 m over 30 years that may impact stock and domestic wells in some areas. In terms of managing the groundwater resource, this could be based on an agreement to take water from storage at an accepted rate.

For potential groundwater level decline RCLs, the potential RCTs could be defined on the basis of a specified number or percentage of observation wells exceeding a specific groundwater level above an RCL. The current observation well network could be used for this assessment and the area of impact defined by spatial analysis of the distribution of wells exceeding the RCTs and hydrogeological interpretation. It should be noted that there may be parts of the PWA where the spatial coverage of observation wells is sparse and unable to resolve the regional or local scale influence of groundwater extraction (e.g. Shaugh GMA). For hydraulic gradient RCLs, the representative observation well pairs would be the focus of the RCTs and could be developed based on specified hydraulic gradients greater than the RCL. The northern, central and southern observation well pairs could be used to trigger a management response in their respective areas for the hydraulic gradient RCLs. It should be noted that only the hydraulic gradient RCLs for the western side of the coastal plain are considered critical from a hydrogeological perspective. These should not be allowed to reach a flat hydraulic gradient (i.e. 0) and ideally stay above 0.0001, so that increasing groundwater salinity trends due to irrigation recycling are not further enhanced.

This analysis is intended to help form the basis of consequence categories within the risk assessment and gauge the range of attitudes towards risk and the nature of potential management responses within the WAP. Selecting appropriate RCLs within this context may help enable the WAP to be adaptive over a range of relevant time scales with specific and measureable objectives for each hydrogeological zone.

4 Appendices

A. Detailed model scenario mass balance for all model scenarios (including those of Li and Cranswick, 2017)

Table 4.1 10-year average groundwater mass balances for the Tatiara PWA showing minimum (left), average (bold) and maximum (right) flux values

		Tatiara PWA																	
	Date	Diffuse recharge			Extraction			Storage			Point recharge			Groundwater ET			Inflow			Outflow		
Calibration	Steady State	116	**132**	147	-72	**-82**	-93	0	**0**	0	3	**3**	3	-8	**-10**	-14	18	**21**	24	-57	**-63**	-68
	1986-1995	120	**129**	138	-81	**-92**	-104	6	**-9**	-24	6	**6**	6	-9	**-11**	-15	18	**21**	25	-61	**-62**	-63
	1996-2005	81	**98**	112	-81	**-93**	-105	-25	**-30**	-38	4	**4**	4	-5	**-6**	-7	18	**22**	25	-53	**-55**	-56
	2006-2015	48	**53**	56	-83	**-86**	-88	-49	**-50**	-50	3	**3**	3	-1	**-1**	-1	20	**23**	27	-37	**-41**	-45
S1I	2015-2024	79	**94**	112	-129	**-130**	-131	-28	**-44**	-56	5	**7**	7	0	**-1**	-1	22	**26**	29	-33	**-40**	-46
	2025-2034	83	**92**	108	-124	**-127**	-130	-28	**-39**	-47	5	**7**	10	0	**0**	-1	23	**28**	32	-31	**-39**	-47
	2035-2045	78	**89**	106	-123	**-124**	-127	-29	**-38**	-44	4	**5**	6	0	**0**	0	25	**29**	34	-28	**-36**	-46
S1H	2015-2024	65	**73**	85	-128	**-128**	-129	-54	**-62**	-68	5	**6**	6	0	**0**	0	22	**26**	30	-32	**-38**	-43
	2025-2034	64	**69**	77	-123	**-124**	-127	-54	**-58**	-61	1	**2**	4	0	**0**	0	24	**28**	32	-27	**-33**	-40
	2035-2045	62	**68**	76	-118	**-121**	-124	-42	**-45**	-48	4	**5**	6	0	**0**	0	26	**31**	35	-23	**-28**	-35
S2I	2015-2024	79	**94**	112	-87	**-93**	-97	1	**-13**	-21	5	**7**	7	-1	**-2**	-3	21	**25**	29	-38	**-44**	-50
	2025-2034	83	**92**	108	-91	**-93**	-95	-3	**-16**	-24	5	**7**	10	-1	**-2**	-3	23	**27**	31	-40	**-48**	-58
	2035-2045	78	**89**	106	-91	**-93**	-95	-10	**-20**	-26	4	**5**	6	-1	**-1**	-3	24	**28**	33	-38	**-47**	-58
S2H	2015-2024	65	**73**	85	-89	**-89**	-91	-20	**-29**	-36	5	**6**	6	-1	**-1**	-1	21	**25**	29	-36	**-43**	-49
	2025-2034	64	**69**	77	-89	**-89**	-91	-28	**-34**	-39	1	**2**	4	-1	**-1**	-1	23	**27**	31	-36	**-43**	-50
	2035-2045	62	**68**	76	-86	**-90**	-93	-26	**-28**	-31	4	**5**	6	0	**0**	-1	25	**29**	33	-33	**-41**	-49
S3I	2015-2024	79	**94**	112	-84	**-84**	-84	9	**-6**	-18	5	**7**	7	-1	**-2**	-3	21	**25**	29	-39	**-45**	-52
	2025-2034	83	**92**	108	-84	**-84**	-84	-2	**-12**	-20	5	**7**	10	-1	**-2**	-4	23	**27**	31	-43	**-52**	-62
	2035-2045	78	**89**	106	-84	**-84**	-84	-8	**-17**	-23	4	**5**	6	-1	**-2**	-4	23	**28**	32	-43	**-52**	-63
S3H	2015-2024	65	**73**	85	-84	**-84**	-84	-16	**-25**	-31	5	**6**	6	-1	**-1**	-1	21	**25**	29	-38	**-43**	-49
	2025-2034	64	**69**	77	-84	**-84**	-84	-27	**-32**	-35	1	**2**	4	-1	**-1**	-2	23	**27**	31	-38	**-45**	-53
	2035-2045	62	**68**	76	-84	**-84**	-84	-21	**-26**	-29	4	**5**	6	0	**-1**	-1	25	**29**	33	-36	**-43**	-50
S4I	2015-2024	79	**94**	112	-63	**-63**	-63	25	**10**	-2	5	**7**	7	-1	**-2**	-4	21	**25**	28	-43	**-50**	-56
	2025-2034	83	**92**	108	-63	**-63**	-63	6	**-2**	-9	5	**7**	10	-2	**-4**	-9	22	**26**	30	-51	**-60**	-69
	2035-2045	78	**89**	106	-63	**-63**	-63	-2	**-9**	-14	4	**5**	6	-2	**-5**	-10	22	**27**	31	-53	**-61**	-70
S4H	2015-2024	65	**73**	85	-63	**-63**	-63	-1	**-9**	-14	5	**6**	6	-1	**-1**	-2	21	**25**	28	-41	**-47**	-53
	2025-2034	64	**69**	77	-63	**-63**	-63	-17	**-21**	-24	1	**2**	4	-1	**-2**	-3	22	**26**	30	-46	**-54**	-62
	2035-2045	62	**68**	76	-63	**-63**	-63	-13	**-16**	-19	4	**5**	6	-1	**-1**	-2	24	**28**	32	-46	**-53**	-61
S5I	2015-2024	79	**94**	112	-133	**-134**	-134	-28	**-44**	-56	5	**7**	7	-1	**-2**	-3	30	**34**	38	-37	**-43**	-49
	2025-2034	83	**92**	108	-133	**-133**	-134	-31	**-43**	-51	5	**7**	10	-1	**-2**	-4	36	**41**	45	-39	**-47**	-57
	2035-2045	78	**89**	106	-133	**-133**	-134	-33	**-43**	-50	4	**5**	6	-1	**-2**	-3	39	**44**	49	-37	**-46**	-56
S5H	2015-2024	65	**73**	85	-133	**-133**	-134	-53	**-63**	-69	5	**6**	6	-1	**-1**	-1	30	**34**	38	-35	**-41**	-47
	2025-2034	64	**69**	77	-133	**-133**	-134	-57	**-63**	-67	1	**2**	4	-1	**-1**	-1	36	**41**	45	-34	**-41**	-48
	2035-2045	62	**68**	76	-132	**-133**	-133	-47	**-52**	-56	4	**5**	6	0	**0**	-1	40	**45**	50	-31	**-37**	-44
S6I	2015-2024	79	**94**	112	-162	**-162**	-163	-50	**-66**	-79	5	**7**	7	-1	**-2**	-3	36	**40**	44	-36	**-42**	-48
	2025-2034	83	**92**	108	-161	**-162**	-163	-49	**-60**	-70	5	**7**	10	-1	**-2**	-3	44	**49**	54	-37	**-45**	-54
	2035-2045	78	**89**	106	-161	**-162**	-163	-48	**-58**	-66	4	**5**	6	-1	**-1**	-3	49	**54**	60	-35	**-43**	-53
S6H	2015-2024	65	**73**	85	-162	**-162**	-163	-75	**-85**	-91	5	**6**	6	-1	**-1**	-1	36	**40**	44	-35	**-40**	-45
	2025-2034	64	**69**	77	-161	**-162**	-162	-75	**-80**	-85	1	**2**	4	-1	**-1**	-1	45	**50**	55	-33	**-39**	-46
	2035-2045	62	**68**	76	-160	**-161**	-162	-62	**-67**	-71	4	**5**	6	0	**0**	-1	50	**56**	61	-28	**-34**	-41

Table 4.2 10-year average groundwater mass balances for the coastal plain showing minimum (left), average (bold) and maximum (right) flux values

		Coastal Plain																				
	Date	Diffuse recharge			Extraction			Storage			Point recharge			Groundwater ET			Inflow			Outflow		
Calibration	Steady State	85	**97**	108	-65	**-74**	-84	0	**0**	0	3	**3**	3	-8	**-10**	-14	32	**36**	41	-49	**-52**	-56
	1986-1995	92	**99**	106	-73	**-84**	-94	4	**-4**	-12	6	**6**	6	-9	**-11**	-15	31	**36**	42	-51	**-52**	-52
	1996-2005	57	**67**	76	-73	**-84**	-94	-16	**-21**	-26	4	**4**	4	-5	**-6**	-7	36	**41**	46	-43	**-44**	-45
	2006-2015	35	**38**	41	-69	**-71**	-73	-16	**-19**	-20	3	**3**	3	-1	**-1**	-1	38	**42**	47	-28	**-31**	-34
S1I	2015-2024	63	**75**	88	-102	**-103**	-104	-2	**-12**	-21	5	**7**	7	0	**-1**	-1	34	**38**	43	-24	**-28**	-33
	2025-2034	63	**69**	77	-97	**-100**	-103	-11	**-13**	-18	5	**7**	10	0	**0**	-1	32	**36**	40	-20	**-26**	-34
	2035-2045	60	**66**	73	-96	**-98**	-101	-12	**-14**	-15	4	**5**	6	0	**0**	0	33	**36**	40	-17	**-23**	-32
S1H	2015-2024	57	**63**	72	-101	**-102**	-103	-14	**-21**	-26	5	**6**	6	0	**0**	0	35	**38**	42	-23	**-27**	-31
	2025-2034	55	**58**	62	-96	**-98**	-100	-20	**-21**	-23	1	**2**	4	0	**0**	0	34	**37**	41	-16	**-21**	-27
	2035-2045	54	**58**	62	-92	**-94**	-97	-10	**-11**	-12	4	**5**	6	0	**0**	0	32	**35**	39	-12	**-16**	-21
S2I	2015-2024	63	**75**	88	-70	**-75**	-79	16	**7**	1	5	**7**	7	-1	**-2**	-3	32	**36**	40	-30	**-35**	-40
	2025-2034	63	**69**	77	-73	**-75**	-77	1	**-3**	-7	5	**7**	10	-1	**-2**	-3	31	**34**	38	-31	**-38**	-47
	2035-2045	60	**66**	73	-73	**-75**	-77	-6	**-8**	-10	4	**5**	6	-1	**-1**	-3	31	**35**	39	-30	**-38**	-47
S2H	2015-2024	57	**63**	72	-72	**-72**	-73	6	**-1**	-6	5	**6**	6	-1	**-1**	-1	33	**36**	40	-28	**-33**	-38
	2025-2034	55	**58**	62	-72	**-72**	-73	-8	**-11**	-13	1	**2**	4	-1	**-1**	-1	32	**35**	38	-28	**-34**	-40
	2035-2045	54	**58**	62	-69	**-72**	-75	-4	**-6**	-8	4	**5**	6	0	**0**	-1	31	**33**	37	-24	**-31**	-38
S3I	2015-2024	63	**75**	88	-68	**-68**	-68	22	**12**	3	5	**7**	7	-1	**-2**	-3	32	**35**	40	-30	**-36**	-41
	2025-2034	63	**69**	77	-68	**-68**	-68	1	**-2**	-6	5	**7**	10	-1	**-2**	-4	30	**34**	38	-35	**-42**	-51
	2035-2045	60	**66**	73	-68	**-68**	-68	-5	**-6**	-8	4	**5**	6	-1	**-2**	-4	31	**34**	39	-35	**-42**	-52
S3H	2015-2024	57	**63**	72	-68	**-68**	-68	9	**2**	-2	5	**6**	6	-1	**-1**	-1	33	**36**	39	-29	**-34**	-39
	2025-2034	55	**58**	62	-68	**-68**	-68	-8	**-10**	-11	1	**2**	4	-1	**-1**	-2	31	**34**	38	-30	**-36**	-42
	2035-2045	54	**58**	62	-68	**-68**	-68	-3	**-5**	-6	4	**5**	6	0	**-1**	-1	30	**33**	37	-28	**-33**	-40
S4I	2015-2024	63	**75**	88	-51	**-51**	-51	32	**23**	14	5	**7**	7	-1	**-2**	-4	30	**34**	38	-34	**-40**	-46
	2025-2034	63	**69**	77	-51	**-51**	-51	5	**3**	0	5	**7**	10	-2	**-4**	-9	28	**32**	36	-43	**-50**	-59
	2035-2045	60	**66**	73	-51	**-51**	-51	-3	**-3**	-4	4	**5**	6	-2	**-5**	-10	29	**33**	37	-45	**-52**	-59
S4H	2015-2024	57	**63**	72	-51	**-51**	-51	20	**14**	10	5	**6**	6	-1	**-1**	-2	31	**34**	38	-33	**-38**	-43
	2025-2034	55	**58**	62	-51	**-51**	-51	-3	**-4**	-4	1	**2**	4	-1	**-2**	-3	30	**33**	36	-38	**-45**	-51
	2035-2045	54	**58**	62	-51	**-51**	-51	1	**0**	-1	4	**5**	6	-1	**-1**	-2	28	**32**	36	-38	**-44**	-50
S5I	2015-2024	63	**75**	88	-68	**-68**	-68	19	**9**	0	5	**7**	7	-1	**-2**	-3	30	**33**	37	-31	**-36**	-42
	2025-2034	63	**69**	77	-68	**-68**	-68	-3	**-6**	-10	5	**7**	10	-1	**-2**	-4	26	**29**	33	-35	**-42**	-51
	2035-2045	60	**66**	73	-68	**-68**	-68	-10	**-11**	-12	4	**5**	6	-1	**-2**	-3	25	**29**	33	-34	**-41**	-51
S5H	2015-2024	57	**63**	72	-68	**-68**	-68	6	**-1**	-5	5	**6**	6	-1	**-1**	-1	30	**33**	37	-30	**-34**	-39
	2025-2034	55	**58**	62	-68	**-68**	-68	-13	**-14**	-15	1	**2**	4	-1	**-1**	-1	27	**30**	33	-30	**-36**	-43
	2035-2045	54	**58**	62	-68	**-68**	-68	-8	**-10**	-10	4	**5**	6	0	**0**	-1	24	**27**	31	-27	**-32**	-39
S6I	2015-2024	63	**75**	88	-68	**-68**	-68	17	**8**	-1	5	**7**	7	-1	**-2**	-3	28	**32**	36	-31	**-37**	-43
	2025-2034	63	**69**	77	-68	**-68**	-68	-6	**-8**	-12	5	**7**	10	-1	**-2**	-3	24	**27**	31	-35	**-42**	-52
	2035-2045	60	**66**	73	-68	**-68**	-68	-12	**-14**	-15	4	**5**	6	-1	**-1**	-3	23	**26**	30	-33	**-41**	-51
S6H	2015-2024	57	**63**	72	-68	**-68**	-68	4	**-2**	-6	5	**6**	6	-1	**-1**	-1	29	**32**	36	-30	**-34**	-40
	2025-2034	55	**58**	62	-68	**-68**	-68	-15	**-16**	-17	1	**2**	4	-1	**-1**	-1	25	**28**	31	-30	**-36**	-43
	2035-2045	54	**58**	62	-68	**-68**	-68	-11	**-12**	-13	4	**5**	6	0	**0**	-1	22	**25**	28	-27	**-32**	-39

Table 4.3 10-year average groundwater mass balances for the Mallee highland showing minimum (left), average (bold) and maximum (right) flux values

