Estimation of groundwater resource capacity and recommended extraction limits for the Adelaide Plains Water Allocation Plan

DEWNR Technical Report 2017/03

Government of South Australia
Department of Environment, Water and Natural Resources

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March, 2017

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ISBN 978-1-925510-62-1

Preferred way to cite this publication

Department of Environment, Water and Natural Resources (DEWNR), 2017, *Resource capacity and recommended extraction limits for the Adelaide Plains Water Allocation Plan,* DEWNR Technical report 2017/03, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.

Foreword

The Department of Environment, Water and Natural Resources (DEWNR) 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.

DEWNR'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.

Sandy Pitcher
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

Acknowledgements

This work has been supported by Jenny Awbery, Fiona Gill and Heather Hill of Natural Resources Adelaide and Mount Lofty Ranges, who have facilitated this significant advancement in the approach taken by DEWNR to evaluate groundwater resource capacity. The authors would like to thank Stuart Richardson (CDM Smith Pty Ltd) for his helpful external review containing constructive and targeted comments that have improved the focus and clarity of this report.

The authors would also like to thank their DEWNR colleague Graham Green, Principal Hydrogeologist, for his internal review—Chris Li, Stuart Wright and Mojtaba Karbasi for additional scenario modelling, and Daniel Pierce for editorial assistance.

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Summary

The *Natural Resources Management Act 2004* (the Act) requires the Adelaide and Mount Lofty Ranges Natural Resources Management Board (the Board) to prepare a water allocation plan for each of the prescribed water resources in its area. The Board is developing the Adelaide Plains Water Allocation Plan (WAP) to cover the Northern Adelaide Plains, Central Adelaide and Dry Creek Prescribed Wells Areas. The water allocation plan will manage groundwater across the whole of the Adelaide Plains in an integrated way.

The Northern Adelaide Plains (NAP) Prescribed Wells Area has an existing water allocation plan, adopted in 2000, that has been reviewed and needs updating. Water licences have been employed for many decades because of the wide-scale use of groundwater that supports an important horticultural industry.

In the Central Adelaide (CA) Prescribed Wells Area, the use of groundwater has increased rapidly over the last 20–30 years, mainly for industrial purposes and turf irrigation. The wells in this area were prescribed in 2007, but the new water allocation plan will be the first one for this prescribed area. Licences will be issued to existing groundwater users for the first time. These existing users have applied for licences, based on their groundwater use (or recognised financial or legal commitment to take groundwater) during the period 1 July 2002 to 30 November 2005.

The new water allocation plan will also include the small Dry Creek Prescribed Wells Area, as this does not yet have a water allocation plan.

This report presents findings from the *Groundwater resource capacity of the Adelaide Plains* project. The broad objectives of the project were to determine the groundwater resource capacity and recommend ranges for acceptable extraction limits of the prescribed areas, to be used to inform development of the WAP. The project steering committee has considered the use of a system of groundwater management zones with recommended extraction limits as a scheme to underpin the WAP. The project has three purposes:

- the delineation of groundwater management zones
- determination of the resource capacity and recommended extraction limits to inform the issuing of new allocations in the CA Prescribed Wells Area (PWA) and the development of principles for the draft WAP about any future approval of new or increased allocations
- determination of levels of extraction in some zones of the NAP PWA (which is considered to be over-allocated) that would trigger a management response to prevent unacceptable impacts on the resource.

An assessment of the resource capacity needs to take into account not only the impact of groundwater extraction on the groundwater resource, but also the impact of extraction on all groundwater users—environmental, social and economic. In order to manage the resource effectively for current and future users, it is important a balance is reached so that the needs of all users are considered. This can be achieved by estimating an acceptable volume that can be extracted per year, a 'recommended extraction limit'. This will require some trade-off between the different users of the groundwater resource.

Ranges of recommended extraction limits for the proposed groundwater management zones in the CA and NAP prescribed areas were estimated by using either a water balance approach or scenario modelling in combination with an assessment of resource condition indicators and limits:

- volume of water extracted annually from the Quaternary aquifers must not result in unacceptable impacts to GDEs or existing users
- winter drawdown in the T1 aquifer should not drop below –5 m AHD in the Waterloo Corner area and –15 m AHD in the Central Adelaide PWA by 2040. This is to mitigate the salinity threat from increased downward leakage of salty water from the Q4 aquifer and the encroachment of higher-salinity water from surrounding areas

- winter drawdown in the T2 aquifer should not drop below the base of the confining layer separating the T1 and T2 aquifers by 2040 to avoid continued dewatering of the T2 aquifer that could compromise the integrity of the aquifer material
- annual volume of baseflow from the fractured rock aquifers is maintained within the range of historic observations
- volume of water extracted annually from the Quaternary and Tertiary aquifers in the Noarlunga Embayment must not result in unacceptable impacts to GDEs or existing users.

Once the resource condition limits (RCLs) were defined, it was possible to determine recommended extraction limits—the volume of extraction for consumptive use that can be sustained over time to keep the system from exceeding these resource condition limits. The recommended extraction limits that are set for each groundwater management zone (GMZ) of the resource then reflect the capacity of the resource to meet various demands, current and future.

The recommended extraction limit for the proposed Quaternary aquifers GMZ is 1600–2000 ML/y. This range covers existing licensed holders, allows further development of the aquifer, but also 'reserves' some water for GDEs as well.

For the T1 and T2 aquifers, a recommended extraction limit equal to a 20–30% increase from the current average extraction is proposed for most T1 and T2 GMZs. This range of limits was derived from modelling Scenarios 5 and 10 that show increases in the amount of drawdown were within the resource condition limits set for the aquifers and any unacceptable impacts on existing users should be limited. These volumes still allow some development of the aquifers.

The recommended extraction limit for the proposed T2 Virginia GMZ has been kept at the lower range of 10–20% increase on current average extractions to limit major increases in the existing cone of depression in this area of intensive extraction.

The recommended extraction limit for the proposed T2 NAP GMZ is the current allocation volume of 4483 ML. The risk of structural damage to the confining layer above the T2 aquifer under this scenario is considered acceptable.