		Mallee Highland																				
	Date	Diffuse recharge			Extraction			Storage			Point recharge			Groundwater ET			Inflow			Outflow		
Calibration	Steady State	31	**35**	39	-7	**-8**	-9	0	**0**	0	0	**0**	0	0	**0**	0	17	**19**	22	-40	**-45**	-51
	1986-1995	28	**30**	33	-7	**-8**	-9	3	**-5**	-12	0	**0**	0	0	**0**	0	17	**20**	23	-39	**-45**	-52
	1996-2005	25	**30**	36	-8	**-9**	-10	-9	**-10**	-11	0	**0**	0	0	**0**	0	17	**20**	23	-44	**-50**	-56
	2006-2015	13	**14**	15	-15	**-15**	-15	-30	**-31**	-32	0	**0**	0	0	**0**	0	18	**22**	25	-45	**-51**	-57
S1I	2015-2024	16	**19**	25	-27	**-27**	-27	-26	**-32**	-36	0	**0**	0	0	**0**	0	20	**24**	28	-42	**-48**	-54
	2025-2034	18	**23**	31	-27	**-27**	-27	-17	**-25**	-30	0	**0**	0	0	**0**	0	22	**26**	31	-42	**-47**	-52
	2035-2045	17	**23**	33	-27	**-27**	-27	-16	**-24**	-29	0	**0**	0	0	**0**	0	23	**28**	33	-42	**-47**	-53
S1H	2015-2024	8	**10**	13	-27	**-27**	-27	-38	**-41**	-44	0	**0**	0	0	**0**	0	20	**24**	28	-43	**-48**	-53
	2025-2034	9	**11**	15	-27	**-27**	-27	-34	**-37**	-39	0	**0**	0	0	**0**	0	23	**27**	31	-43	**-48**	-53
	2035-2045	8	**10**	13	-27	**-27**	-27	-32	**-34**	-36	0	**0**	0	0	**0**	0	25	**30**	34	-41	**-46**	-52
S2I	2015-2024	16	**19**	25	-17	**-18**	-19	-15	**-20**	-23	0	**0**	0	0	**0**	0	20	**24**	28	-39	**-44**	-50
	2025-2034	18	**23**	31	-17	**-18**	-18	-4	**-13**	-18	0	**0**	0	0	**0**	0	22	**26**	30	-38	**-43**	-48
	2035-2045	17	**23**	33	-17	**-18**	-18	-5	**-13**	-17	0	**0**	0	0	**0**	0	22	**27**	32	-39	**-43**	-49
S2H	2015-2024	8	**10**	13	-17	**-17**	-17	-26	**-29**	-31	0	**0**	0	0	**0**	0	20	**24**	28	-40	**-45**	-50
	2025-2034	9	**11**	15	-17	**-17**	-17	-20	**-24**	-26	0	**0**	0	0	**0**	0	22	**26**	31	-39	**-43**	-48
	2035-2045	8	**10**	13	-17	**-17**	-18	-20	**-22**	-24	0	**0**	0	0	**0**	0	23	**28**	33	-38	**-42**	-47
S3I	2015-2024	16	**19**	25	-16	**-16**	-16	-12	**-18**	-22	0	**0**	0	0	**0**	0	20	**24**	28	-39	**-44**	-50
	2025-2034	18	**23**	31	-16	**-16**	-16	-3	**-11**	-16	0	**0**	0	0	**0**	0	21	**25**	30	-37	**-42**	-47
	2035-2045	17	**23**	33	-16	**-16**	-16	-3	**-11**	-15	0	**0**	0	0	**0**	0	22	**26**	31	-38	**-43**	-48
S3H	2015-2024	8	**10**	13	-16	**-16**	-16	-25	**-28**	-29	0	**0**	0	0	**0**	0	20	**24**	28	-40	**-44**	-49
	2025-2034	9	**11**	15	-16	**-16**	-16	-19	**-23**	-25	0	**0**	0	0	**0**	0	22	**26**	30	-38	**-43**	-48
	2035-2045	8	**10**	13	-16	**-16**	-16	-18	**-21**	-23	0	**0**	0	0	**0**	0	23	**28**	32	-37	**-42**	-47
S4I	2015-2024	16	**19**	25	-12	**-12**	-12	-7	**-13**	-17	0	**0**	0	0	**0**	0	20	**24**	28	-38	**-43**	-49
	2025-2034	18	**23**	31	-12	**-12**	-12	2	**-6**	-10	0	**0**	0	0	**0**	0	21	**25**	29	-36	**-41**	-46
	2035-2045	17	**23**	33	-12	**-12**	-12	1	**-6**	-11	0	**0**	0	0	**0**	0	21	**25**	30	-36	**-41**	-47
S4H	2015-2024	8	**10**	13	-12	**-12**	-12	-20	**-23**	-24	0	**0**	0	0	**0**	0	20	**24**	28	-39	**-43**	-48
	2025-2034	9	**11**	15	-12	**-12**	-12	-14	**-18**	-20	0	**0**	0	0	**0**	0	21	**25**	30	-37	**-41**	-46
	2035-2045	8	**10**	13	-12	**-12**	-12	-14	**-16**	-18	0	**0**	0	0	**0**	0	22	**27**	31	-35	**-40**	-45
S5I	2015-2024	16	**19**	25	-65	**-65**	-65	-46	**-53**	-57	0	**0**	0	0	**0**	0	29	**34**	39	-35	**-39**	-45
	2025-2034	18	**23**	31	-65	**-65**	-65	-28	**-37**	-43	0	**0**	0	0	**0**	0	35	**40**	45	-29	**-34**	-39
	2035-2045	17	**23**	33	-65	**-65**	-65	-23	**-32**	-38	0	**0**	0	0	**0**	0	38	**44**	49	-29	**-33**	-38
S5H	2015-2024	8	**10**	13	-65	**-65**	-65	-59	**-62**	-64	0	**0**	0	0	**0**	0	29	**34**	38	-35	**-40**	-44
	2025-2034	9	**11**	15	-65	**-65**	-65	-44	**-49**	-52	0	**0**	0	0	**0**	0	36	**41**	46	-31	**-35**	-39
	2035-2045	8	**10**	13	-65	**-65**	-65	-39	**-42**	-45	0	**0**	0	0	**0**	0	40	**45**	51	-28	**-32**	-37
S6I	2015-2024	16	**19**	25	-94	**-94**	-95	-66	**-73**	-78	0	**0**	0	0	**0**	0	35	**40**	45	-33	**-37**	-42
	2025-2034	18	**23**	31	-93	**-94**	-95	-43	**-52**	-58	0	**0**	0	0	**0**	0	44	**50**	55	-26	**-30**	-35
	2035-2045	17	**23**	33	-93	**-93**	-94	-36	**-45**	-51	0	**0**	0	0	**0**	0	49	**55**	61	-25	**-28**	-33
S6H	2015-2024	8	**10**	13	-94	**-94**	-94	-79	**-83**	-85	0	**0**	0	0	**0**	0	35	**40**	45	-33	**-38**	-42
	2025-2034	9	**11**	15	-93	**-93**	-94	-59	**-64**	-67	0	**0**	0	0	**0**	0	45	**50**	56	-27	**-31**	-36
	2035-2045	8	**10**	13	-92	**-93**	-94	-51	**-55**	-58	0	**0**	0	0	**0**	0	50	**56**	62	-24	**-28**	-32

B. First and average groundwater level decline RCL exceedances for each scenario

Table 4.4. Potential 1 m groundwater level decline RCL

Obswell	S1		S2		S3		S4		S5		S6	
	First	*Average*	*First*	*Average*	*First*	*Average*	*First*	*Average*	*First*	*Average*	*First*	*Average*
ARC10	2021	2030										
ARC12	2016	2016	2024									
ARC13	2016	2016	2016	2039								
ARC4	2016	2016	2042									
ARC5	2016	2016	2016									
ARC6	2016	2016	2039									
ARC7	2016	2016	2039									
ARC8	2016	2016	2016									
ARC9	2016	2016	2039									
BMA10	2025	2031	2029	2041	2030	2042	2036		2027	2036	2026	2033
BMA11	2023	2025	2028	2035	2028	2036	2032	2042	2026	2032	2026	2030
BMA9	2026	2033	2029	2042	2031	2043	2037		2029	2039	2028	2037
CAN1	2023	2023	2025	2028	2026	2028	2028	2031	2020	2020	2018	2019
CAN103	2023	2023	2026	2028	2026	2028	2028	2033	2020	2020	2018	2018
CAN104	2022	2023	2026	2029	2027	2030	2030	2036	2020	2020	2019	2019
CAN11	2022	2022	2027	2031	2028	2033	2033	2040	2021	2022	2020	2020
CAN12	2022	2023	2030	2034	2031	2037	2038		2022	2024	2021	2021
CAN13	2022	2023	2026	2027	2026	2027	2027	2029	2018	2019	2017	2018
CAN14	2022	2023	2026	2029	2027	2030	2030	2036	2019	2020	2018	2018
CAN15	2022	2023	2027	2030	2028	2031	2033	2041	2021	2021	2019	2020
CAN16	2023	2025	2026	2027	2026	2028	2027	2030	2021	2021	2020	2020
CAN17	2022	2023	2026	2028	2026	2028	2027	2031	2018	2018	2017	2017
CAN18	2020	2021	2034	2039	2035	2041			2029	2032	2027	2028
CAN8	2021	2024	2031	2038	2033	2040			2030	2033	2028	2032
CMB11	2032											
CMB12	2020	2027										
CMB14	2019	2021										
CMB15												
CMB18	2016	2016										
CMB23												
CMB25												

CMB27												
CMB28	2016	2016										
CMB35	2016	2016										
CMB36												
CMB45	2017	2018										
CMB55	2016	2016										
CMB56												
CMB57												
CMB58	2020	2027										
CMB6												
GGL12	2023	2024	2027	2032	2028	2034	2030	2039	2026	2029	2025	2027
GGL14	2025	2026	2029	2032	2030	2034	2033	2038	2028	2030	2027	2029
GGL2	2024	2025	2028	2030	2028	2031	2030	2035	2025	2026	2023	2024
GGL4	2024	2025	2029	2032	2030	2033	2032	2038	2028	2030	2027	2029
LAF1	2036											
LAF17												
LAF18												
LAF2	2032	2039										
LAF3												
LAF30												
LAF34	2037											
LAF35												
LAF36												
LAF37												
LAF38												
LAF4												
LAF6												
LEW1	2029											
MAR1	2016	2016	2016	2016	2016	2016			2016	2016	2016	2016
MAR124	2016	2016	2016	2032	2029				2028		2027	
MAR125	2016	2016	2016	2016	2016	2016			2016	2016	2016	2016
MAR25	2016	2016	2019		2031				2030		2030	
MAR26	2017	2017	2027		2031				2029		2028	
MAR27	2017	2018	2031		2034				2033		2033	
MAR30	2032	2042	2038						2041		2040	
MAR31	2019	2019	2028	2040	2031				2030		2029	
MAR32	2020	2025	2030		2033				2032		2032	

MAR33	2024	2028	2032		2034				2033		2033	
MAR4	2020	2024	2030		2033				2032		2032	
MAR67	2030	2038	2037		2039				2038		2038	
MAR68	2028	2032	2034		2036				2036		2035	
MAR69	2029	2036	2036		2038				2037		2037	
MAR70	2029	2036	2035		2037				2036		2036	
MAR79	2032	2039	2037		2038				2038		2038	
MAR80	2033											
MAR81	2026	2030	2034		2036				2035		2035	
MCA10	2023	2024	2030	2032	2031	2034	2040	2045	2026	2027	2024	2025
MCA2	2017	2017	2027	2027	2028	2030	2034	2038	2026	2027	2025	2026
MCA3	2016	2016	2023	2024	2025	2027	2032	2035	2024	2025	2024	2025
MCA5	2018	2018	2027	2029	2029	2031	2036	2040	2027	2029	2026	2028
MCA6	2018	2018	2025	2027	2026	2028	2030	2033	2024	2025	2024	2024
MCA7	2019	2020	2027	2028	2028	2030	2035	2039	2025	2026	2025	2025
MCA8	2020	2020	2027	2029	2028	2030	2033	2037	2025	2026	2024	2025
MCA9	2019	2019	2027	2029	2028	2030	2034	2038	2025	2026	2024	2025
MKN1	2022	2023	2028	2031	2029	2032	2034	2040	2027	2029	2027	2028
MKN11	2023	2024	2029	2032	2030	2033	2034	2045	2026	2028	2025	2027
MKN12	2023	2024	2029	2033	2030	2034	2034	2043	2027	2030	2026	2028
MKN15	2016	2016	2016	2019	2018	2021	2026	2030	2018	2021	2018	2021
MKN17	2017	2017	2023	2024	2026	2028	2034	2038	2025	2027	2025	2027
MKN18	2021	2021	2026	2027	2026	2028	2030	2033	2025	2026	2024	2025
MKN19	2017	2018	2024	2027	2027	2029	2035	2040	2026	2028	2026	2027
MKN2	2016	2016	2019	2021	2020	2022	2024	2027	2020	2021	2020	2021
MKN20	2024	2025	2037	2045	2038		2043		2035	2041	2034	2038
MKN21	2021	2021	2027	2030	2029	2031	2034	2038	2027	2028	2026	2028
MKN23	2023	2024	2029	2033	2030	2034	2034	2043	2027	2030	2026	2028
MKN4	2019	2019	2027	2029	2028	2031	2034	2039	2026	2028	2026	2027
MKN6	2024	2025	2038		2039		2044		2035	2041	2034	2038
MKN8	2024	2025	2033	2039	2034	2040	2038		2031	2034	2030	2032
PAR28	2023	2032	2044						2041		2039	
PAR29	2016	2016	2016	2038	2030				2029		2029	
PAR33	2030	2042	2037		2038		2043		2033		2031	2042
PAR36	2026	2041	2042						2033		2029	2041
PAR39	2027	2044	2038		2040				2023	2032	2021	2023
PAR43	2016	2016	2016	2039	2033				2031		2031	

PEC10												
PEC11												
PEC12												
PEC13												
PEC14												
PEC15												
PEC16												
PEC17												
PEC18												
PEC19												
PEC20												
PEC21												
PEC22	2032											
PEC39												
PEC40												
PEC41												
PEC42												
PEC54												
PEC55												
PEC56												
PEC57												
PEC58												
PEC6												
PEC61												
PEC62												
PEC63												
PEC9												
PET102	2020	2021	2034	2043	2038				2032	2035	2030	2033
PET103	2031	2034							2041		2038	2041
PET104	2026	2027	2037	2044	2040				2029	2033	2027	2029
PET105	2022	2023	2026	2030	2027	2030	2031	2041	2020	2021	2019	2019
PET14	2019	2021	2034	2040	2036				2031	2034	2029	2032
PET15	2020	2021	2027	2031	2028	2032	2034		2021	2021	2019	2019
PET17	2023	2024	2027	2030	2028	2032	2033	2041	2021	2022	2020	2020
PET2	2023	2024	2034	2040	2037	2042			2028	2031	2026	2027
PET4	2027	2029	2040						2035	2039	2032	2035
PET6	2028	2031	2039						2038		2036	2040

PET8	2018	2018	2034	2042	2036				2032	2035	2031	2034
PET9	2023	2027	2039						2034	2039	2031	2035
PRK1												
PRK10												
PRK15												
PRK16												
PRK17												
PRK18												
PRK19												
PRK20												
PRK21												
PRK22												
PRK23												
PRK24												
PRK25												
PRK26												
PRK27												
PRK28												
PRK29												
PRK3												
PRK30												
PRK31												
PRK33	2038											
PRK34	2033											
PRK35	2038											
PRK36												
PRK37												
PRK39												
PRK4												
PRK40												
PRK41												
PRK42												
PRK47	2036											
PRK48	2038											
PRK49												
PRK5												
PRK6												

PRK7												
PRK8												
PRK9												
SEN101	2024	2025	2027	2030	2028	2031	2029	2032	2018	2018	2017	2017
SEN12	2024	2025	2028	2031	2028	2031	2029	2033	2018	2018	2017	2017
SEN13	2022	2023	2026	2028	2026	2028	2027	2029	2019	2020	2018	2019
SEN14	2020	2021	2028	2032	2028	2032	2029	2033	2019	2019	2018	2018
SEN15	2023	2024	2026	2029	2026	2029	2027	2030	2020	2020	2019	2019
SEN2	2024	2025	2027	2030	2027	2030	2027	2031	2020	2020	2018	2019
SEN3	2024	2025	2026	2029	2026	2029	2027	2030	2020	2020	2019	2019
SEN4	2023	2024	2026	2028	2026	2028	2027	2030	2021	2022	2020	2020
SEN5	2031	2035	2036	2043	2036	2043	2038		2022	2023	2021	2021
SEN6	2025	2027	2027	2030	2027	2030	2028	2031	2020	2020	2019	2019
SEN8	2022	2023	2026	2027	2026	2028	2027	2029	2019	2019	2018	2018
SEN9	2024	2025	2027	2031	2027	2031	2028	2032	2020	2021	2019	2019
SHG2	2038	2042	2042		2043				2022	2023	2020	2020
SHG4	2026	2027	2027	2028	2029	2031	2036	2041	2022	2023	2021	2021
SHG5	2025	2026	2028	2029	2029	2031	2035	2039	2022	2023	2021	2021
SHG7	2036	2038							2023	2024	2019	2019
STR11	2021	2029										
STR110	2025	2033										
STR111	2020	2026	2042									
STR112	2016	2017	2039									
STR113	2021	2026	2041									
STR114	2018	2020	2016								2040	
STR115	2023	2030										
STR116	2019	2021										
STR117	2023	2028	2042								2043	
STR118	2018	2020	2041									
STR119	2023	2028	2041						2040		2037	2043
STR12	2019	2021	2041									
STR120	2026	2034										
STR121	2025	2033										
STR122	2026	2034										
STR123	2024	2033										
STR124	2026	2034										
STR125	2026	2034										

STR126	2018	2020	2041									
STR127	2018	2020	2041									
STR128	2018	2020	2041									
STR13	2021	2026	2042								2045	
STR133	2019	2020	2041								2044	
STR134	2020	2026	2042									
STR14	2026	2034										
STR15	2018	2020	2016						2041		2038	
STR16	2020	2023	2039						2043		2040	
STR17	2023	2029									2045	
STR18	2028	2037										
STR19	2021	2029	2041									
STR2	2033	2044										
STR20	2029	2038										
STR21	2019	2021	2041									
STR22	2029	2038										
STR23	2019	2020										
STR24	2021	2028										
STR25	2021	2028										
STR5	2022	2027	2037		2042				2019	2021	2017	2017
STR8	2021	2028									2040	
STR9	2020	2028										
TAT10	2022	2023	2025	2027	2025	2028	2029	2035	2022	2023	2021	2022
TAT105	2025	2027	2027	2030	2028	2030	2028	2032	2022	2022	2020	2021
TAT106	2030	2033	2035	2041	2035	2042	2037		2023	2025	2021	2022
TAT107	2016	2016	2016	2019	2017	2018	2020	2022	2017	2018	2017	2017
TAT108	2022	2022	2024	2025	2025	2026	2027	2032	2023	2023	2022	2022
TAT111	2022	2022	2025	2028	2026	2031	2031	2040	2022	2024	2021	2022
TAT15	2022	2022	2025	2027	2026	2029	2029	2039	2024	2025	2023	2024
TAT18	2019	2020	2021	2027	2027	2033	2034		2026	2027	2022	2026
TAT20	2029	2032	2033	2037	2033	2038	2036	2044	2024	2025	2022	2023
TAT21	2023	2025	2026	2029	2027	2029	2028	2030	2021	2022	2020	2021
TAT23	2028	2031	2032	2037	2032	2037	2033	2040	2018	2019	2017	2017
TAT24	2024	2025	2026	2028	2027	2029	2029	2032	2023	2024	2021	2022
TAT25	2023	2025	2026	2029	2027	2029	2028	2030	2021	2022	2020	2020
TAT26	2021	2023	2025	2028	2026	2031	2031	2041	2022	2025	2021	2022
TAT28	2020	2021	2027	2030	2028	2034	2034		2026	2027	2024	2026

TAT4	2019	2020	2026	2030	2027	2034	2034		2026	2028	2026	2027
TAT9	2021	2021	2027	2031	2028	2034	2034		2026	2028	2025	2026
WLL104	2016	2016	2016	2017	2017	2017			2017	2017	2017	2017
WLL105	2020	2026										
WLL106	2024	2028										
WLL107	2023	2029										
WLL108	2023	2029	2042									
WLL109	2030	2039	2042						2035		2033	2045
WLL13	2027	2035	2034		2037				2021	2023	2019	2020
WLL15	2030	2036										
WLL16	2020	2027										
WLL17	2019	2019	2029	2038	2032				2031		2031	2045
WLL18	2026	2032										
WLL19	2023	2029	2038						2042		2041	
WLL2	2022	2028										
WLL20	2020	2025	2032		2035				2033		2033	
WLL21	2023	2027										
WLL22	2019	2019										
WLL23	2029	2031										
WLL24												
WLL25	2030	2037										
WLL5	2018	2018										
WLL7	2019	2020										
WLL8	2025	2029	2035		2037				2036		2036	
WRG109	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
WRG11	2019	2020	2029	2037	2032	2040			2029	2034	2028	2033
WRG110	2018	2020	2030	2037	2032	2038			2030	2034	2028	2032
WRG111	2019	2020	2027	2031	2028	2035	2038		2027	2028	2026	2027
WRG112	2019	2020	2029	2037	2031	2040			2029	2034	2028	2032
WRG113	2022	2026	2035		2040				2038		2037	
WRG114	2020	2021	2033	2040	2035				2031	2035	2030	2033
WRG115	2020	2021	2032	2039	2035				2032	2037	2031	2035
WRG116	2019	2019	2021	2032	2028	2037	2039		2026	2031	2023	2027
WRG117	2021	2025	2034		2038				2036		2035	2042
WRG121	2021	2025	2034	2043	2037				2033	2036	2032	2035
WRG122	2028	2032	2039		2045				2035	2045	2033	2040
WRG123	2018	2020	2027	2033	2030	2036			2028	2033	2027	2031

WRG13	2030	2037	2038		2041			2028	2037	2025	2031
WRG16	2022	2024	2027	2034	2028	2038	2036	2025	2028	2023	2026
WRG18	2024	2027	2029	2038	2030	2040	2037	2025	2029	2023	2025
WRG19	2020	2026	2034	2044	2036			2033	2038	2031	2036
WRG20	2026	2039	2037		2039		2044	2023	2025	2021	2022
WRG22	2018	2020	2035		2039			2035	2042	2034	2038
WRG23	2019	2020	2027	2033	2028	2036	2039	2027	2033	2027	2028
WRG26	2030	2037	2036		2038			2016	2016	2016	2016
WRG27	2029	2038	2036		2037		2043	2023	2025	2021	2022
WRG28	2021	2025	2034	2043	2036			2033	2036	2031	2035
WRG29	2028	2032	2037		2042			2039		2038	2045
WRG3	2020	2021	2032	2040	2034			2032	2035	2030	2034
WRG32	2017	2018	2021	2031	2027	2034	2036	2027	2028	2026	2027
WRG35	2017	2018	2021	2031	2027	2034	2035	2026	2028	2026	2027
WRG4	2019	2020	2028	2034	2031	2038		2028	2033	2028	2031
WRG5	2019	2020	2027	2033	2030	2035		2027	2031	2027	2028
WRG8	2019	2020	2030	2038	2032	2040		2030	2034	2029	2033
WRG9	2018	2020	2028	2034	2030	2037		2028	2033	2027	2031
60450											
60475											
75333	2043							2031	2033	2027	2028
75365	2034	2039	2040		2041		2043	2026	2027	2023	2024
75651											
75669											
98254											
98290											
98297								2025	2026	2022	2022
108158											
109768											
116203											
138351								2038	2040	2031	2032
138352											
138353								2034	2036	2029	2031
140675											
140934											
140935											
8001949											

8003861
8003862
8003879
8003961

Table 4.5. Potential 3 m groundwater level decline RCL

Obswell	S1		S2		S3		S4		S5		S6	
	First	*Average*	*First*	*Average*	*First*	*Average*	*First*	*Average*	*First*	*Average*	*First*	*Average*
ARC10												
ARC12												
ARC13												
ARC4												
ARC5												
ARC6												
ARC7												
ARC8												
ARC9												
BMA10												
BMA11	2043											
BMA9												
CAN1	2039	2042							2033	2035	2028	2029
CAN103	2039	2042							2033	2035	2027	2029
CAN104	2038	2041							2032	2035	2027	2028
CAN11	2036	2040							2035	2038	2030	2032
CAN12	2039	2044							2039	2044	2034	2036
CAN13	2038	2040							2027	2029	2023	2024
CAN14	2036	2039							2031	2033	2026	2027
CAN15	2039	2042							2036	2039	2031	2032
CAN16	2041	2044							2032	2033	2028	2029
CAN17	2038	2040							2027	2028	2023	2023
CAN18	2037	2042									2043	
CAN8	2035	2040									2045	
CMB11												
CMB12												

CMB14				
CMB15				
CMB18				
CMB23				
CMB25				
CMB27				
CMB28				
CMB35				
CMB36				
CMB45				
CMB55				
CMB56				
CMB57				
CMB58				
CMB6				
GGL12	2042			2044
GGL14				
GGL2				2043
GGL4				
LAF1				
LAF17				
LAF18				
LAF2				
LAF3				
LAF30				
LAF34				
LAF35				
LAF36				
LAF37				
LAF38				
LAF4				
LAF6				
LEW1				
MAR1	2017	2017	2034	2042
MAR124	2017	2018		
MAR125	2019	2021	2037	
MAR25	2020	2023		

MAR26	2033					
MAR27	2032					
MAR30						
MAR31	2032					
MAR32	2037					
MAR33						
MAR4	2036					
MAR67						
MAR68						
MAR69						
MAR70						
MAR79						
MAR80						
MAR81						
MCA10	2045				2040	2041
MCA2	2027	2029			2043	2045
MCA3	2021	2023			2042	2045
MCA5	2029	2031			2045	
MCA6	2029	2030	2044		2040	2042
MCA7	2035	2037			2040	2042
MCA8	2033	2035	2043		2039	2041
MCA9	2033	2035	2044		2039	2041
MKN1	2038	2041				
MKN11	2042					
MKN12	2041	2045				
MKN15	2025	2027			2043	
MKN17	2029	2031				
MKN18	2034	2036			2042	2045
MKN19	2028	2030				
MKN2	2017	2020	2040	2044	2037	2040
MKN20						
MKN21	2034	2037				
MKN23	2041	2045				
MKN4	2031	2033			2044	
MKN6						
MKN8	2045					
PAR28						

PAR29	2022	2026				
PAR33						
PAR36						
PAR39					2043	
PAR43	2019	2023				
PEC10						
PEC11						
PEC12						
PEC13						
PEC14						
PEC15						
PEC16						
PEC17						
PEC18						
PEC19						
PEC20						
PEC21						
PEC22						
PEC39						
PEC40						
PEC41						
PEC42						
PEC54						
PEC55						
PEC56						
PEC57						
PEC58						
PEC6						
PEC61						
PEC62						
PEC63						
PEC9						
PET102	2039					
PET103						
PET104						
PET105	2038	2042	2037	2041	2030	2033
PET14	2037	2042				

PET15	2037	2042	2040	2045	2033	2035
PET17	2040	2044	2039	2043	2033	2035
PET2					2044	
PET4						
PET6						
PET8	2034	2039				
PET9						
PRK1						
PRK10						
PRK15						
PRK16						
PRK17						
PRK18						
PRK19						
PRK20						
PRK21						
PRK22						
PRK23						
PRK24						
PRK25						
PRK26						
PRK27						
PRK28						
PRK29						
PRK3						
PRK30						
PRK31						
PRK33						
PRK34						
PRK35						
PRK36						
PRK37						
PRK39						
PRK4						
PRK40						
PRK41						
PRK42						

PRK47						
PRK48						
PRK49						
PRK5						
PRK6						
PRK7						
PRK8						
PRK9						
SEN101	2045		2027	2028	2022	2023
SEN12	2045		2027	2028	2023	2023
SEN13	2039	2041	2029	2029	2025	2025
SEN14	2042	2045	2029	2030	2024	2025
SEN15	2041	2044	2029	2030	2025	2026
SEN2	2044		2029	2030	2025	2025
SEN3	2042		2030	2031	2026	2026
SEN4	2041	2043	2033	2035	2029	2030
SEN5			2041	2044	2033	2034
SEN6			2032	2034	2027	2028
SEN8	2038	2040	2028	2029	2024	2025
SEN9	2045		2031	2033	2027	2027
SHG2			2042	2045	2032	2033
SHG4			2038	2040	2032	2033
SHG5			2037	2038	2032	2033
SHG7					2039	2040
STR11						
STR110						
STR111						
STR112						
STR113						
STR114						
STR115						
STR116						
STR117						
STR118						
STR119	2041					
STR12						
STR120						

STR121								
STR122								
STR123								
STR124								
STR125								
STR126								
STR127								
STR128								
STR13								
STR133								
STR134								
STR14								
STR15	2041							
STR16	2040							
STR17								
STR18								
STR19								
STR2								
STR20								
STR21								
STR22								
STR23								
STR24								
STR25								
STR5	2043						2034	
STR8								
STR9								
TAT10	2036	2039			2037	2042	2034	2037
TAT105					2039	2042	2032	2034
TAT106							2040	2044
TAT107	2018	2018	2039	2043	2031	2033	2028	2030
TAT108	2038	2042			2041		2037	2041
TAT111	2035	2040			2038		2035	2039
TAT15	2039	2044			2044		2040	2045
TAT18	2031	2036			2038		2035	2040
TAT20							2044	
TAT21	2044				2037	2040	2031	2033

TAT23							2038	2043	2028	2030
TAT24	2044						2043		2037	2039
TAT25	2043						2035	2036	2030	2030
TAT26	2035	2040					2039		2035	2040
TAT28	2033	2038					2040		2037	2042
TAT4	2031	2036					2039		2036	2042
TAT9	2033	2038					2040		2037	2042
WLL104	2019	2019	2029	2039	2034		2032		2032	
WLL105	2045									
WLL106										
WLL107										
WLL108										
WLL109										
WLL13									2042	
WLL15										
WLL16	2045									
WLL17										
WLL18										
WLL19										
WLL2										
WLL20	2035									
WLL21	2040									
WLL22	2037									
WLL23										
WLL24										
WLL25										
WLL5	2036									
WLL7	2039									
WLL8										
WRG109	2028	2033	2016	2016	2016	2018	2016	2018	2016	2018
WRG11	2034	2040								
WRG110	2033	2038								
WRG111	2031	2036					2044		2038	
WRG112	2033	2040								
WRG113	2039									
WRG114	2035	2041								
WRG115	2035	2042								

WRG116	2033	2039	2045		2039	
WRG117	2038					
WRG121	2037					
WRG122						
WRG123	2032	2037			2042	
WRG13						
WRG16	2037	2044	2044		2039	
WRG18	2044				2042	
WRG19	2036					
WRG20					2040	
WRG22	2035	2042				
WRG23	2032	2038	2045		2039	
WRG26			2016	2016	2016	2016
WRG27					2040	
WRG28	2037					
WRG29						
WRG3	2035	2041				
WRG32	2030	2035	2044		2038	
WRG35	2030	2035	2044		2038	
WRG4	2032	2038			2045	
WRG5	2032	2037			2039	
WRG8	2034	2039				
WRG9	2032	2037			2044	
60450						
60475						
75333						
75365						
75651						
75669						
98254						
98290						
98297					2040	2044
108158						
109768						
116203						
138351						
138352						

138353									2034	2036	2029	2031
140675												
140934												
140935												
8001949												
8003861												
8003862												
8003879												
8003961												

Table 4.6. Potential 5 m groundwater level decline RCL

Obswell	S1		S2		S3		S4		S5		S6	
	First	*Average*	*First*	*Average*	*First*	*Average*	*First*	*Average*	*First*	*Average*	*First*	*Average*
ARC10												
ARC12												
ARC13												
ARC4												
ARC5												
ARC6												
ARC7												
ARC8												
ARC9												
BMA10												
BMA11												
BMA9												
CAN1											2040	2042
CAN103											2039	2042
CAN104											2038	2041
CAN11											2041	2045
CAN12												
CAN13									2039	2042	2031	2032
CAN14									2043		2035	2038
CAN15											2044	
CAN16											2037	2039
CAN17									2039	2043	2030	2032

CAN18
CAN8
CMB11
CMB12
CMB14
CMB15
CMB18
CMB23
CMB25
CMB27
CMB28
CMB35
CMB36
CMB45
CMB55
CMB56
CMB57
CMB58
CMB6
GGL12
GGL14
GGL2
GGL4
LAF1
LAF17
LAF18
LAF2
LAF3
LAF30
LAF34
LAF35
LAF36
LAF37
LAF38
LAF4
LAF6
LEW1

MAR1	2033	
MAR124		
MAR125		
MAR25		
MAR26		
MAR27		
MAR30		
MAR31		
MAR32		
MAR33		
MAR4		
MAR67		
MAR68		
MAR69		
MAR70		
MAR79		
MAR80		
MAR81		
MCA10		
MCA2	2043	
MCA3	2035	2041
MCA5		
MCA6	2044	
MCA7		
MCA8		
MCA9		
MKN1		
MKN11		
MKN12		
MKN15	2041	
MKN17		
MKN18		
MKN19		
MKN2	2027	2033
MKN20		
MKN21		
MKN23		

MKN4
MKN6
MKN8
PAR28
PAR29
PAR33
PAR36
PAR39
PAR43
PEC10
PEC11
PEC12
PEC13
PEC14
PEC15
PEC16
PEC17
PEC18
PEC19
PEC20
PEC21
PEC22
PEC39
PEC40
PEC41
PEC42
PEC54
PEC55
PEC56
PEC57
PEC58
PEC6
PEC61
PEC62
PEC63
PEC9
PET102

PET103
PET104
PET105
PET14
PET15
PET17
PET2
PET4
PET6
PET8
PET9
PRK1
PRK10
PRK15
PRK16
PRK17
PRK18
PRK19
PRK20
PRK21
PRK22
PRK23
PRK24
PRK25
PRK26
PRK27
PRK28
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PRK34
PRK35
PRK36
PRK37
PRK39

PRK4				
PRK40				
PRK41				
PRK42				
PRK47				
PRK48				
PRK49				
PRK5				
PRK6				
PRK7				
PRK8				
PRK9				
SEN101	2038	2041	2029	2030
SEN12	2038	2041	2030	2031
SEN13	2040	2042	2032	2033
SEN14	2041	2044	2032	2033
SEN15	2041	2044	2033	2034
SEN2	2042	2044	2033	2034
SEN3	2042	2045	2034	2035
SEN4			2039	2041
SEN5				
SEN6			2037	2040
SEN8	2039	2042	2032	2033
SEN9			2036	2038
SHG2				
SHG4			2045	
SHG5			2043	
SHG7				
STR11				
STR110				
STR111				
STR112				
STR113				
STR114				
STR115				
STR116				
STR117				

STR118				
STR119				
STR12				
STR120				
STR121				
STR122				
STR123				
STR124				
STR125				
STR126				
STR127				
STR128				
STR13				
STR133				
STR134				
STR14				
STR15				
STR16				
STR17				
STR18				
STR19				
STR2				
STR20				
STR21				
STR22				
STR23				
STR24				
STR25				
STR5				
STR8				
STR9				
TAT10				
TAT105				
TAT106				
TAT107	2032	2038	2040	2044
TAT108				
TAT111				

TAT15												
TAT18												
TAT20												
TAT21												
TAT23												
TAT24												
TAT25											2041	2044
TAT26												
TAT28												
TAT4												
TAT9												
WLL104	2023	2028	2039						2042		2041	
WLL105												
WLL106												
WLL107												
WLL108												
WLL109												
WLL13												
WLL15												
WLL16												
WLL17												
WLL18												
WLL19												
WLL2												
WLL20												
WLL21												
WLL22												
WLL23												
WLL24												
WLL25												
WLL5												
WLL7												
WLL8												
WRG109	2043		2034								2045	
WRG11												
WRG110												
WRG111												

WRG112				
WRG113				
WRG114				
WRG115				
WRG116				
WRG117				
WRG121				
WRG122				
WRG123				
WRG13				
WRG16				
WRG18				
WRG19				
WRG20				
WRG22				
WRG23				
WRG26	2018	2019	2016	2016
WRG27				
WRG28				
WRG29				
WRG3				
WRG32				
WRG35				
WRG4				
WRG5				
WRG8				
WRG9				
60450				
60475				
75333				
75365				
75651				
75669				
98254				
98290				
98297				
108158				

109768
116203
138351
138352
138353
140675
140934
140935
8001949
8003861
8003862
8003879
8003961

C. Maps showing average percentage of time exceeding the 1, 3 and 5 m decline RCLs for all scenarios

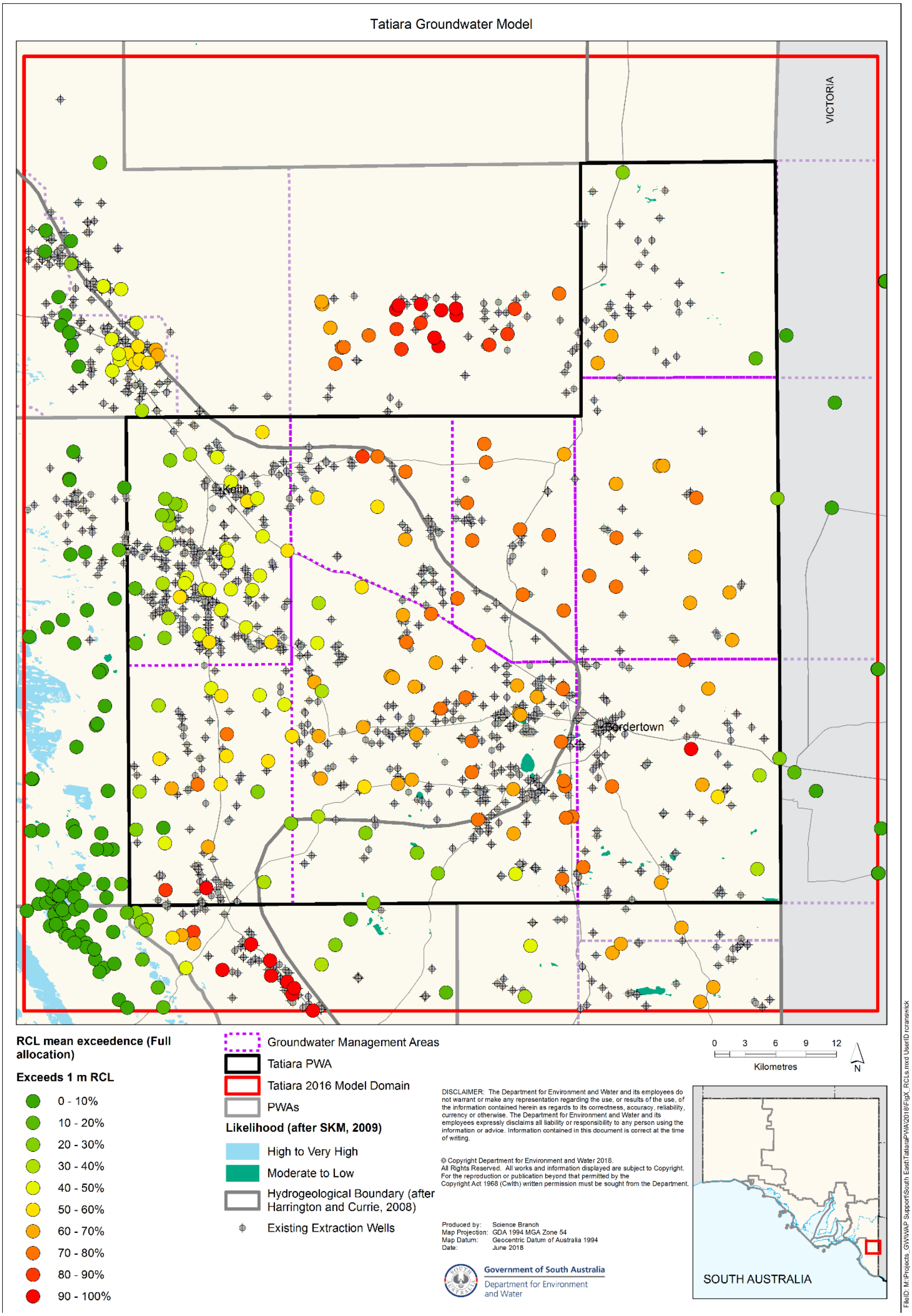

Figure 4.1. Percentage of time the 1 m decline RCL is exceeded for the full allocation extraction scenario