An extraction limit of 2212 ML is recommended for the proposed T2 Regional GMZ (Table 6.1). This recommended volume is accompanied with the proviso that for any application over 250 ML/y a hydrogeological investigation should be conducted to determine the impact on the resource and other users.

Scenario modelling for the T1 and T2 Golden Grove Embayment GMZ has shown that a doubling of the estimated existing user demand would have only a minor impact on groundwater pressure levels within the GMZ and extracting an extra 1000 ML/y is likely to have a tolerable impact, hence the recommended extraction limit is set at this level. A condition is also recommended for this GMZ that for any application over 250 ML/y a hydrogeological investigation should be conducted to determine the impact on the resource and other users.

An assessment of the T2 aquifer in the Kangaroo Flat region of the NAP PWA confirmed 1500 ML/y as the recommended extraction limit.

There is currently no extraction from the T3 and T4 aquifers and further development is likely to be limited by the depth of the aquifers and the poor water quality of the resource. The recommended extraction limits range from 2300 ML to 4000 ML. A condition is also recommended for this GMZ that for any application over 250 ML/y a hydrogeological investigation should be conducted to determine the impact on the resource and other users.

The volume of groundwater available for licensed extraction from the fractured rock aquifer GMZs was derived using a water balance approach. Due to the uncertainties in the water balance calculations for the fractured rock aquifers, the lower range recommended extraction limits for the fractured rock aquifer GMZs are based on maintaining current extractions and conditions. The higher range of recommended extraction limits are based on the calculations of water available while still maintaining baseflow and accounting for current allocations.

There is insufficient information to use the water balance method for the proposed Golden Grove Embayment fractured rock aquifer GMZ. Non-licensed use and existing user demand is relatively low at about 19 and 14 ML/y respectively, with a low risk of significant demand in the future because of the urbanised nature of the GGE and relatively high groundwater salinity. Therefore, an extraction limit of 500 ML/y is recommended, with a caveat that any application over 50 ML requires a hydrogeological investigation to determine the impact on the resource and other users.

The upper recommended extraction limit for the Noarlunga Embayment GMZ is 1717 ML/y. There is no existing user demand for licensed purposes. Furthermore, throughflow from the adjacent fractured rock aquifers has not been included in the capacity calculation. Therefore, the recommended extraction limit is a based on a conservative estimate of the capacity of this resource.

It should be noted that the recommended extraction limits for each zone do not necessarily equate to the recommended extraction limits that will be defined in the WAP. Consideration of social and economic factors and what might be considered by stakeholders to be acceptable impacts may affect the eventual extraction limits defined by the WAP.

If the recommended extraction limits of a GMZ are exceeded, the resource condition limits should be examined and if they have also been exceeded, this could potentially trigger management action that would temporarily reduce the extraction within the GMZ. This should prevent unacceptable impacts to the groundwater resource.

1. Introduction

The Adelaide and Mount Lofty Ranges Natural Resources Management Board (the Board) has a responsibility to generate water allocation plans for their region's prescribed groundwater resources. A draft Adelaide Plains Water Allocation Plan (WAP) is currently being developed, which will cover the groundwater of the Central Adelaide (CA), Northern Adelaide Plains (NAP) and Dry Creek[1] PWAs (refer Figure 1.1). The South Australian *Natural Resources Management Act 2004* (the Act) requires a WAP to assess the capacity of the water resources to meet the demands for water on a continuing basis.

In February 2014, the Board commissioned the Science, Monitoring and Knowledge Branch of the Department of Environment, Water and Natural Resources (DEWNR) to undertake the *Groundwater resource capacity of the Adelaide Plains* project. The broad objectives of the project were to determine the groundwater resource capacity and recommend ranges of acceptable extraction limits for the prescribed areas, to be used to inform development of the WAP. The Adelaide Plains Working Group has considered the use of a system of GMZs with recommended extraction limits as a scheme to underpin the WAP. The project has three purposes:

- delineation of groundwater management zones
- determination of the resource capacity and recommended extraction limits to inform the issuing of new allocations in the CA PWA and the development of principles for the draft WAP about any future approval of new or increased allocations
- determination of levels of extraction in some zones of the NAP PWA (which is considered to be over-allocated) that would trigger a management response to prevent unacceptable impacts on the resource.

An assessment of the resource capacity needs to take into account not only the impact of groundwater extraction on the groundwater resource, but also the impact of extraction on all groundwater users—environmental, social and economic. In order to manage the resource effectively for current and future users, it is important a balance is reached so that the needs of all users are considered. This can be achieved by estimating an acceptable volume that can extracted per year, a 'recommended extraction limit'. This will require some trade-off between the different users of the groundwater resource.

1.1 Hydrogeology of the Northern Adelaide Plains and Central Adelaide PWAs

Physiography, topography, climate, geology, land use and surface hydrology of the Northern Adelaide Plains and Central Adelaide PWAs have been described in *Resource capacity and sustainability development limits for the aquifers of the Noarlunga Embayment and hills zone* (SKM 2011a) and *Adelaide Plains groundwater investigation projects, part 3: surface water/groundwater interactions* (SKM 2011b), among others. Following is a description of the hydrogeology of the prescribed areas, as this is the main focus of the project.

The study area includes several different hydrogeological environments, including both sedimentary and fractured rock aquifers within the following regions: Adelaide Plains Sub-basin, Golden Grove Embayment, Noarlunga Embayment and the fractured rock aquifers of the Adelaide Hills (Gerges 2006; Fig. 1.1).