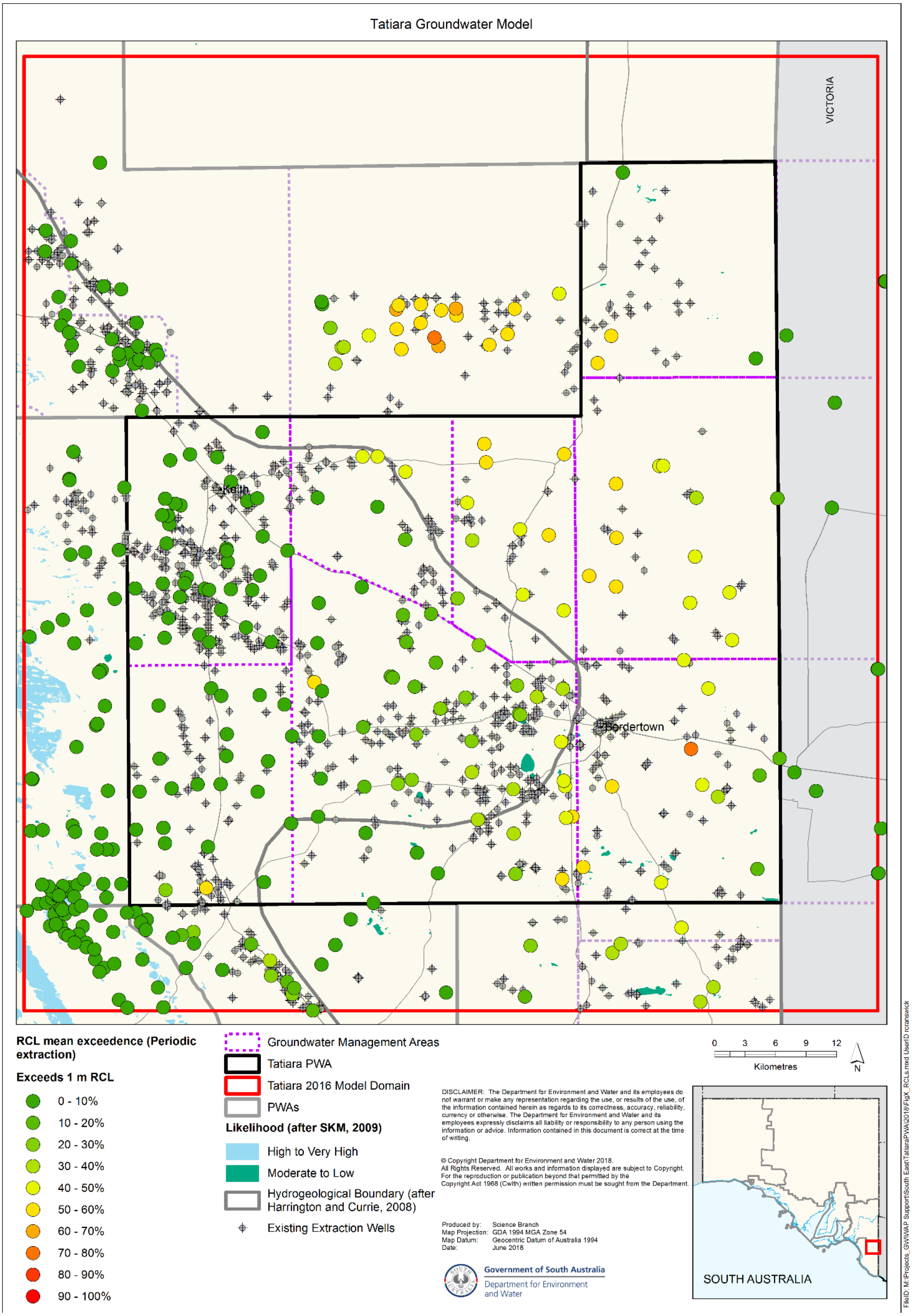

Figure 4.2. Percentage of time the 1 m decline RCL is exceeded for the higher extraction scenario

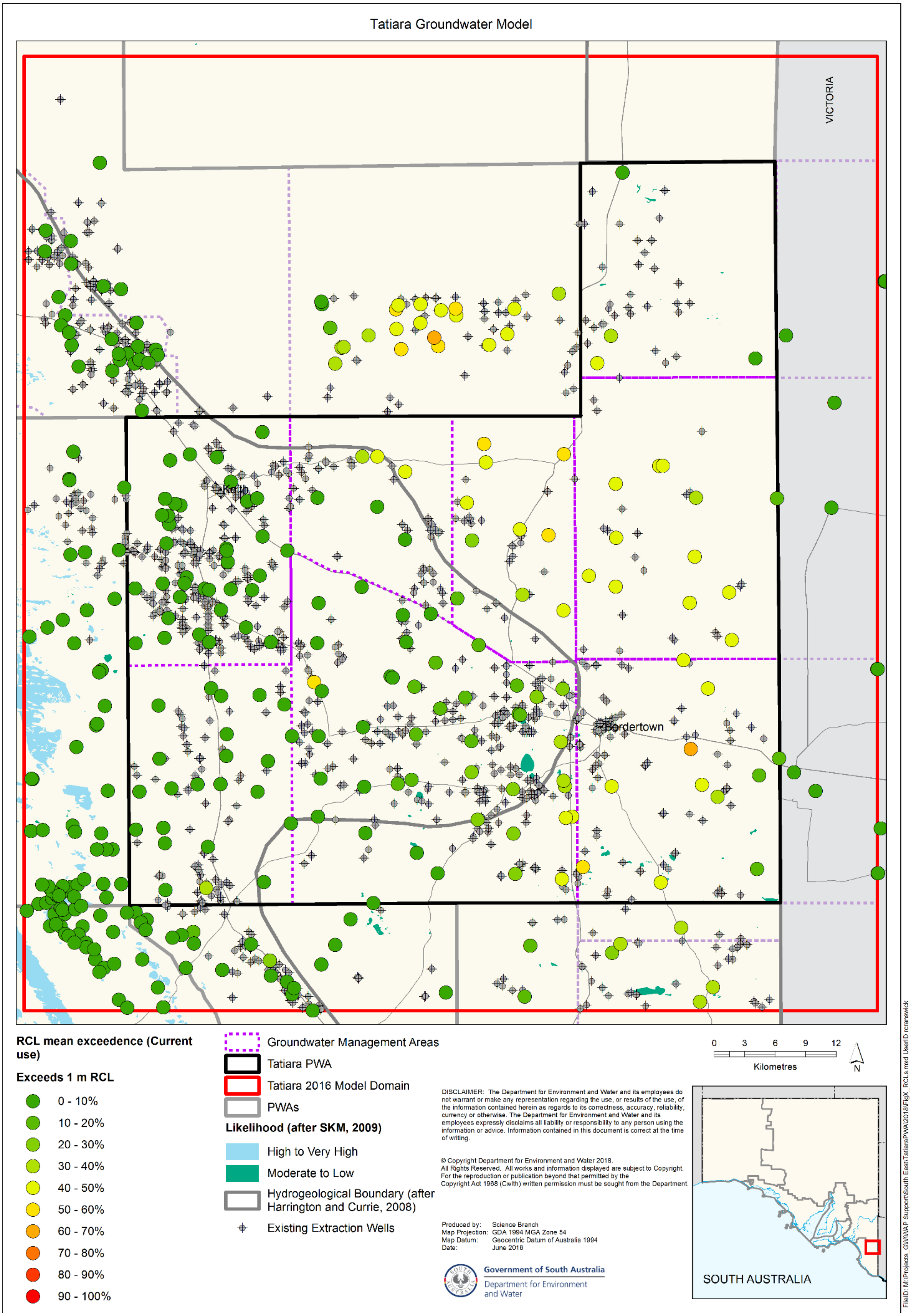

Figure 4.3. Percentage of time the 1 m decline RCL is exceeded for the current extraction scenario

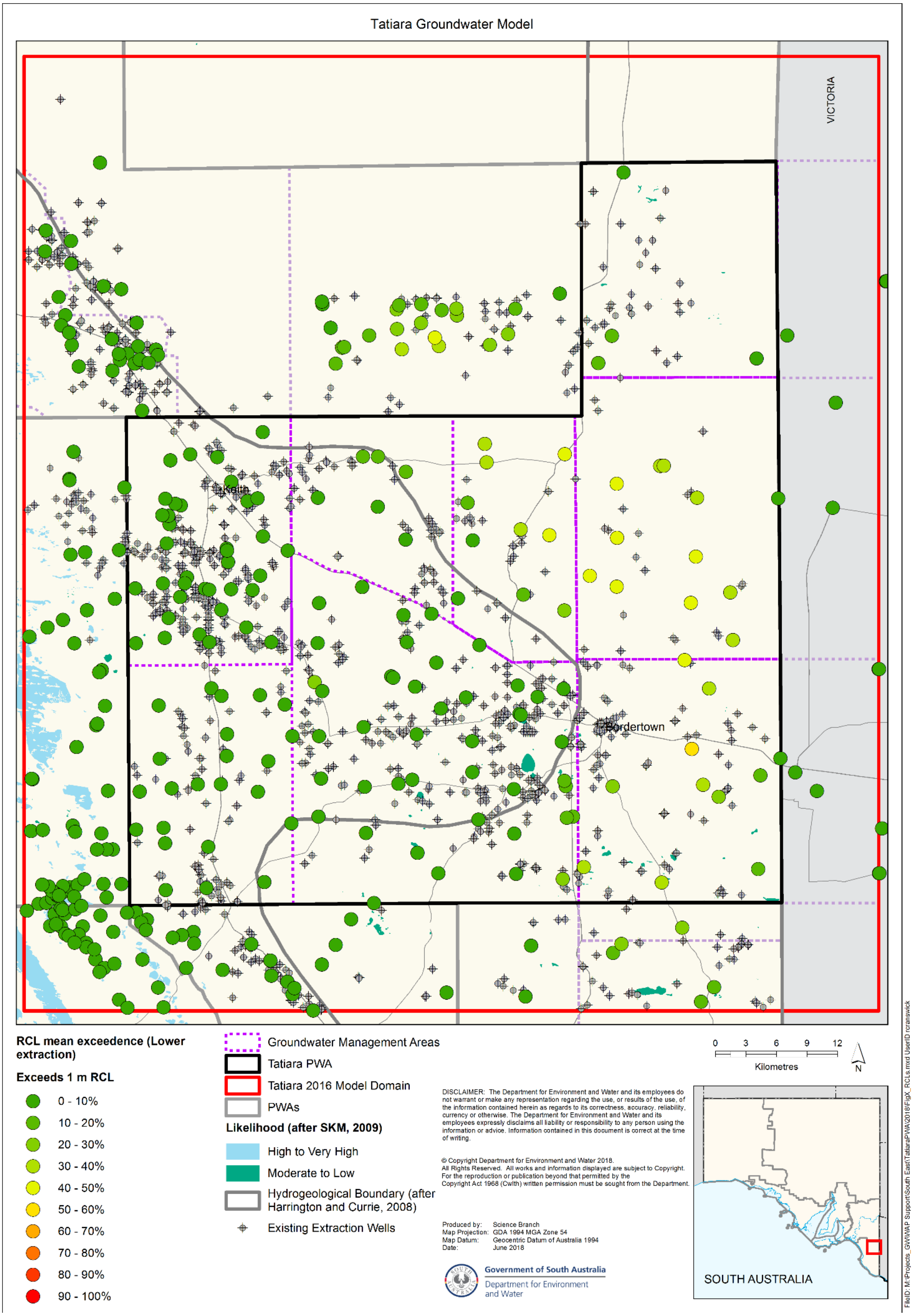

Figure 4.4. Percentage of time the 1 m decline RCL is exceeded for the lower extraction scenario

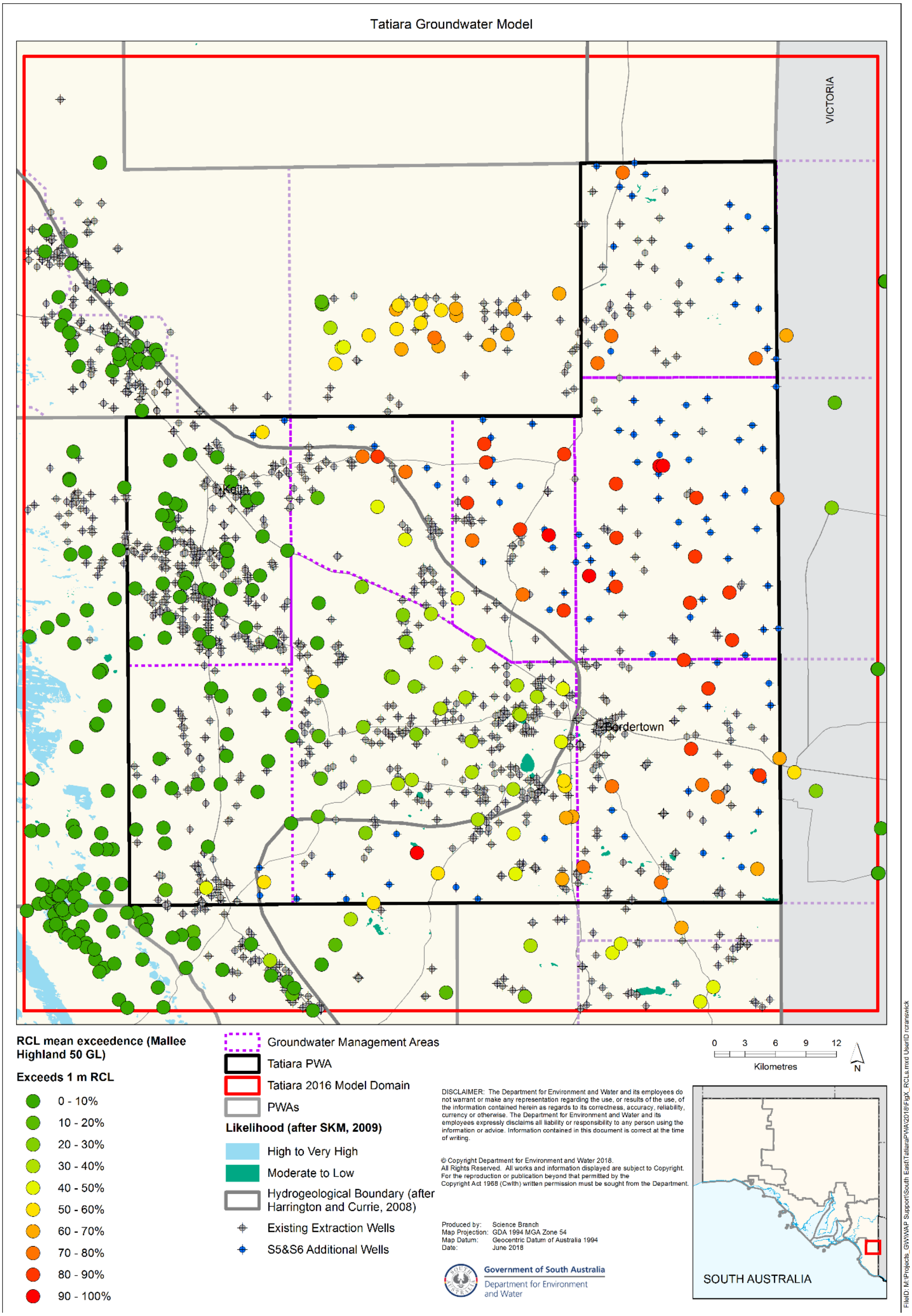

Figure 4.5. Percentage of time the 1 m decline RCL is exceeded for the current extraction scenario plus additional 50 GL/y on the Mallee highlands

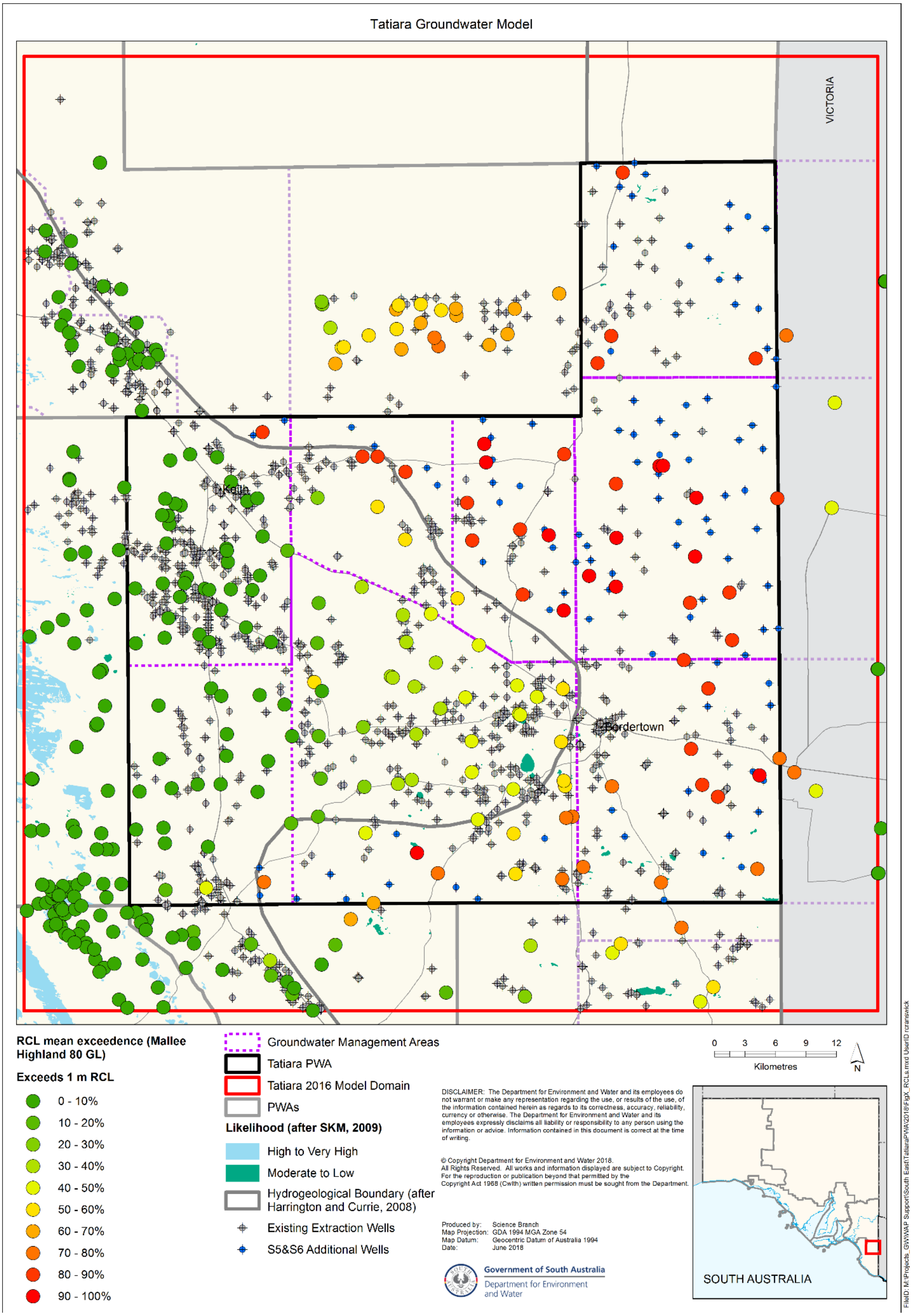

Figure 4.6. Percentage of time the 1 m decline RCL is exceeded for the current extraction scenario plus additional 80 GL/y on the Mallee highlands

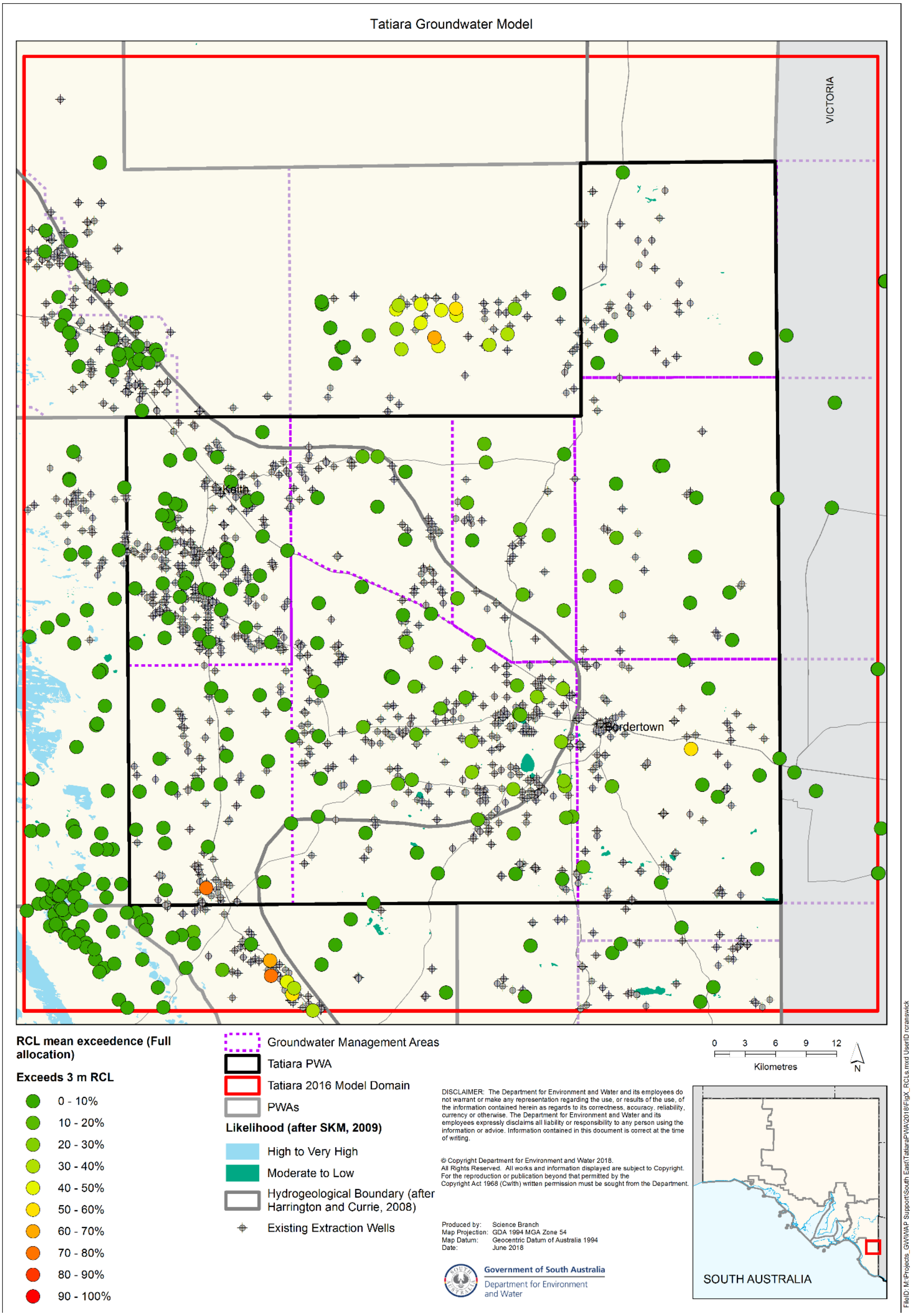

Figure 4.7. Percentage of time the 3 m decline RCL is exceeded for the full allocation extraction scenario

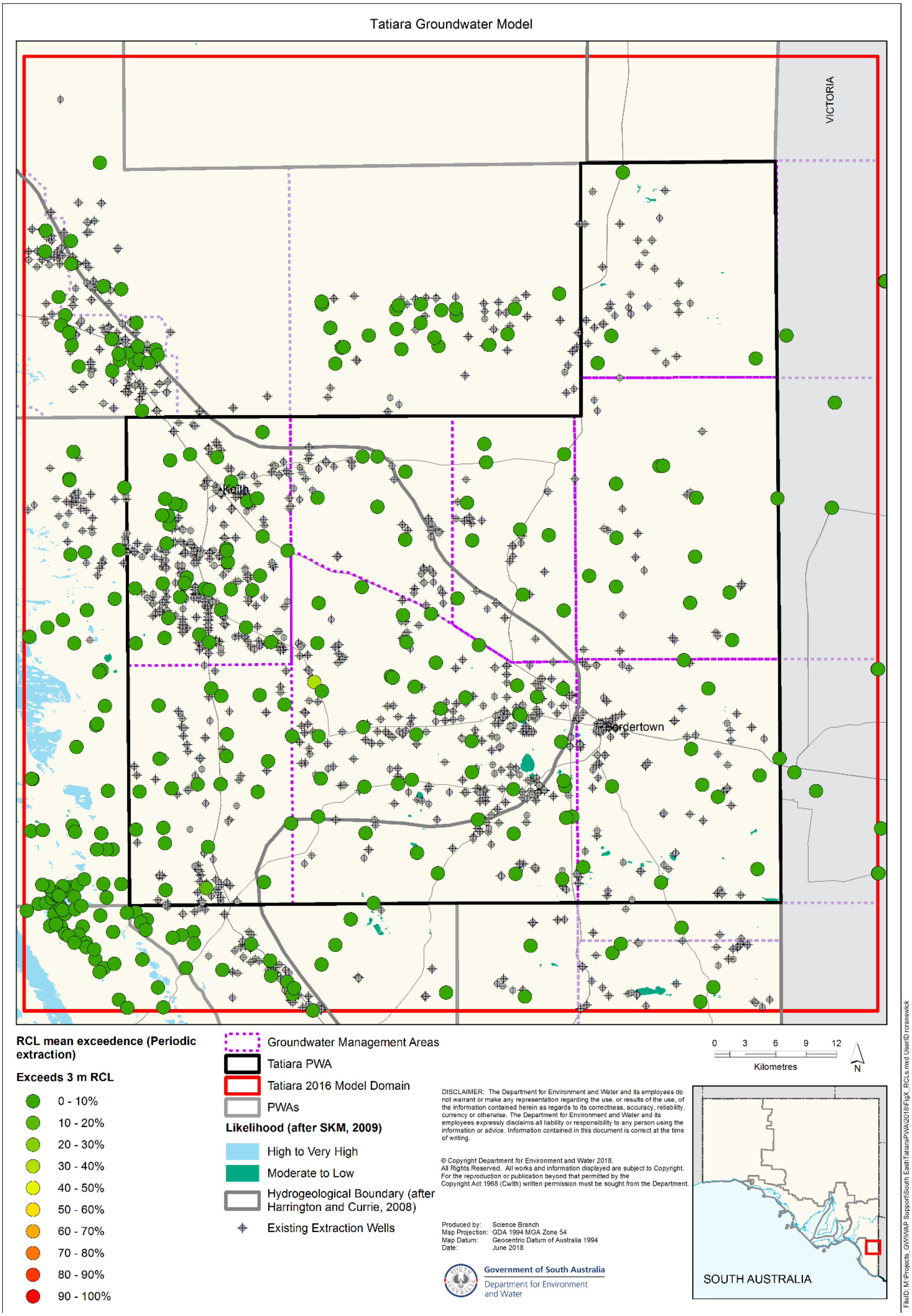

Figure 4.8. Percentage of time the 3 m decline RCL is exceeded for the higher extraction scenario

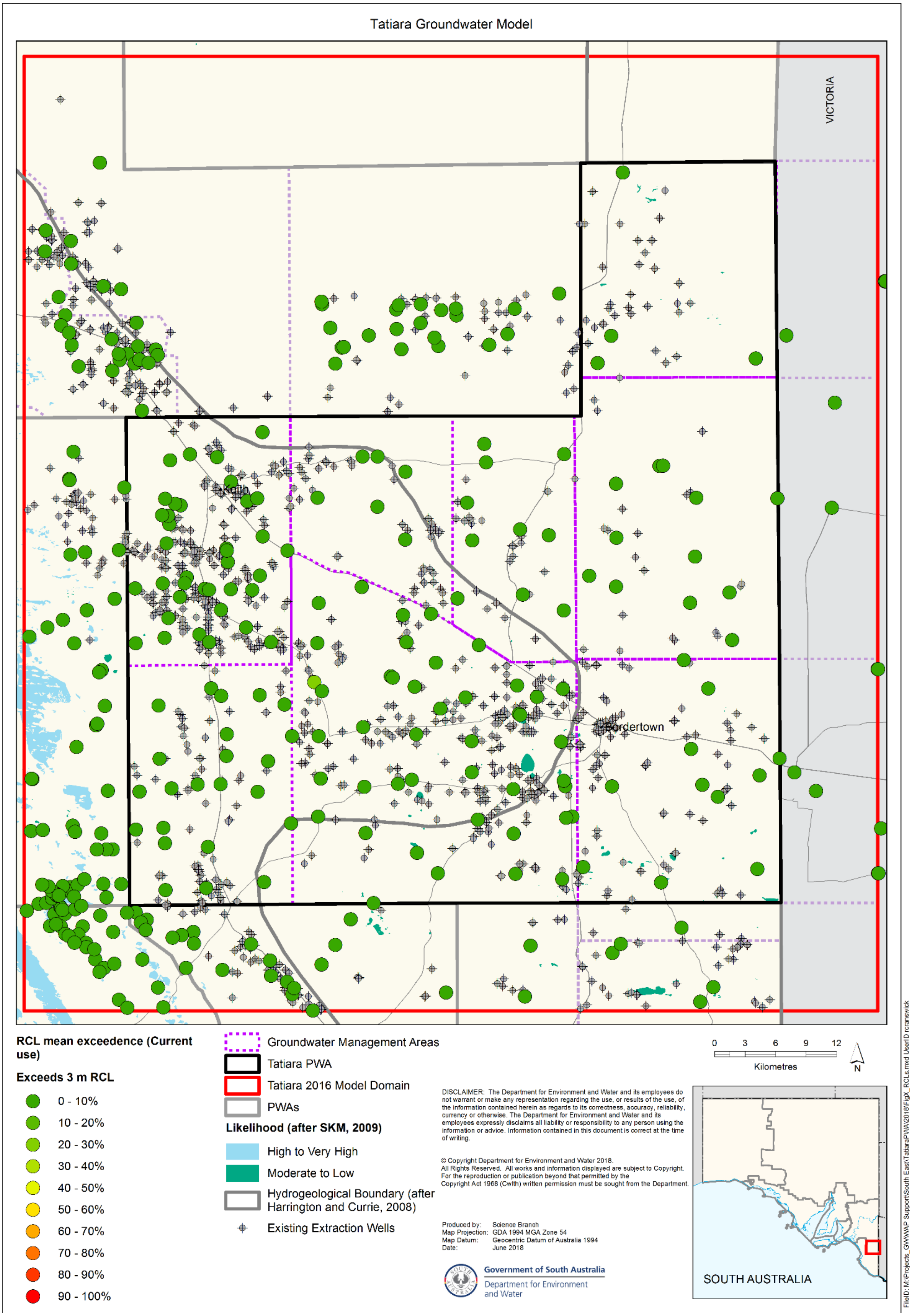

Figure 4.9. Percentage of time the 3 m decline RCL is exceeded for the current extraction scenario

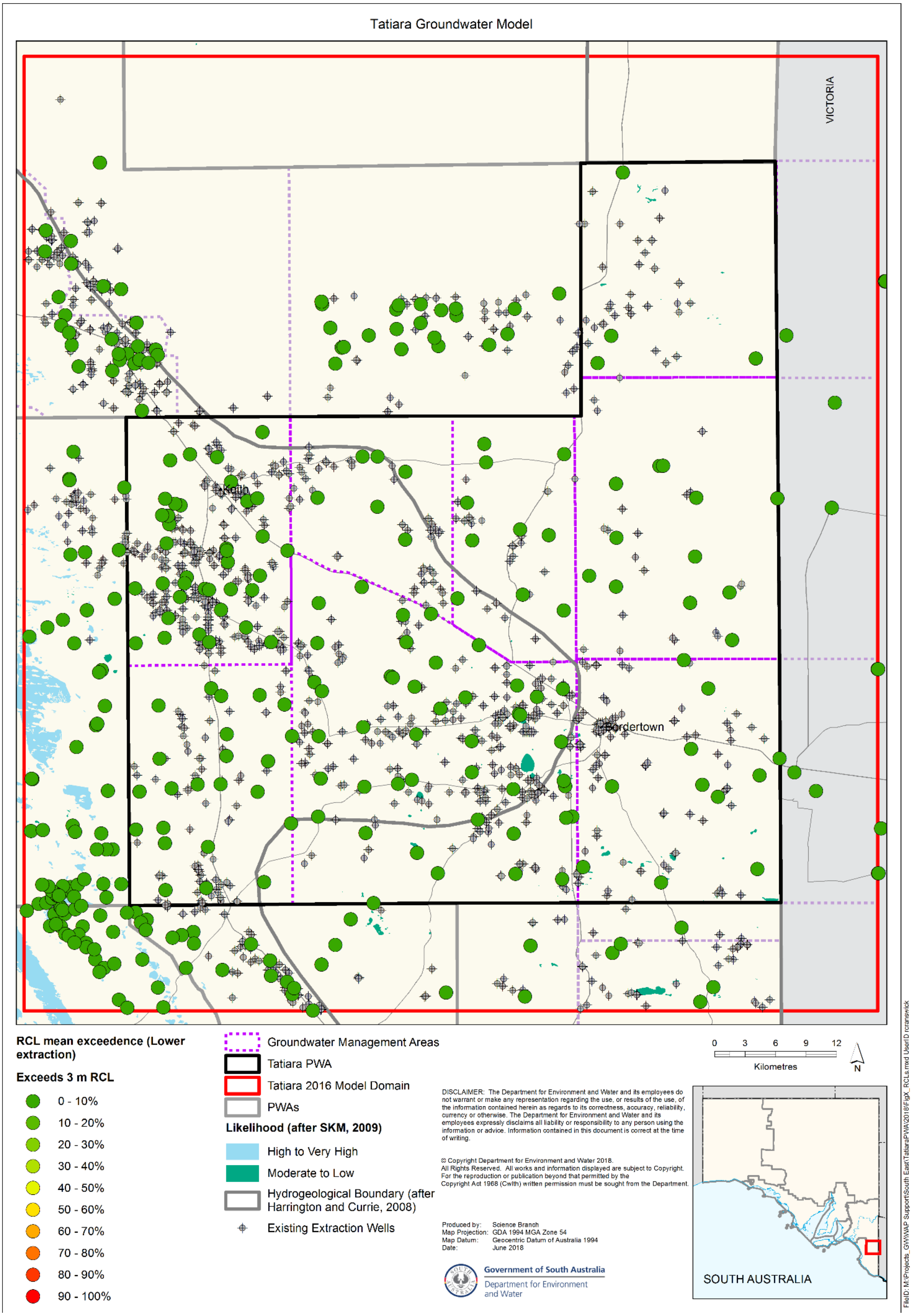

Figure 4.10. Percentage of time the 3 m decline RCL is exceeded for the lower extraction scenario