[1] For the purposes of this report the Dry Creek PWA, although separately prescribed, is considered to be part of the Northern Adelaide Plains PWA

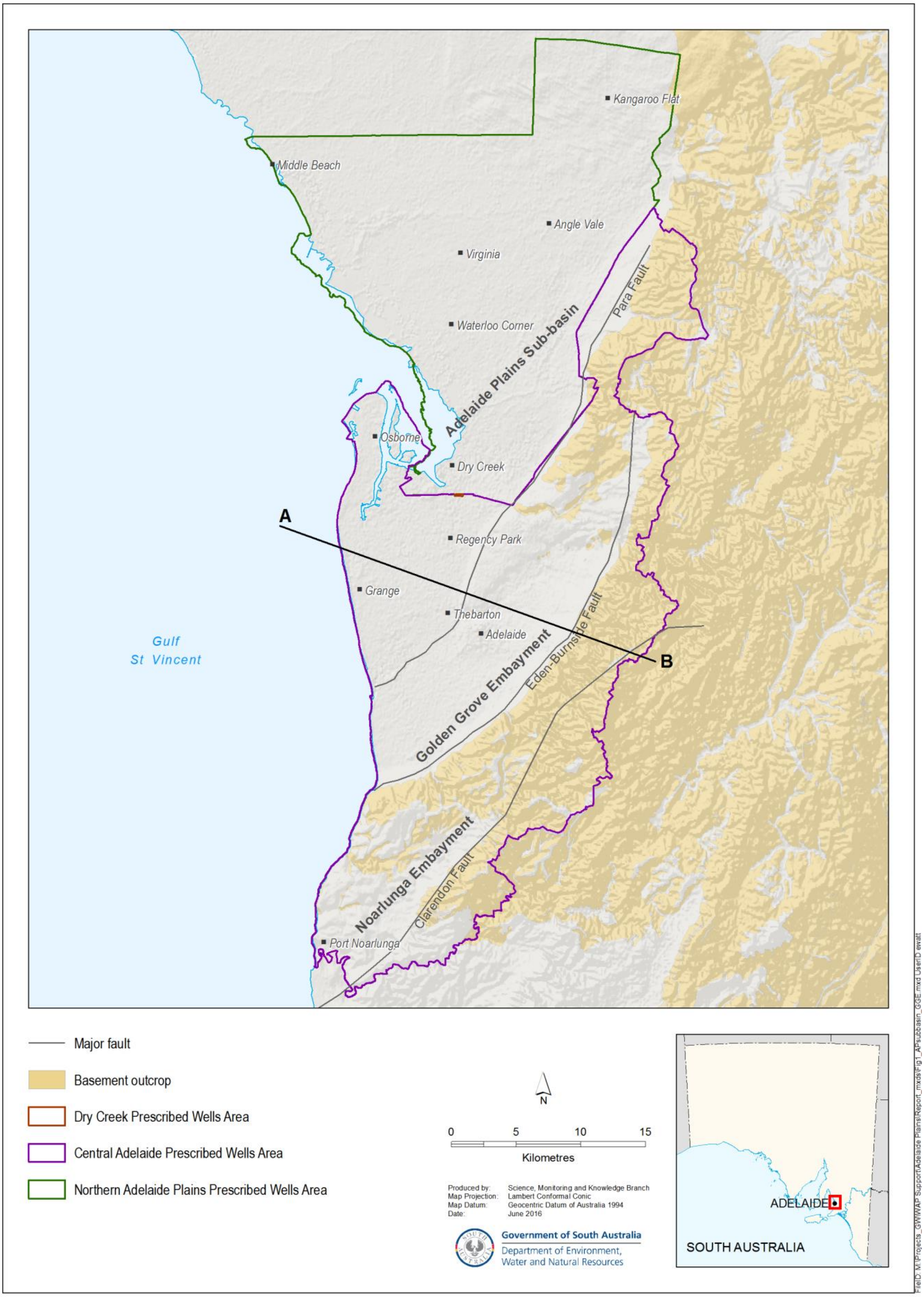

Figure 1.1 Geological setting of the Northern Adelaide Plains and Central Adelaide PWAs

1.1.1 Adelaide Plains Sub-basin and Golden Grove Embayment

The Adelaide Plains Sub-basin and the Golden Grove Embayment, separated by the Para Fault, are the two main geological provinces containing the sedimentary aquifers that underlie the Adelaide Plains (Figs 1.1 & 1.2). There are two main aquifer systems within these provinces, the shallow Quaternary aquifers and the deep, confined Tertiary aquifers. The Quaternary and Tertiary aquifers have differing hydraulic and water-quality characteristics and as a result, different types of users.

1.1.1.1 Quaternary aquifers

The main lithology of the Quaternary sediments beneath Adelaide is mottled clay and silt with interbedded sand, gravel and thin sandstone known as the Hindmarsh Clay. The sands, gravels and sandstones represent aquifers. It contains up to six thin, interbedded sand and gravel layers that form thin aquifers designated Q1 to Q6, in order of increasing depth. The shallowest aquifer, Q1, lies at depths of between 3–10 m below ground level, with an average thickness of 2 m. The deepest aquifer, Q6, occurs up to 50 m below the ground. The confining layers between the Quaternary aquifers consist of clay and silt and range in thickness from 1 to 20 m. They are absent in some areas, allowing hydraulic connection between aquifers and groundwater pumping from the underlying Tertiary aquifer has induced downward leakage (RPS Aquaterra 2011). The Quaternary aquifers provide relatively low yields of up to 3 L/s, to householders who extract the groundwater using domestic wells to water their gardens.

1.1.1.2 Tertiary aquifers

The deep, confined Tertiary aquifers are the largest and most important groundwater resource in the Adelaide metropolitan area. They consist of layers of sand and limestone separated by thin but effective, clay confining layers. A geological cross-section shows significant differences in the thickness and extent of the various Tertiary aquifers in the Adelaide Plains Sub-basin and the Golden Grove Embayment (Fig. 1.2). As with the Quaternary aquifers, the Tertiary aquifers are described by numbers with increasing depth below the ground surface, with the shallowest designated the T1 aquifer.

The sedimentary units in Adelaide Plains Sub-basin are much thicker and more consistent than in the Golden Grove Embayment (Fig. 1.2). The Tertiary aquifers are up to 400 m thick with most extraction coming from the T1 and T2 aquifers, which consist of interbedded limestones, sandstones and fossiliferous sands. The deeper T3 and T4 aquifers are less productive and contain highly saline groundwater.

The Tertiary sediments within the Golden Grove Embayment form a complex sedimentary sequence that thickens from about 20 m in the Tea Tree Gully area to over 300 m near the coast at Brighton. Again, most extractions come from the T1 and T2 aquifers, which consist mainly of sand units that receive lateral recharge across the Eden-Burnside Fault from the fractured rock aquifers of the Mount Lofty Ranges (Figs 1.1 & 1.2). Close to the coast, the deeper T3 and T4 aquifers are encountered below a depth of 150 m and contain brackish groundwater with salinities in excess of 5000 mg/L.

Some leakage occurs between the various Tertiary aquifers; generally, this is downwards from the T1 aquifer to the T2 in the NAP PWA and Regency Park area and upwards from the T2 aquifer to the T1 aquifer in the Central Adelaide PWA.

1.1.2 Noarlunga Embayment

The Noarlunga Embayment is bounded to the south-east by the Clarendon Fault and to the north and north-west by basement outcrop (Fig. 1.1). As a groundwater resource, the Noarlunga Embayment is dominated by sandy aquifers containing brackish or saline groundwater. Sediments reach a maximum thickness of about 170 m in the south-west area of the embayment.

Shallow Quaternary sands and gravels form thin unconfined and confined aquifers with characteristically low well yields (less than 0.5 L/s). Tertiary sands are largely undifferentiated and form mainly confined aquifers beneath the Quaternary sediments at depths ranging between 20–40 m below ground.

The Tertiary aquifers have the lowest salinity (less than 2000 mg/L) in a narrow strip about 1 km wide, adjacent to the Clarendon Fault. Elsewhere, the salinities within the aquifers are typically in excess of 3000 mg/L, possibly higher in the southwest of the embayment where there is little or no data.

1.1.3 Fractured rock aquifers of the Adelaide Hills

The fractured rock aquifers consist of Adelaidean metasediments that form the scarp face of the Adelaide Hills and also underlie the sediments of the Adelaide Plains (Fig. 1.2). These aquifers are highly variable and occur as multiple local aquifer systems. Salinities range from less than 1000 mg/L in higher rainfall areas, to over 3000 mg/L close to the coast. Well yields average about 5 L/s, which is insufficient for extensive irrigation development. However, these aquifers provide significant stock and domestic water supply and are thought to be a significant source of recharge to the sedimentary aquifers beneath the Adelaide Plains.

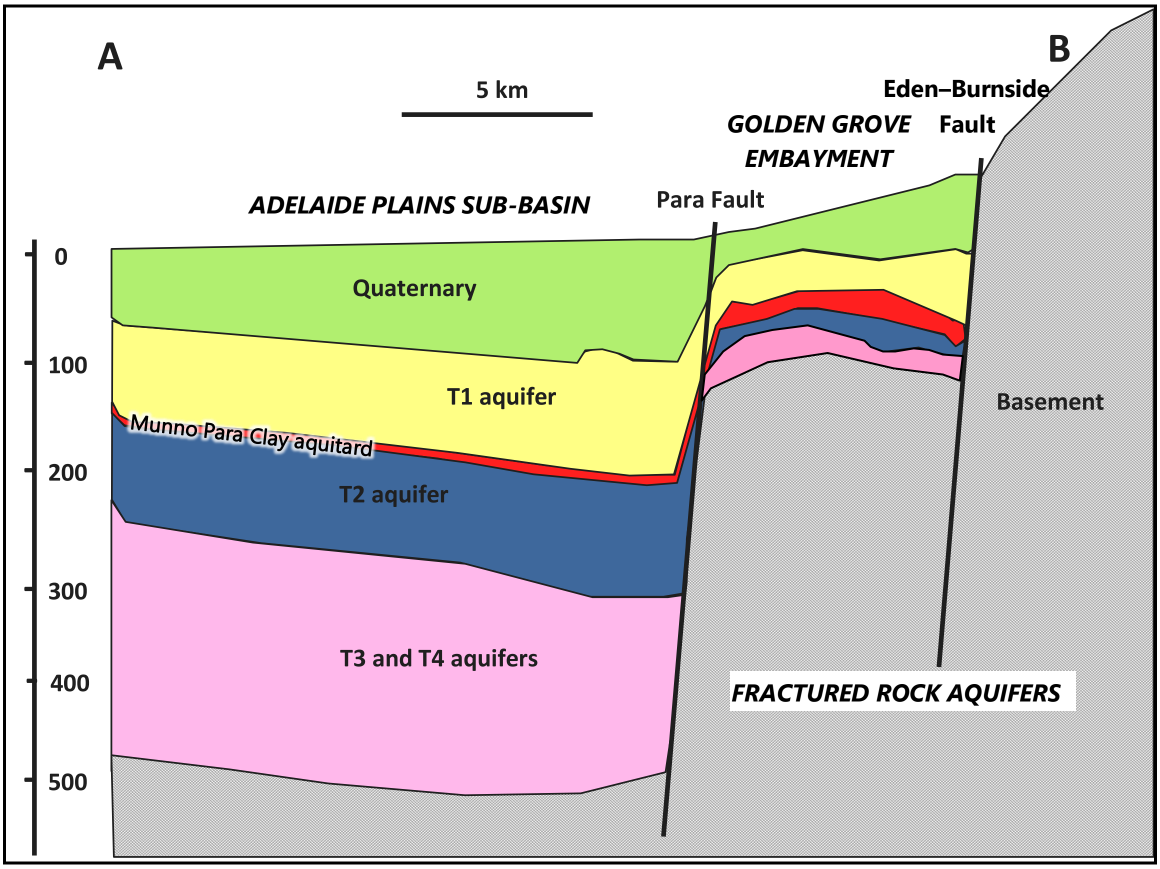

Figure 1.2 Simplified geological cross-section across the Central Adelaide PWA

1.2 Existing data and previous work

The Board has commissioned several groundwater investigations that provide relevant information for determining the groundwater resource capacity for the Adelaide Plains WAP. DEWNR, with RPS Aquaterra, developed the AP2011 groundwater flow and solute transport model that was built upon an understanding of groundwater inflows and outflows, salinity movement and the water budget for the region, as reported in *Adelaide Plains groundwater flow and solute transport model (AP2011)* (RPS Aquaterra 2011). An updated version of the AP2011 model, developed by DEWNR and referred to as AP2013, was used for this project.

This project has also taken into account other previous work commissioned by the Board, including:

- Resource capacity and sustainable development limits for the aquifers of the Noarlunga Embayment and hills zone (SKM 2011a)
- Adelaide Plains groundwater investigation projects, part 3: surface water/groundwater interactions (SKM 2011b)
- Estimating non-licensed groundwater use across the Adelaide Plains PWA (AGT 2011).