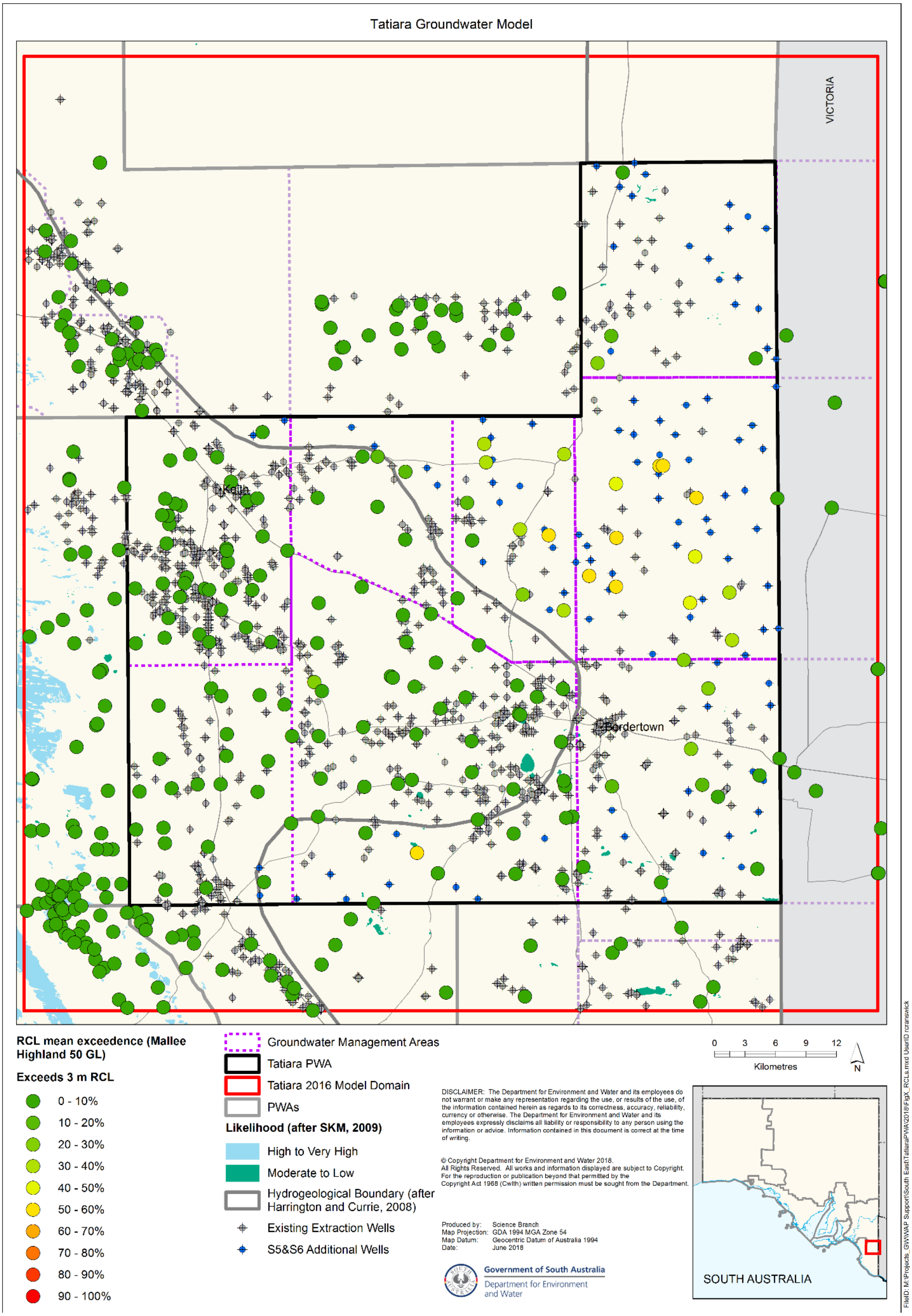

Figure 4.11. Percentage of time the 3 m decline RCL is exceeded for the current extraction scenario plus additional 50 GL/y on the Mallee highlands

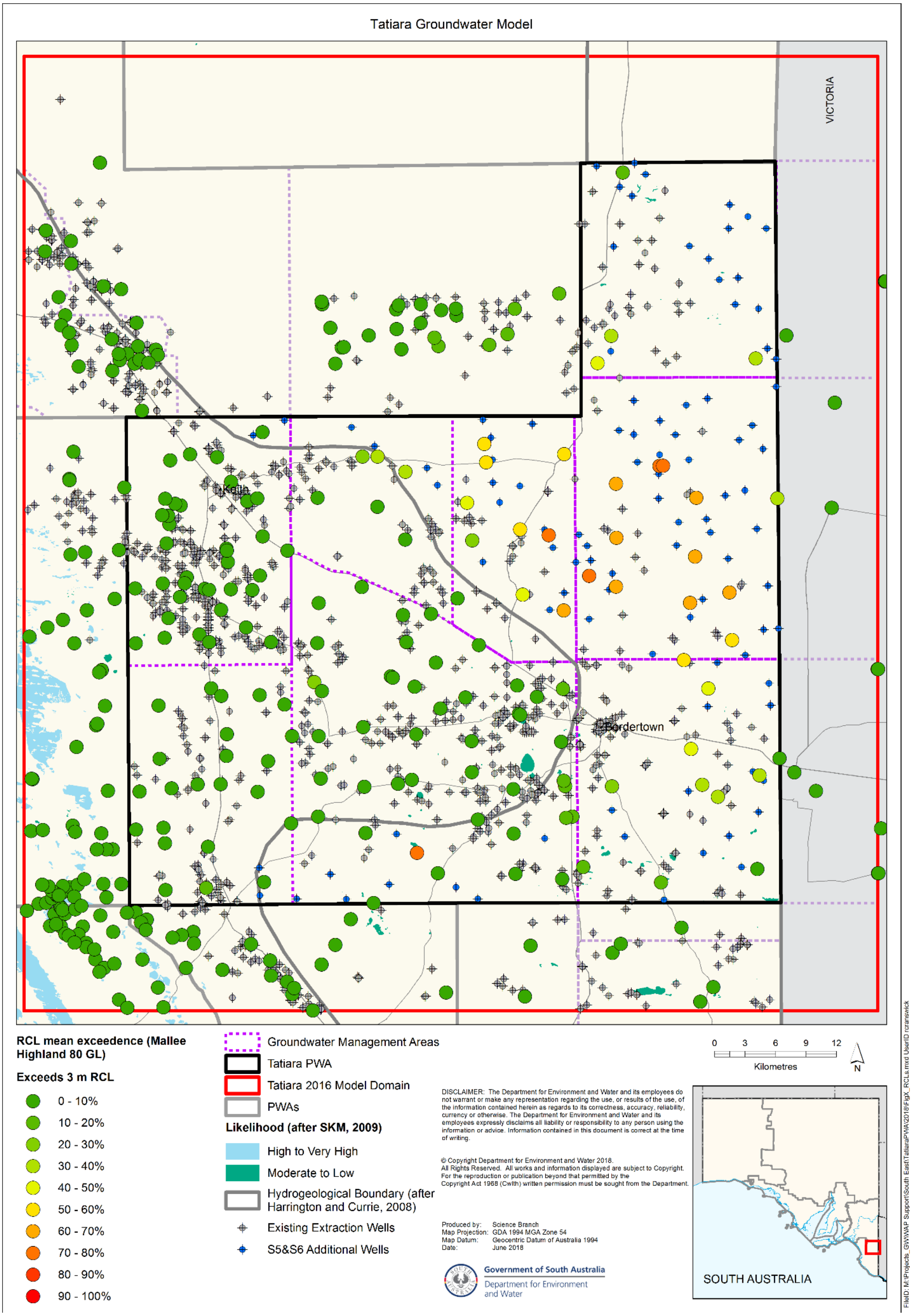

Figure 4.12. Percentage of time the 3 m decline RCL is exceeded for the current extraction scenario plus additional 80 GL/y on the Mallee highlands

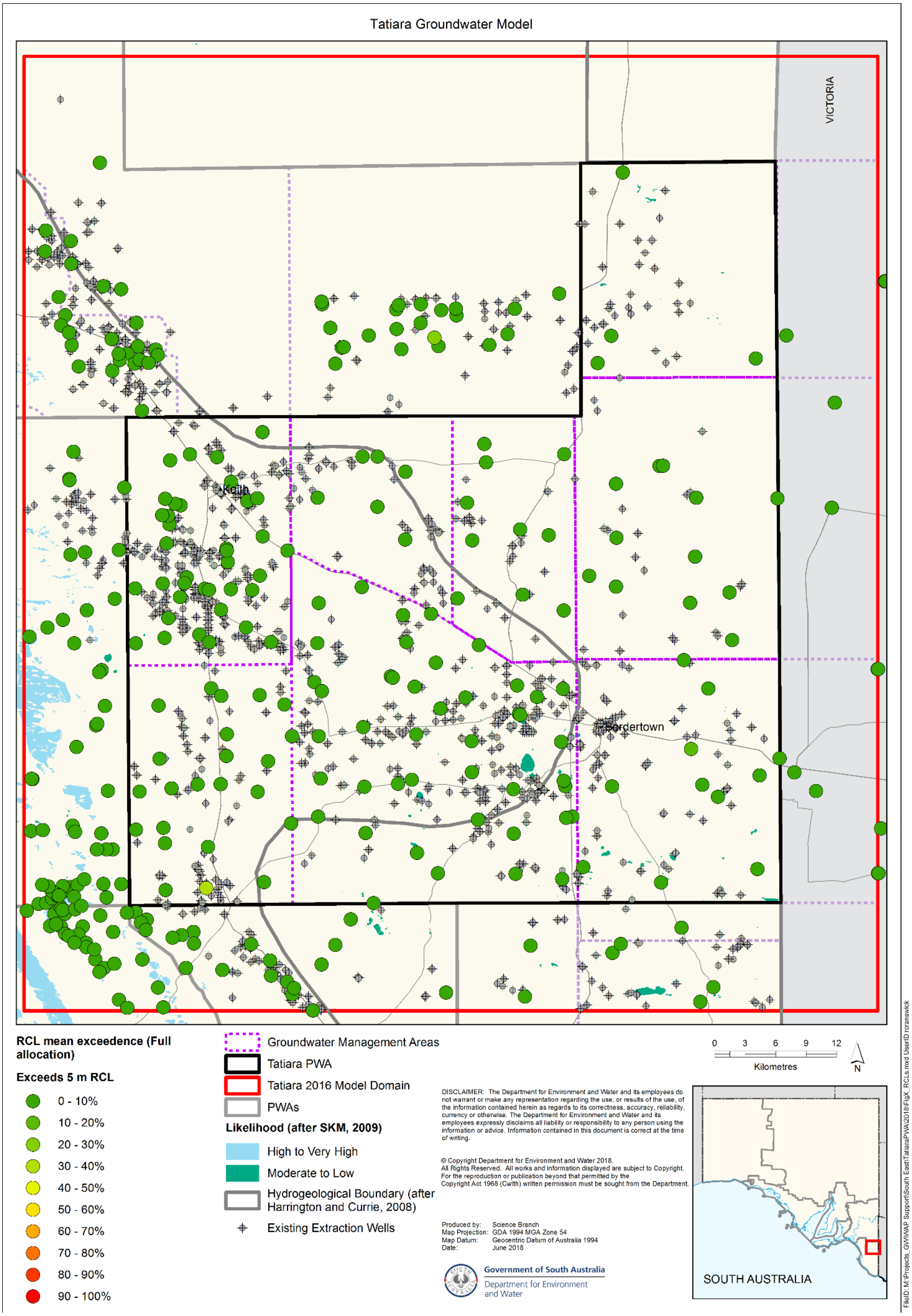

Figure 4.13. Percentage of time the 5 m decline RCL is exceeded for the full allocation extraction scenario

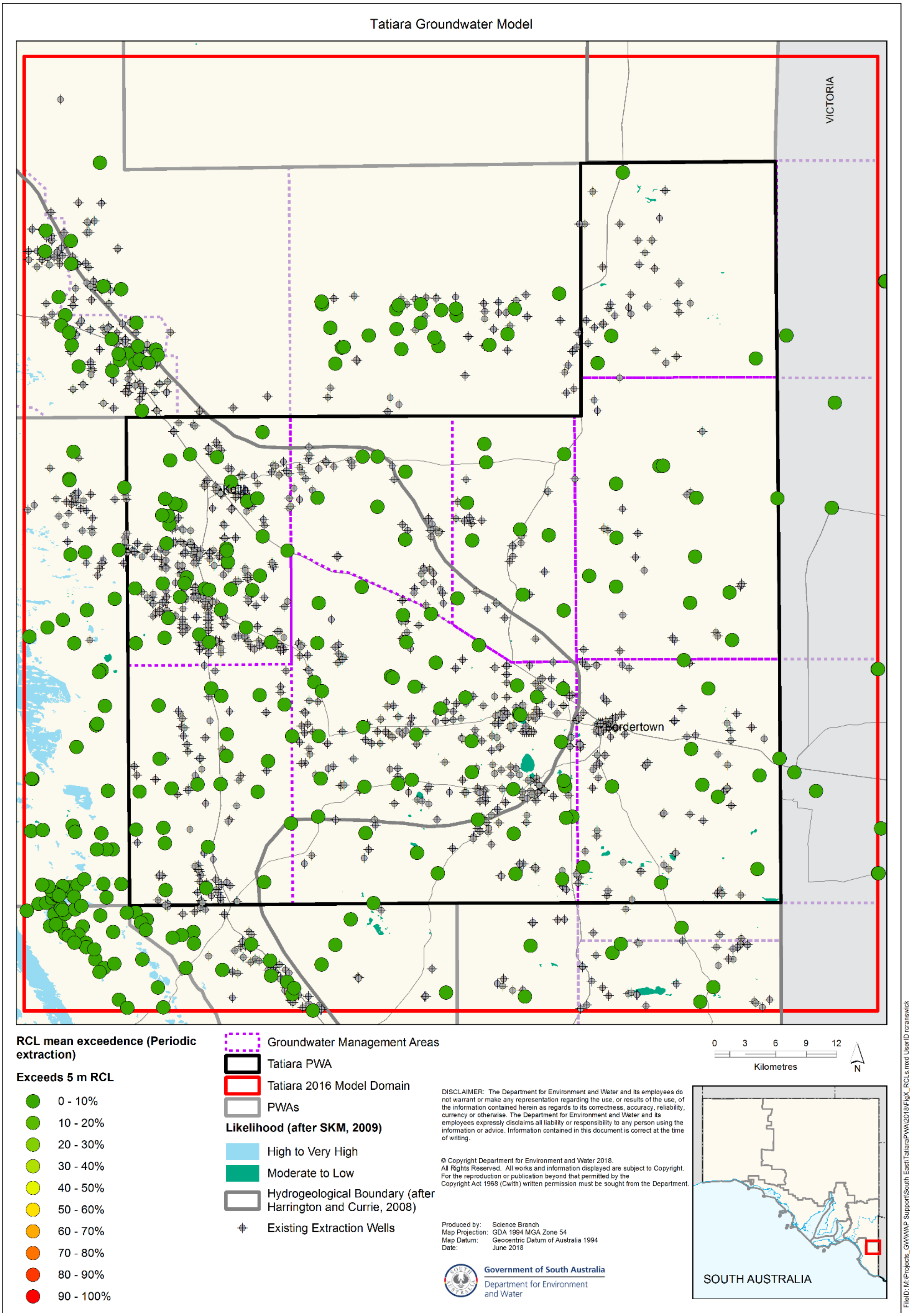

Figure 4.14. Percentage of time the 5 m decline RCL is exceeded for the higher extraction scenario

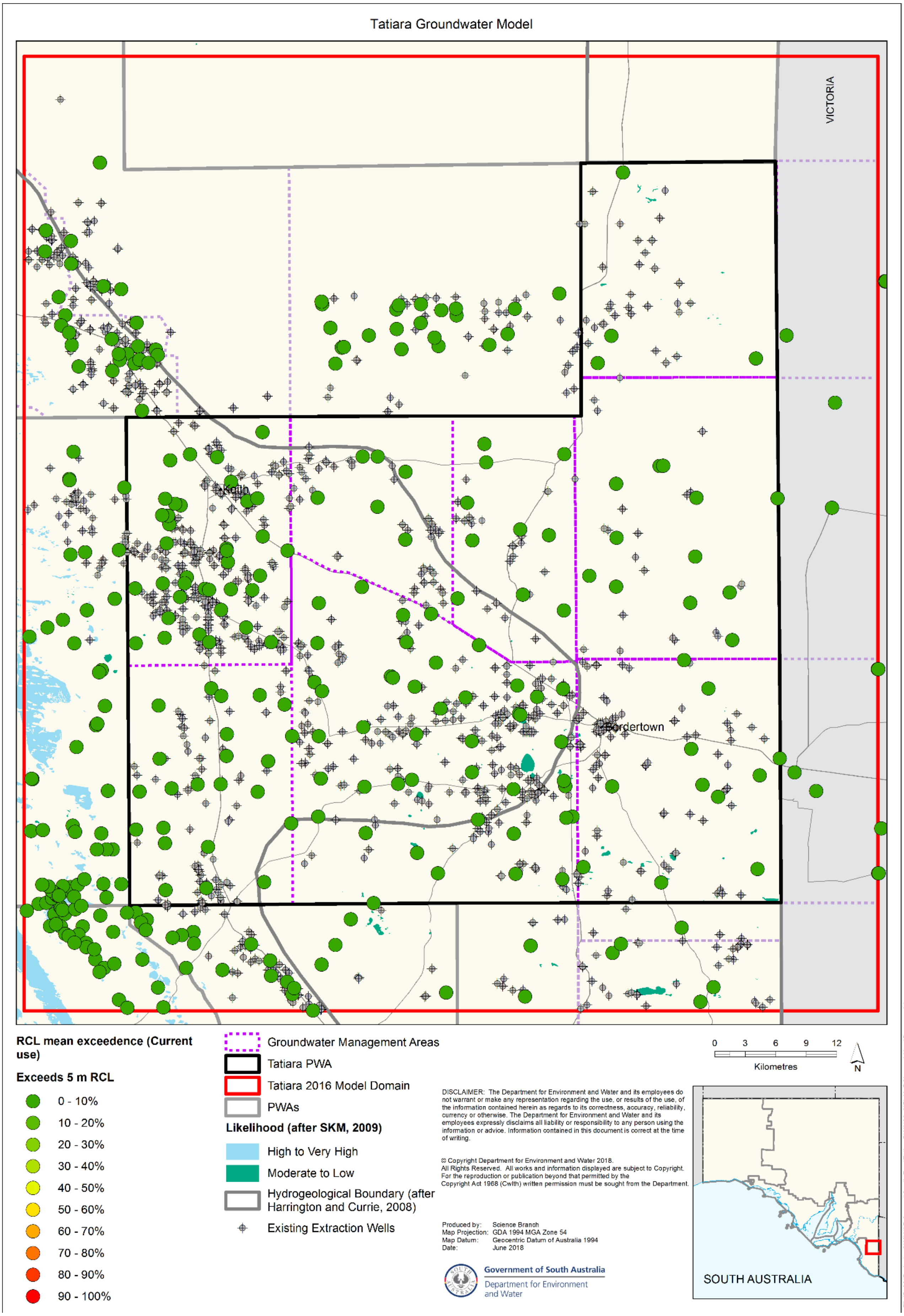

Figure 4.15. Percentage of time the 5 m decline RCL is exceeded for the current extraction scenario