1.2.1 Adelaide Plains groundwater flow and solute transport model

RPS Aquaterra worked closely with the DEWNR (Department for Water at the time) Technical Reference Panel to develop the Adelaide Plains Groundwater Flow and Solute Transport Model 2011, known as the AP2011 model (RPS Aquaterra 2011). While groundwater models had previously been developed for the NAP and CA prescribed areas, they did not have the level of complexity required by DEWNR to manage the Adelaide Plains groundwater resource into the future.

RPS Aquaterra worked with DEWNR to develop a history-matched model that is calibrated to observed groundwater levels and salinity trends from 1950 to 2010. Where long-term and complete abstraction data exists (such as the abstraction bores located in the central region of the NAP), good calibration was demonstrated. However, the unmetered abstraction across CA required assumptions to be made about the historical abstraction data and thus good calibration was not always achieved everywhere across the CA area, especially in terms of short-term water level responses.

To demonstrate the predictive capabilities for WAP purposes, the calibrated and independently peer-reviewed AP2011 model was applied to one 'base case' scenario to represent continuation of the extraction and recharge conditions present in 2010 (representing the 'status quo') up until the year 2040. In consultation with DEWNR, this base case scenario was used to test the main drivers and uncertainties surrounding the Adelaide Plains groundwater system. In addition, six predictive scenarios were developed to test the conceptualisation of the model and key assumptions, sensitivity to variations in parameters used in the flow model, and sensitivity to variations in parameters used in the solute (salt) transport model.

The base case scenario indicated that, assuming that 2010 conditions continue, the predicted groundwater levels exhibit a flat to slightly declining trend, which is consistent with the observed and modelled water level trends throughout the historical calibration period. Additionally, the changes in modelled salinity between March 2010 and 2040 generally show that salinity rarely rises beyond 500 mg/L over the 30 year prediction period. However, areas of salinity increase are most noticeable within the T1 aquifer at Osborne and various locations in proximity to the coast and within the T2 aquifer in the area around Virginia where large concentrated abstraction is assumed to continue.

1.2.2 Resource capacity and sustainable development limits for the aquifers of the Noarlunga Embayment and hills zone

This project by SKM was aimed partly at determining the resource capacity of the fractured rock of the hills area and the Noarlunga Embayment and partly at deriving the sustainable development limit of the resource. The SKM report defines groundwater resource capacity as the volume of annual recharge to a GMZ. The sustainable development limit as used in the WMLR WAP is the resource capacity minus the current extraction, the baseflow and any unlicensed usage within the zone. However, SKM (2011a) argued that a further crucial volume of groundwater that needs to be considered in the derivation of the sustainable development limit is the throughflow to another groundwater management area that has already been accounted for, so they added throughflow to the process.

Two separate groups of sustainable development limits were derived based on two estimates of throughflow—estimates from existing literature and estimates from the AP2011 model. The calculations suggest that the fractured rock areas zones all have a negative sustainable development limit, under different baseflow scenarios based on the throughflow calculated using existing literature. However, analysis of the hydrographs (where available) does not indicate significant drawdown occurring (although there is some evidence of groundwater level decline in one of the zones), signifying that these catchments are not highly stressed at the zonal scale. The sustainable development limit for each zone based on the throughflow estimates from the AP2011 are all still in slight deficit under average baseflow conditions, but appear to be in surplus under drier baseflow conditions.

The AMLR NRM Board asked Sinclair Knight Merz (SKM) to recommend suitable management options to support the long-term sustainability of the groundwater resources. Their management options fall into two broad areas—options that manage the volume of water that can be taken and options that control where the water can be taken from. These included extraction limits, buffer zones to protect areas/entities of high values, approaches to the management of stressed areas, management of trade, monitoring and evaluation and adaptive management principles.

SKM considered a conservative approach to management of these zones would be to set a sustainable development limit equal to current usage, effectively enforcing a moratorium on any further licensing of groundwater extraction until further clarification of recharge to each catchment is obtained and further groundwater monitoring data becomes available. The volume of throughflow, baseflow and current groundwater extractions all need to be maintained at current volume based on the current analysis.

1.2.3 Adelaide Plains groundwater investigation projects, part 3: surface water/groundwater interactions

Each stream covered in the assessment by SKM (2011b) were divided into individual reaches and assigned with various attributes such as geological setting, stream type and connectivity class and a level of certainty associated with the categorisation. Individual reaches were prioritised based on physical setting and the presence of nearby groundwater extraction (from both confined and unconfined aquifers). The highest priority reaches are those where commercial extraction is nearby and the streams have a physical setting where the impacts of groundwater extraction is likely to lead to a more immediate impact on stream flow of a greater potential magnitude (i.e. streams in faulted or fractured rock zones). Lower priority reaches occur where there is no groundwater extraction identified, or where only stock and domestic extraction occurs in sedimentary aquifers. The priority settings can be used to prioritise future technical assessments and monitoring requirements, or to structure management responses.

Comparison of river stage height data and groundwater levels in adjacent shallow bores indicates a likely connection between surface water systems and the shallow aquifer zone.

Results from the comparison of the base flow indices of Brownhill Creek and First Creek with annual rainfall showed that the upper catchment receives a greater proportion of baseflow compared to that occurring on the plains.

Findings that indicated upstream sections of Brown Hill and First Creek to be gaining and then become losing streams on the downthrown side of the fault line are consistent with those of Green *et al*. (2010).

Conceptual models were developed that summarise the nature of groundwater/surface water interactions in the study area. Gaining streams occur throughout the Fractured Rock Zone (Hills), the streams switch to losing as they pass the Fault zone (at the break of slope where the geology changes from basement rock to sedimentary); and the streams continue to lose water (albeit at a more gradual rate) as they pass across the plains. Some streams may gain water in parts of the plains, particularly as they near the coast.