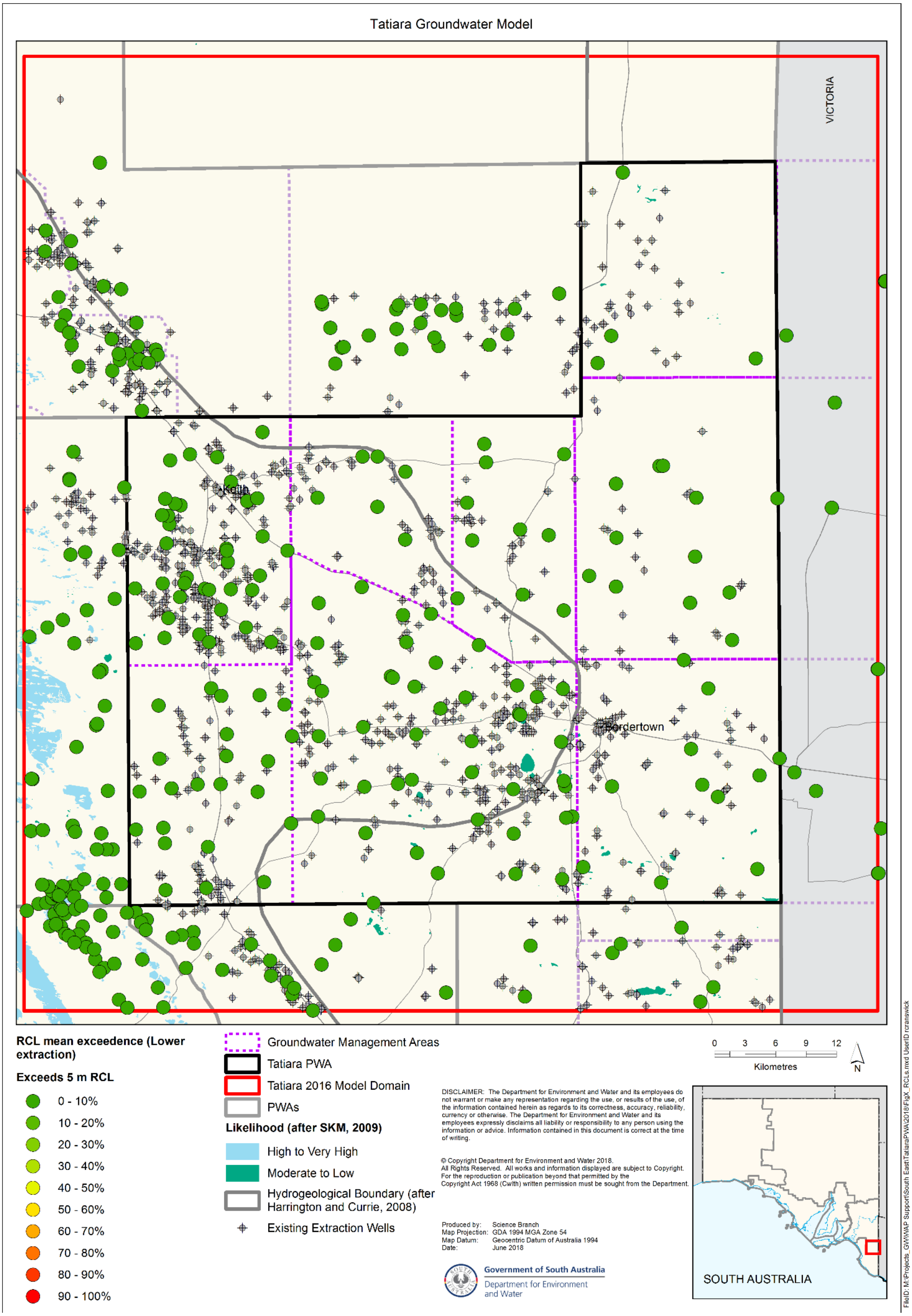

Figure 4.16. Percentage of time the 5 m decline RCL is exceeded for the lower extraction scenario

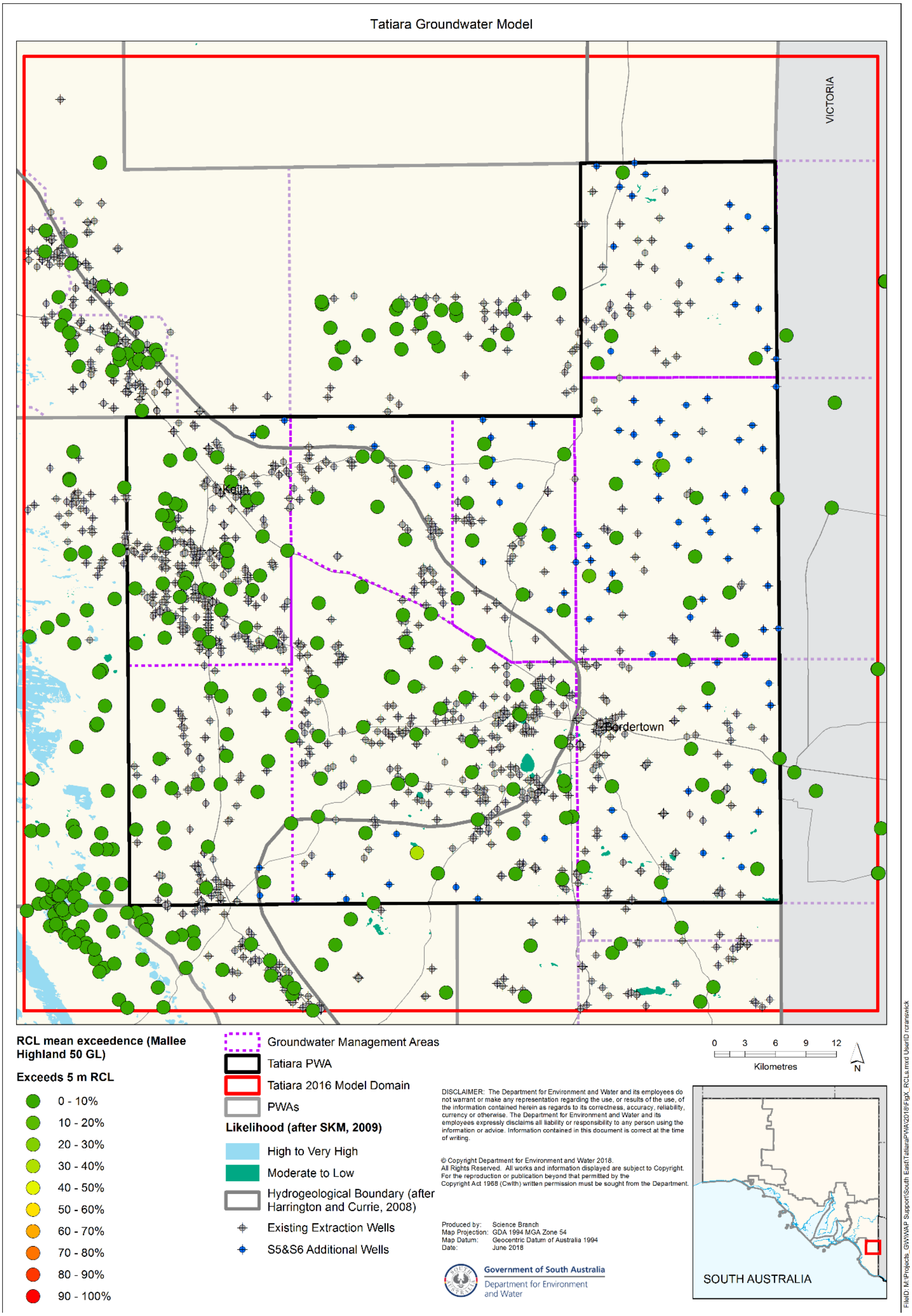

Figure 4.17. Percentage of time the 5 m decline RCL is exceeded for the current extraction scenario plus additional 50 GL/y on the Mallee highlands

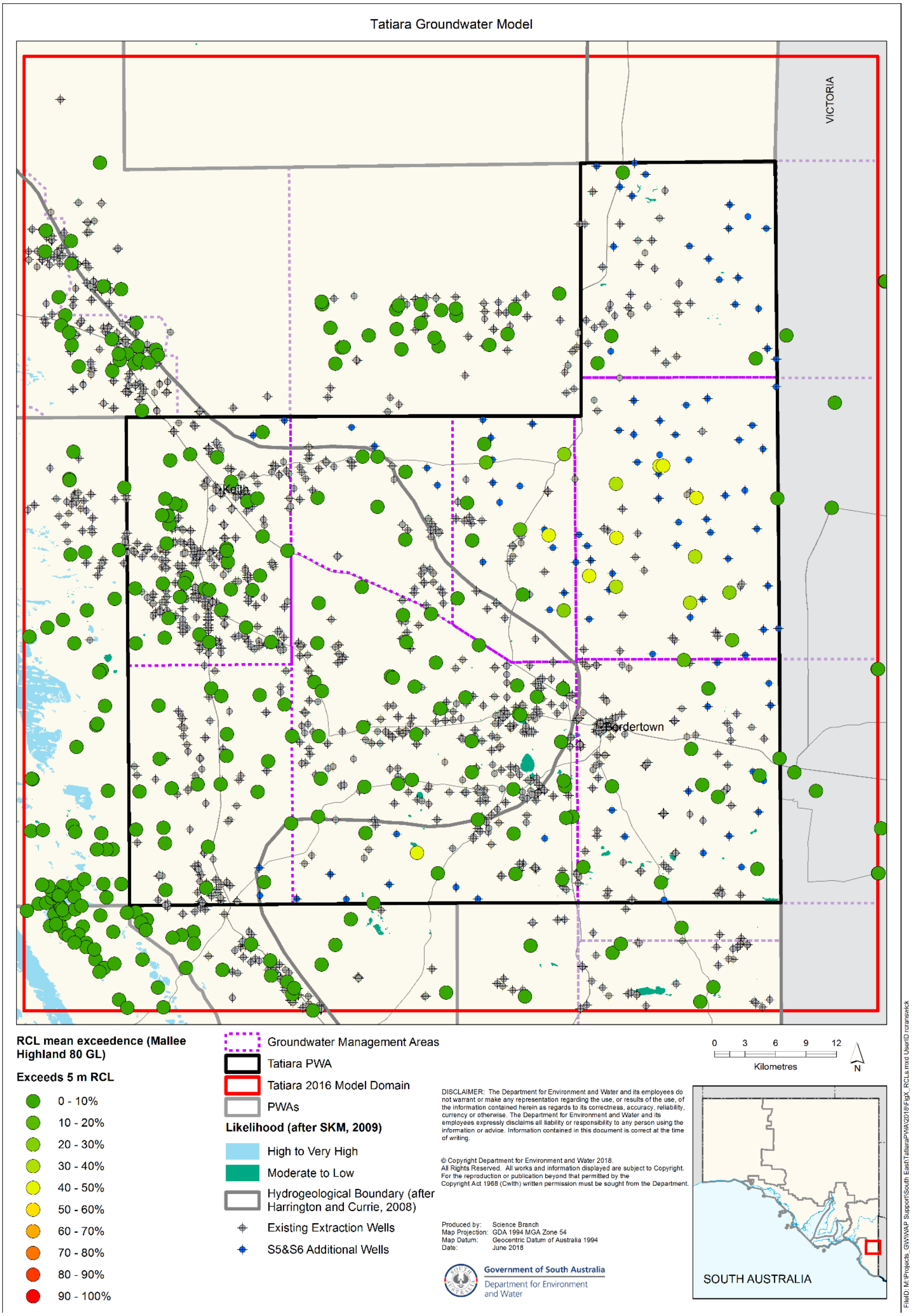

Figure 4.18. Percentage of time the 5 m decline RCL is exceeded for the current extraction scenario plus additional 80 GL/y on the Mallee highlands

D. Maps showing Model B average 2030 winter drawdown from winter 2015 groundwater levels

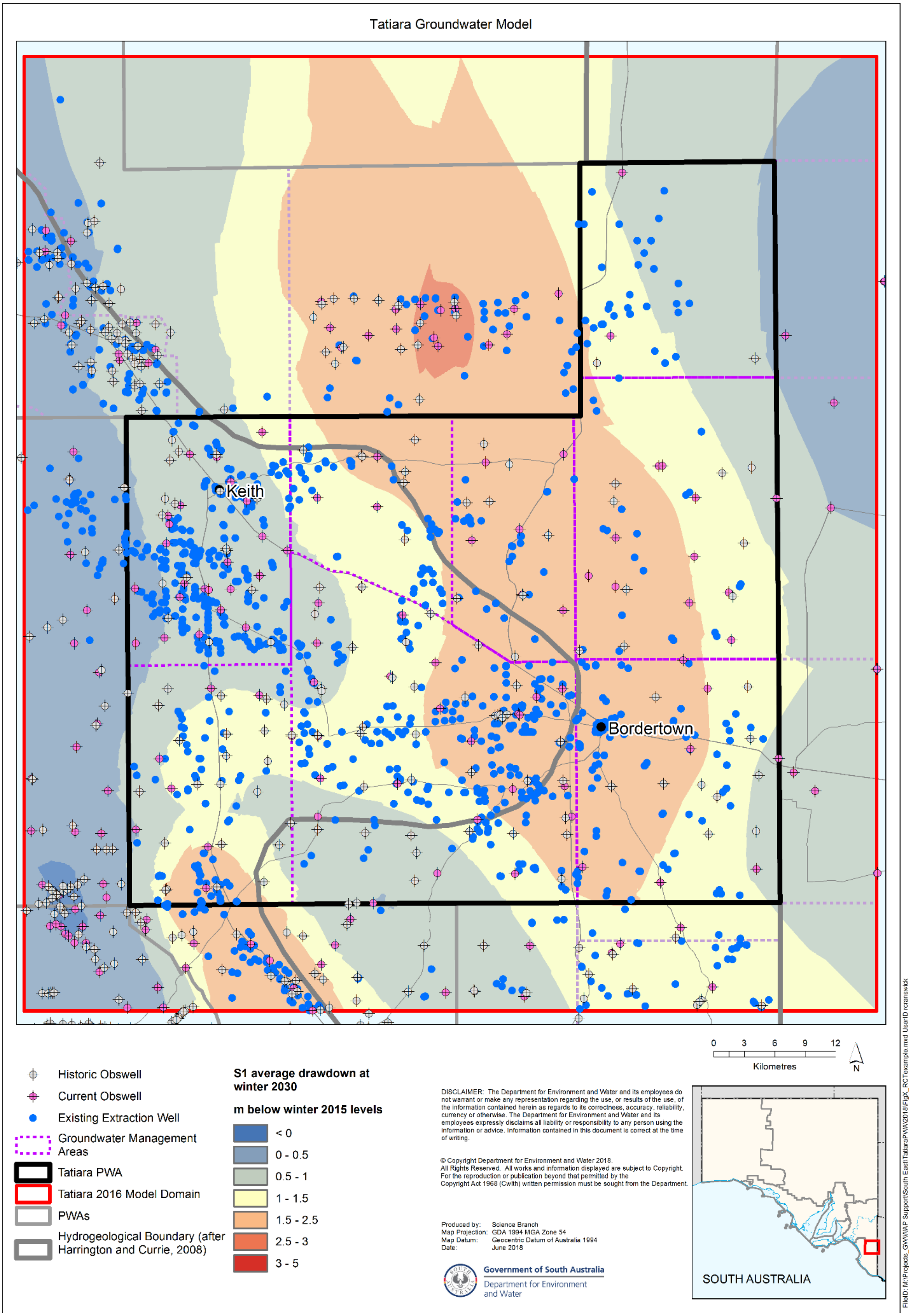

Figure 4.19. Example RCT exceedance analysis for the 5 m decline RCL, using average 2030 winter projected groundwater levels under S1, full allocation extraction

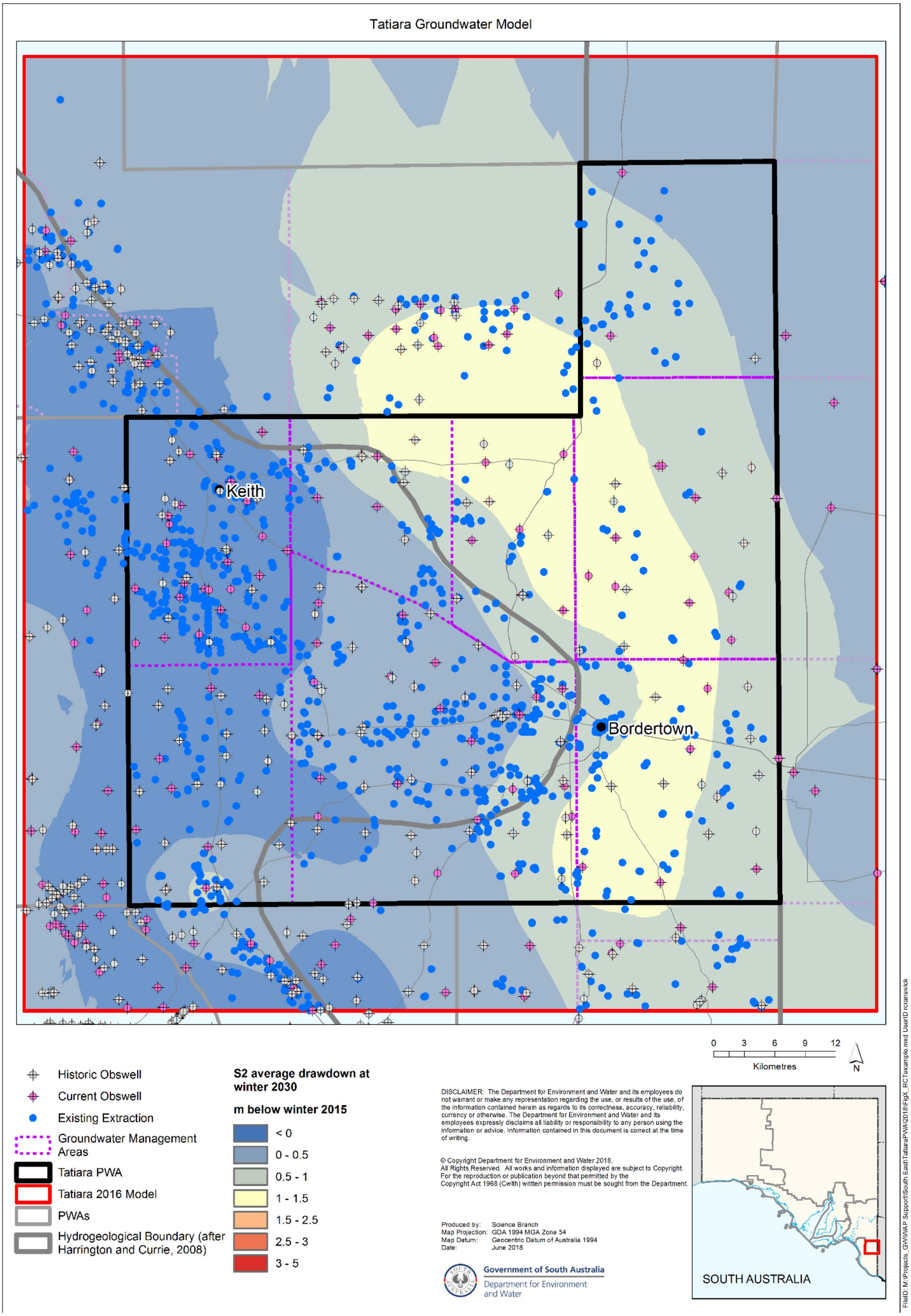

Figure 4.20. Example RCT exceedance analysis for the 5 m decline RCL, using average 2030 winter projected groundwater levels under S2, higher extraction