1.2.4 Estimating non-licensed groundwater use across the Adelaide Plains PWA

The Board engaged Australian Groundwater Technologies (AGT) to undertake the estimation of groundwater extraction by non-licensed users across the CA and NAP prescribed areas. In the NAP PWA, stock and domestic groundwater use is licensed and is therefore known but there is currently a limited understanding of non-licensed extraction throughout the Central Adelaide. Non-licensed water extraction includes stock and domestic use and water authorised by the Minister for Water and the River Murray under Section 128 of the Act, e.g. commercial forestry groundwater use and water used for firefighting and public road making.

AGT (2011) developed a systematic methodology for querying the SA Geodata drillhole database in order to determine the number of operational, non-licensed drillholes within the NAP and CA prescribed areas. Various assumptions about typical rates of extraction were used to estimate the non-licensed extraction for each major aquifer.

1.3 Established conceptual model

A conceptual model of the aquifer systems within the CA and NAP PWAs can be developed from a synopsis of existing information.

The fractured rock aquifers of the Mount Lofty Ranges that crop out along the eastern and southern border of the CA PWA are recharged predominantly via rainfall but may also receive some recharge from streams during periods of high flood. Discharge from the fractured rock aquifers occurs through springs and seeps at the break of slope, as baseflow to streams and from groundwater extraction from pumping. Discharge also occurs at depth as throughflow to the adjoining Quaternary and Tertiary sedimentary aquifers of the plains across the Para and Eden–Burnside Faults. The faults also provide pathways for groundwater to flow from streams into the sedimentary aquifers.

Streams change from gaining to losing as they move across the faults and are thought to be predominantly losing throughout the Adelaide Plains, with water percolating from the streams into the shallow Quaternary aquifers. However, the Quaternary sediments present across the plains are not highly permeable and as such, any recharge to the aquifer from overlying streams is likely to be localised and occur over a long period of time. Streams that cross the plains are then thought to become gaining just before they discharge into the Gulf of St Vincent.

Discharge from the Quaternary aquifers occurs from groundwater extractions for stock and domestic use and uptake from groundwater dependent ecosystems (GDEs) where they may form shallow watertables that plant roots can access, or by providing baseflow to creeks and streams. The Quaternary Hindmarsh Clay confining layer reduces leakage to or from the underlying Tertiary aquifers in the NAP PWA. However, these confining beds are absent or thin out in some areas, allowing hydraulic connection between aquifers. This can be observed, for example, between the deep Quaternary aquifers in the Little Para area, the Waterloo Corner area (between the Q4 and T1 aquifers) and in an area several kilometres north of the Gawler River. Vertical leakage between the Quaternary aquifers and the T1 aquifer can happen in both directions. However, the vertical gradient downwards increases dramatically during summer due to T1 abstraction, particularly throughout the CA PWA. However, the rate of leakage will be affected by the permeability of the confining layer separating the Tertiary and Quaternary aquifers.

Due to the predominantly confined nature of the Tertiary aquifers, their main source of recharge is thought to be lateral throughflow from the fractured rock aquifers. In regions where the Tertiary aquifers crop out, recharge occurs via direct rainfall infiltration. The main source of discharge from the Tertiary aquifers (mainly T1 in the central area and T2 in the northern area) is groundwater extraction for commercial purposes. Intensive extraction in Virginia, Waterloo Corner, Osborne, West Lakes, Grange, Thebarton, Regency Park and Dry Creek has created long-standing cones of depression where present-day groundwater pressure levels are much lower than pre-development levels. Extraction can also impact the shallow aquifer systems in areas where it crops out. The Tertiary aquifer discharges along the coastline into the Gulf St Vincent or via upward leakage to the Quaternary aquifers in the NAP PWA. Historically, upward gradients have existed from T2 to T1 in the Central Adelaide PWA and downwards from T1 to T2 in the NAP PWA. Pumping has increased this effect.

The Noarlunga Embayment region is similar conceptually to the Adelaide Plains region, but there have been fewer studies and there is limited data in the region to validate the conceptualisation. The fractured rock aquifers adjoins the sedimentary aquifers of the Noarlunga Embayment, separated by the Clarendon Fault. The upper stream reaches are thought to be gaining where they are deeply incised and pass through the fractured rock aquifers. The streams change to losing as they flow across the fault at the upper edge of the Noarlunga Embayment. The Field River passes back into fractured rock and is likely to be gaining before it discharges into the sea. Christies Creek passes throughout the Golden Grove Embayment and is thought to be predominantly losing in this area. The sediments associated with the Noarlunga Embayment tend to be less permeable than those of the Adelaide Plains region.

2 Methodology

2.1 Management based on resource condition limits (RCLs)

In keeping with the standards set by the National Water Initiative (NWI) for sustainable groundwater use (NWC 2010), South Australia has developed a water planning framework that provides a set of instruments to manage groundwater extraction in priority resources around the state. In developing a WAP for a prescribed area, it is a statutory requirement to determine the capacity of the groundwater resource to meet the current and future needs of various users. To date, most WAPs have done this using a water balance approach, in which the resource capacity (RC) is taken to be the long-term average amount of water recharging or discharging from the groundwater system each year. The RC is then divided between consumptive and non-consumptive requirements, in a manner that balances the different demands, which can be at some times in conflict (e.g. increased irrigation for economic purposes can induce a decrease in streamflow which impacts environmental and social values).

An alternative, risk-based approach can be adopted if both the likelihood of an impact on the resource condition (or associated value) and the consequence of that impact are assessed, with a subsequent consensus on the acceptability of such risks. An assessment of the likelihood of potential impacts on the condition of the groundwater resource can be quantified in a number of ways, for example, using a numerical model to project the response of a groundwater resource to future extraction scenarios. The consequence of such impacts on the groundwater condition or associated value may then be developed through stakeholder and community consultation, to develop a risk assessment of a particular groundwater extraction rate. The condition of the resource is then monitored from year to year, allowing management of the total volume of licensed allocation and extraction, mainly through the means of statutory reviews of the Adelaide Plains WAP.

There are certain limitations associated with using a water balance approach to determining groundwater RC, particularly when establishing the portion of this volume that is available for consumptive use: it can lead to an overly conservative approach to groundwater use in some parts of the system that can limit economic development, and in other parts of a system can lead to impacts associated with over-use. Problems can also arise from the large uncertainties involved in determining the inputs to or outputs from a resource. For example, recharge estimates to an unconfined aquifer can vary by more than 100%, depending on the method used (Cranswick *et al*. 2015), and similarly estimates of throughflow into a confined sedimentary aquifer from an adjoining fractured rock aquifer are difficult to quantify with confidence. Furthermore, a resource with limited storage capacity, such as a fractured rock aquifer, is likely to respond more markedly to variations in recharge and groundwater extraction, and therefore may not be able to sustain extraction at long-term recharge rates in drier short-term periods.

As they evolve, WAPs are increasingly addressing some of these limitations by focusing management efforts on keeping the condition of the resource within acceptable limits—i.e. within thresholds beyond which there is an unacceptable level of risk to the economic, social and environmental values associated with the resource. The **resource condition limit (RCL)** approach has been documented by Richardson, Evans and Harrington (2011), and is applied to the present project in preparation for the development of the Adelaide Plains WAP. This approach requires the identification of bio-physical indicators that track the response of the groundwater system to various stresses such as extraction, land-use change or climate change (e.g. decreased recharge). These **resource condition indicators (RCIs)** are typically parameters that can be directly monitored, such as groundwater levels or salinity, but can also be derived from other field observations, such as estimates of groundwater discharge into watercourses (baseflow), or estimates of aquifer storage. The next step is to determine the acceptable levels of change to the condition of the system, with reference to RCIs. The level of change that may be considered acceptable should be informed by several considerations, including a technical understanding of the vulnerability of the resource and ecosystems that are dependent on it, as well as the economic and social importance of the resource. The determination of RCLs thus requires input from various stakeholders.

In an unconfined aquifer, the RCL could be the water levels at which it becomes uneconomical for irrigators to lower or deepen wells, or the levels of stream discharge (baseflow) which are likely to see major environmental impacts.

In a confined aquifer, it could be the groundwater head levels which are likely to increase downward leakage of overlying more-saline groundwater to the extent that the pumped water becomes unusable, or the level at which groundwater availability in shallower parts of the aquifer is reduced. Water managers can determine these RCLs in a number of ways, the simplest being to identify historical situations where the resource has declined to the state where economic or environmental impacts have been severe or unacceptable. Where insufficient information exists to identify RCLs in this way, it is necessary to make predictions about how the system will respond to unprecedented stresses, noting the level of uncertainty involved, and then determine the limits through a process of community consultation.

A groundwater resource may be divided into smaller units, each of which may have certain impacts of concern. For example, a certain part of the aquifer at risk of ingress of high-salinity water, or another part where extraction impacts on the condition of GDEs. These units can be treated as separate GMZs, where specific RCIs are identified and RCLs determined.

Once RCLs are determined, it then becomes possible to determine **recommended extraction limits (RELs)**—the volume of extraction for consumptive use that can be sustained over time to keep the system from exceeding these RCLs. If extraction management needs to be responsive to the condition of the resource, thresholds can be set beyond which a management response may be developed—an adaptive management approach that allows water users a reasonable amount of security in their access to the resource while also offering protection to GDEs from unacceptable impacts.

When using RCLs, it is no longer necessary to conceptualise the capacity of the resource as the long-term average annual volume of water entering or leaving a system. Instead, the emphasis is placed on the condition of the system that needs to be maintained over a certain timeframe in order to meet the various demands on a resource during that period. The RELs that are set for each GMZ of the resource then reflect the capacity of the resource to meet various demands, current and future.

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

2.2 Aquifer groupings to potential consumptive pools

A consumptive pool is defined in the Act as the water that will from time to time be taken to constitute the resource within a particular part of a prescribed water resource, as determined—(a) by or under a water allocation plan for that water resource; or (b) in prescribed circumstances—by the Minister. A consumptive pool is comprised of the water available for human demand, i.e. licensed and non-licensed extraction, certain uses of water that are authorised under Section 128 of the Act, and any water held by the Minister. However, we do not refer to consumptive pools directly in this study as these will be developed at a later date by the working group. Instead we have created a number of aquifer groupings (AGs) that could in future, act as the starting point for consideration of multiple consumptive pools across the NAP and CA PWAs.

The prescribed areas include a range of hydrogeological settings, with varying degrees of groundwater extraction and potential risks with local water resource management issues. Five different aquifer groupings encompassing both sedimentary and fractured rock aquifers have been delineated (Fig. 2.1). They include:

- T1 and T2 aquifers, and the fractured rock aquifers of the Golden Grove Embayment
- Quaternary aquifers
- Noarlunga Embayment
- T3 and T4 aquifers
- fractured rock aquifers of the hills face zone.