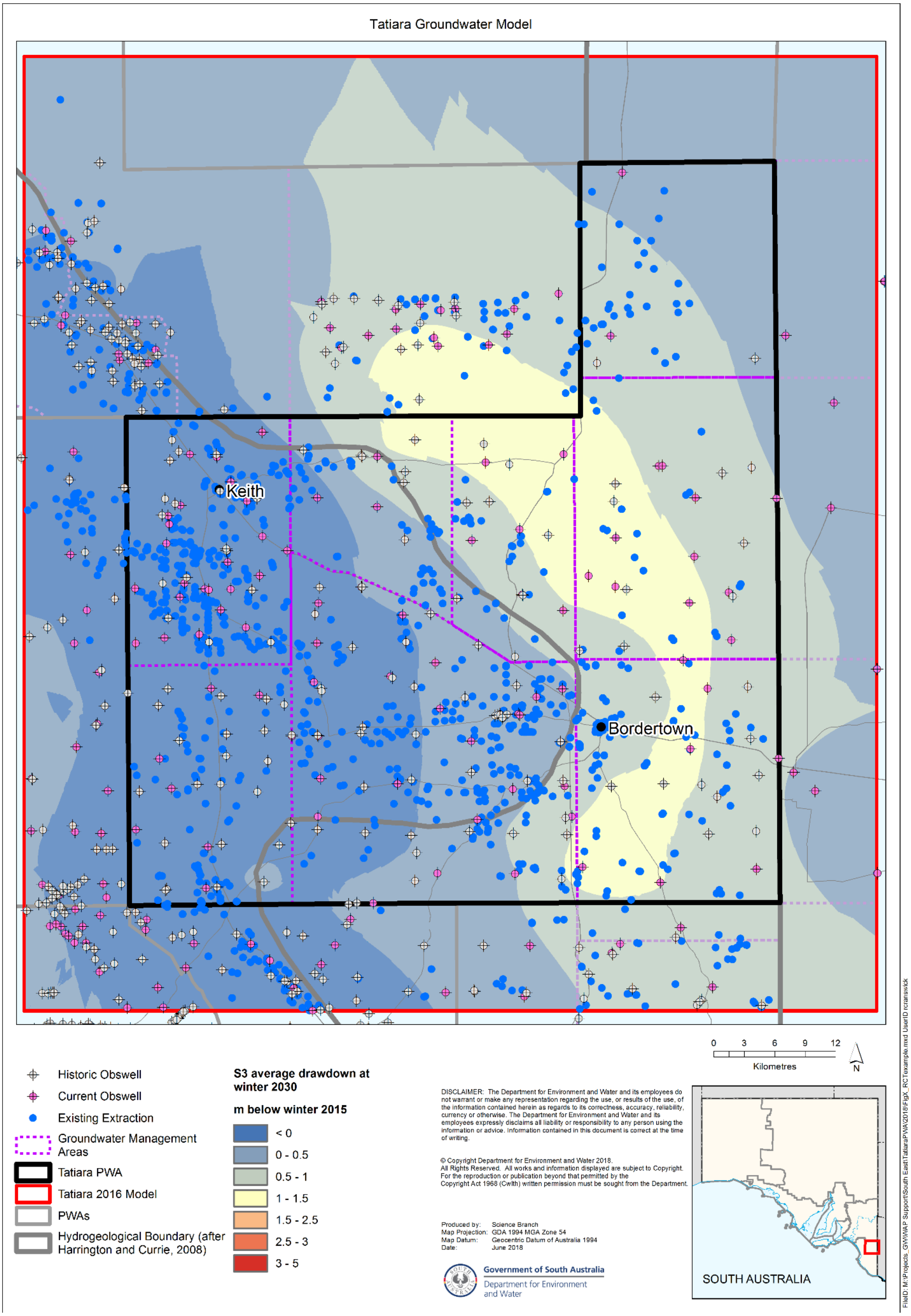

Figure 4.21. Example RCT exceedance analysis for the 5 m decline RCL, using average 2030 winter projected groundwater levels under S3, current extraction

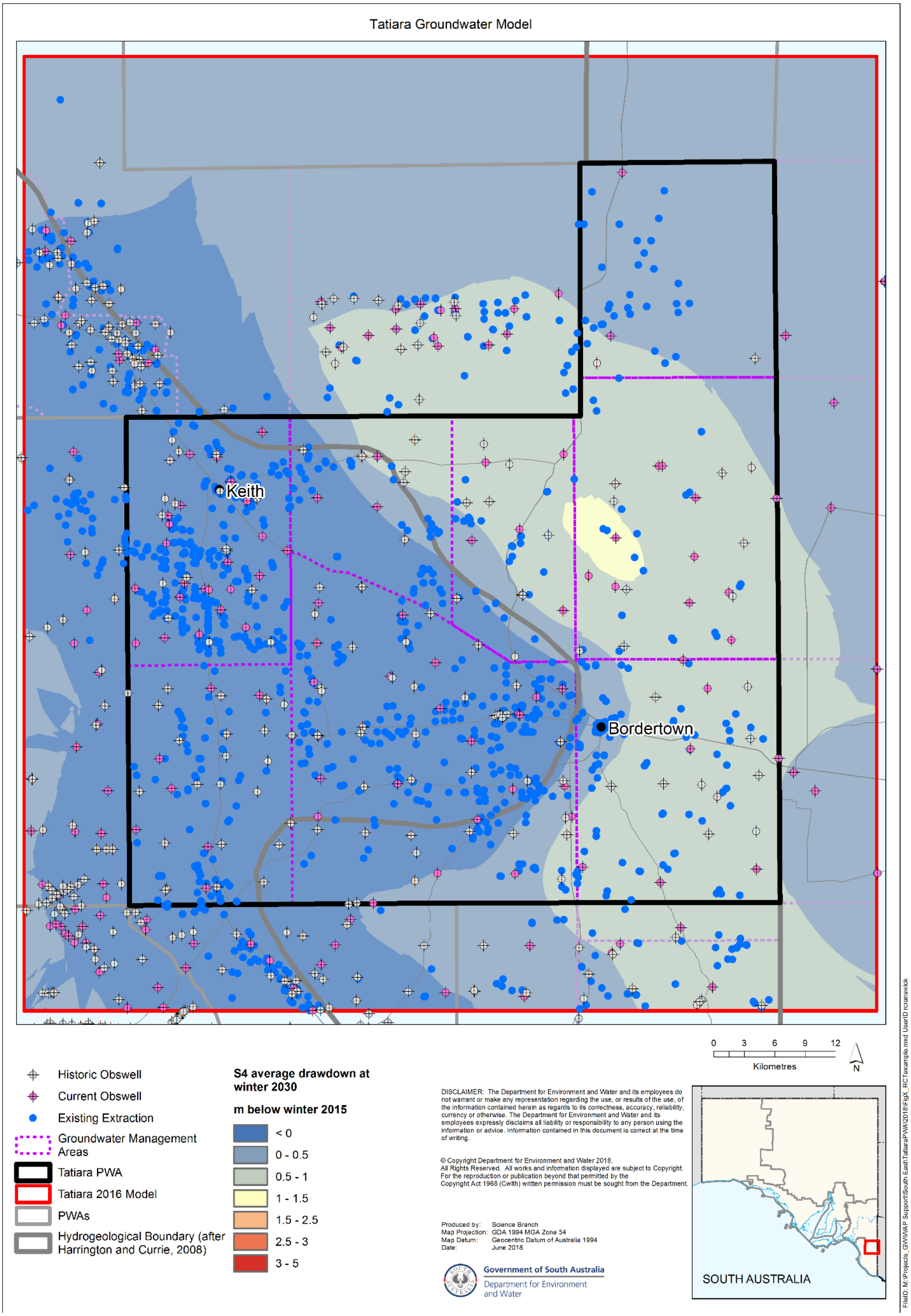

Figure 4.22. Example RCT exceedance analysis for the 5 m decline RCL, using average 2030 winter projected groundwater levels under S4, lower extraction

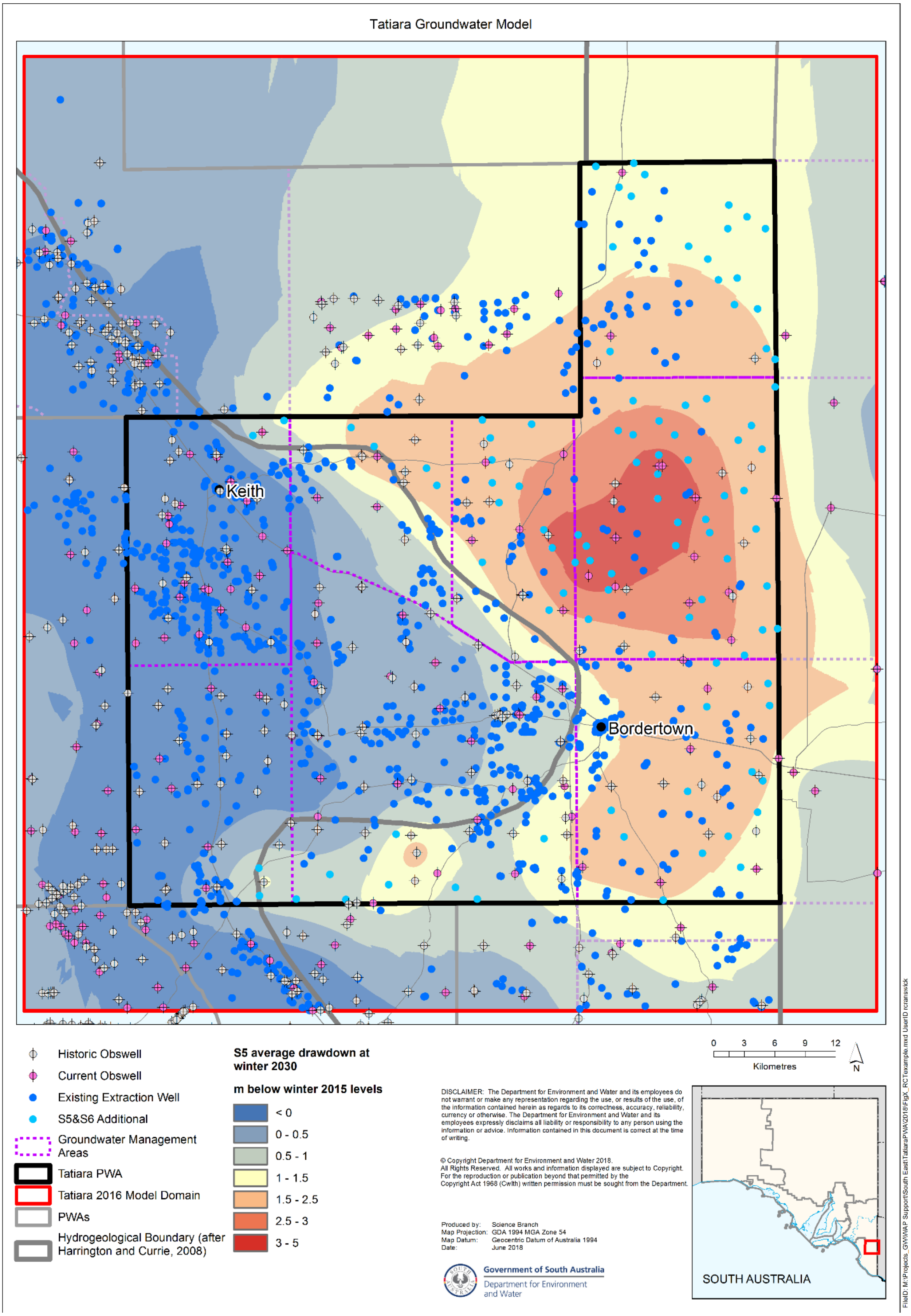

Figure 4.23. Example RCT exceedance analysis for the 5 m decline RCL, using average 2030 winter projected groundwater levels under S5, additional 50 GL/y on Mallee highlands in addition to current extraction

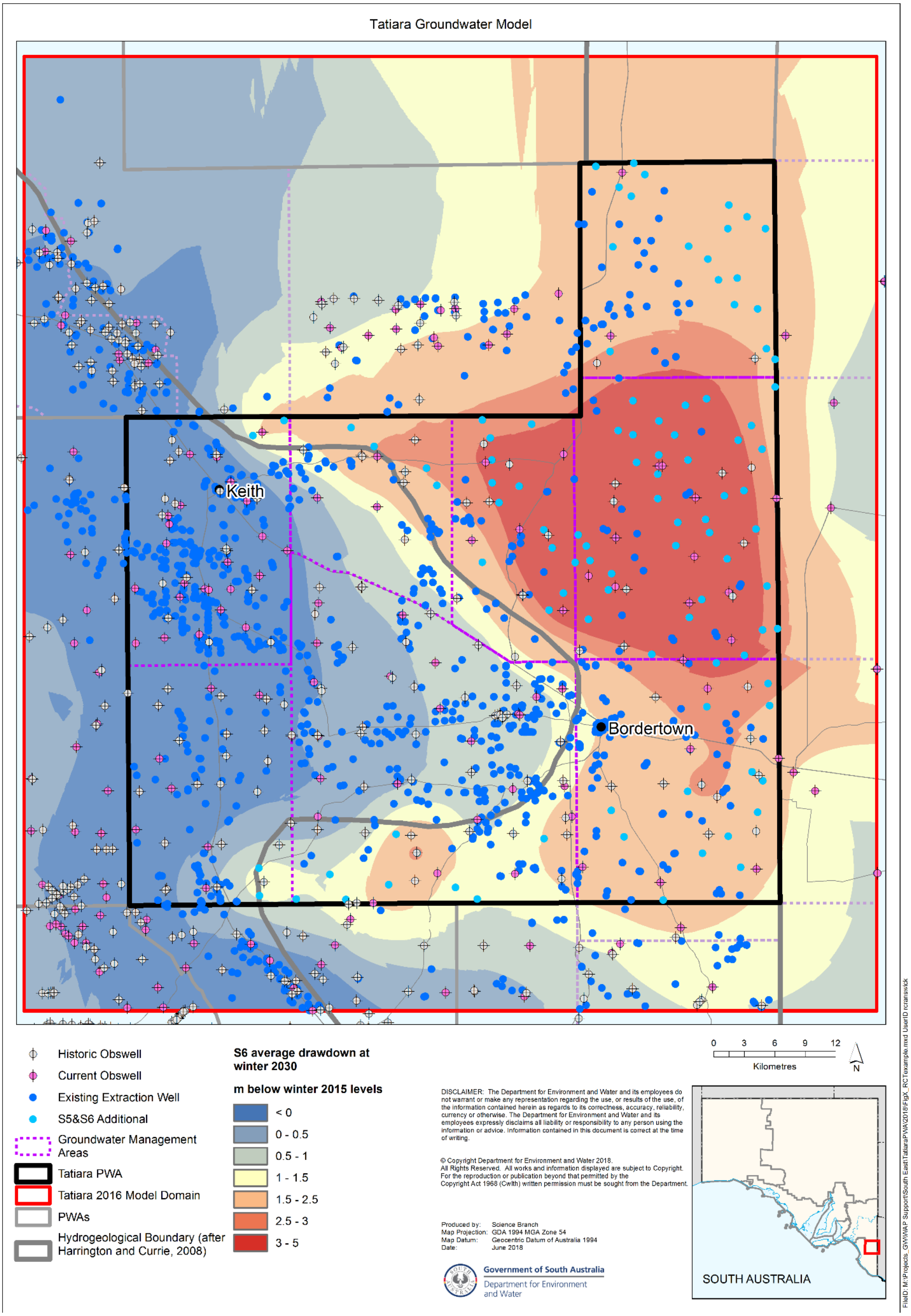

Figure 4.24. Example RCT exceedance analysis for the 5 m decline RCL, using average 2030 winter projected groundwater levels under S6, additional 80 GL/y on Mallee highlands in addition to current extraction

5 Units of measurement

5.1 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
microlitre	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

6 Glossary

Act (the) — In this document, refers to the *Natural Resources Management (SA) Act 2004,* which supersedes the *Water Resources (SA) Act 1997*

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.

Aquatic ecosystem — The stream channel, lake, wetland, or estuary bed, water, and/or biotic communities, and the habitat features that occur therein

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

Baseline – a reference period of time against which projections of future climate are compared

Carry-over — A licensed volume of water equivalent to the unused volume of allocation at the end of the preceding water use year, or 20% of the licensee's annual allocation for the preceding year, whichever is lesser

Climate futures analysis — a method for the grouping of multiple 'GCM' climate projections according to the amount of change they project in two or more climate variables (e.g. average projected future change in temperature and rainfall compared to a baseline period). This may be undertaken to determine where there is the most agreement between models in relation to the likely future change in primary climate variables

Climate projection — a scenario of future climate, generally resulting from running a GCM with a specified greenhouse gas concentration scenario (or RCP). A projection differs from a prediction in that it is conditional on the representation of a particular model (GCM) and the uncertain assumptions of the model inputs (primarily the greenhouse gas concentration scenario, or RCP)

Climate scenario — description of the possible future climate according to a particular GCM and influenced by a specific RCP

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 groundwater levels or water quality

Confining layer — A geological unit that 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)

Discretisation — the characterisation of smaller units of distance (i.e. meters) and time (i.e. days) that are combined using equations within a mathematical model, they can be defined using regularly or irregularly spaced intervals.

Downscaling – The process of deriving local climate change impacts from large scale global climate models

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

Environmental water requirements — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

Ephemeral streams or wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events or due to groundwater discharge. Many arid zone streams and wetlands are ephemeral.

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

GCM — global climate model, sometimes also referred to as generalised circulation model. These are mathematical models that integrate systems of differential equations describing the dynamic processes and interaction between the atmosphere, land and ocean. GCMs typically have a grid resolution on the order of 150 x 250 km and require downscaling for local-scale applications; see also 'statistical downscaling'

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

IPCC – Intergovernmental Panel on Climate Change

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

Irrigation season — The period in which major irrigation diversions or extractions occur, usually starting in October–November and ending in April–May but is defined as October to March in this report

LEACHM — Leaching Estimation and Chemistry Model

Licence — A licence to take water in accordance with the Act; see also 'water licence'

Licensee — A person who holds a water licence

LiDAR — Light Detecting and Ranging; can be used to develop digital elevation models of the land surface

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

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

MODFLOW — A three-dimensional, finite difference code developed by the USGS to simulate groundwater flow

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 with a variety of functions, including to permit the measurement of groundwater level and salinity or enable other hydrochemical and aquifer test analysis that may be designed for that well

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

Phreatophytic vegetation — Vegetation (plants) with deep root systems that obtain a significant portion of the water that it needs from groundwater

Porosity — the ratio between the volume of voids and the volume of solids of a soil or geological material

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

RCP — representative concentration pathway, a scenario of possible future global atmospheric greenhouse gas and aerosol concentrations, applied in GCMs when projecting future climate change.

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

Specific storage (S_s) — The amount of stored water realised from a unit volume of aquifer per unit decline in head; measured in m^{-1}

Specific yield (S_y) — The volume ratio of water that drains by gravity, to that of total volume of the porous medium. It is dimensionless

Statistical downscaling — a process of inferring high-resolution information from low-resolution information (e.g. developing local-scale weather information from regional-scale generalised circulation model outputs that are statistically consistent with historical observed data)

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

TLA — Tertiary Limestone aquifer

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 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

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres

7 References

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