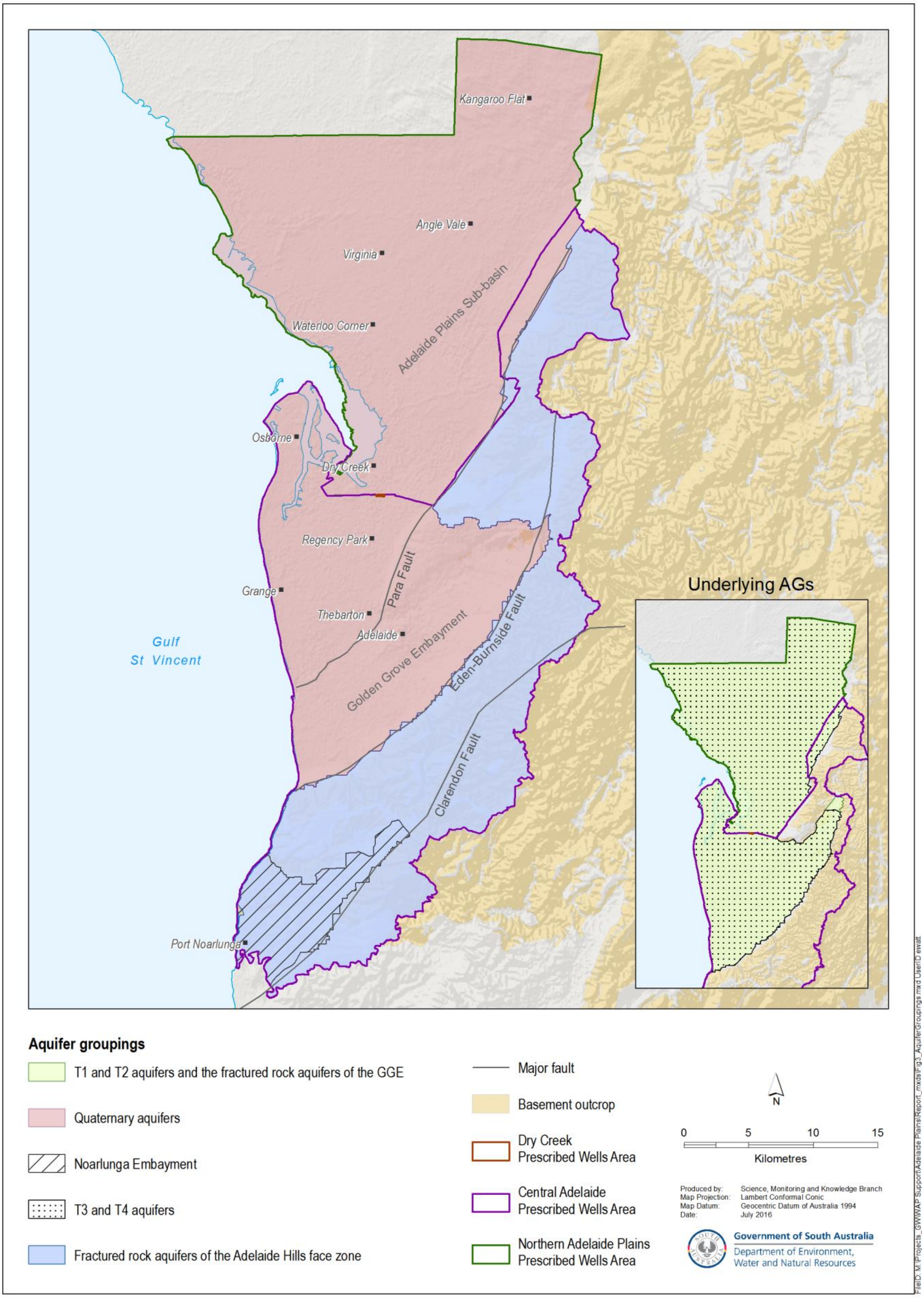

Figure 2.1 Aquifer groupings for the Northern Adelaide Plains and Central Adelaide PWAs

These aquifer groupings contain aquifers with similar characteristics and management issues. The AGs are based on hydrogeological and ecological factors only, and further consideration of management objectives, and social, economic and community values may result in some changes to their boundaries before they could be adopted as consumptive pools.

In accordance with the Act, the WAP will establish the volumes for each consumptive pool. Water entitlements cannot be transferred between the pools but could be transferred within them, subject to any other conditions set out in the WAP.

2.3 Delineating groundwater management zones

A number of different groundwater management zones (GMZs) are proposed for the AGs based on the type of aquifer, demand for groundwater and local management issues (Table 2.1). Cadastral boundaries and roads were used to delineate the boundaries of these zones so they can be easily recognised in the field.

The lack of major licensed extractions, similar characteristics of, and interconnectivity between the Quaternary aquifers, resulted in them being grouped into one GMZ. The different GMZs for the T1 and T2 aquifers were delineated based on the outcomes of the modelling scenarios combined with the RCLs. The fractured rock aquifers management zones were delineated using the same criteria as those used by Green and Zulfic (2008) for the Water Allocation Plan for the Western Mount Lofty Ranges Prescribed Water Resources Area, that is, surface water sub-catchments and geology. The location of gauging stations with sufficient data to calculate baseflow volumes was also considered for the fractured rock aquifer zones.

2.3.1 Quaternary aquifers GMZ

All Quaternary sub-aquifers of the Adelaide Plains Sub-basin and Golden Grove Embayment are contained within the Quaternary aquifers GMZ (Fig. 2.2). The Quaternary aquifers contain good quality water with TDS concentrations of less than 1500 mg/L, typically resulting from recharge from streamflow, but can reach concentrations in excess of 20 000 mg/L in the perched aquifers near Virginia. The Quaternary sub-aquifers provide low yields and as such, have typically been developed only for domestic purposes by hundreds of 'backyard bores' in the CA PWA.

2.3.2 Adelaide Plains T1 aquifer GMZs

The T1 aquifer provides the majority of extractions in the CA PWA. Potentiometric surface contours indicate cones of depression have formed in a number of areas resulting from concentrated extraction. Three GMZs around these areas have been proposed: T1 Dry Creek (industrial), T1 Thebarton (industrial) and T1 Grange (irrigation) (Fig. 2.3). They have been delineated based on the observed −5 m AHD potentiometric surface groundwater elevation contours produced by Scenario 5 of the AP2013 model and aligned with the nearest cadastre boundary or road. The remaining area of the T1 aquifer in the CA PWA that is outside these zones is designated the T1 Central Adelaide GMZ (Fig. 2.3).

A zone for the T1 aquifer within the NAP PWA may be useful for administrative purposes given its extraction history and existing licensing arrangements. It has been delineated in this report (T1 NAP GMZ), but could be combined with the T1 Central Adelaide GMZ to form the T1 Regional GMZ in the final WAP for management purposes.

2.3.3 Adelaide Plains T2 aquifer GMZs

The T2 aquifer provides the majority of extractions in the NAP PWA where the T1 aquifer is thin or absent, and in the northern half of the CA PWA. Five GMZs around areas of concentrated extraction are proposed where potentiometric surface contours indicate cones of depression have formed: T2 Regency Park (industrial), T2 Osborne (industrial), T2 Kangaroo Flat (irrigation), T2 Virginia (intensive irrigation) and T2 NAP (irrigation) (Fig. 2.4). These zones have been delineated based on the observed –30 m AHD potentiometric surface elevation contours produced by Scenario 5 of the AP2013 model and aligned with the nearest cadastre boundary or road. Scenario 5 was chosen as it corresponds to the highest levels of extraction from the T2 aquifer before resource condition limits are projected to be breached.

The remaining area of the T2 aquifer that lies outside of these zones is designated the T2 Regional GMZ (Fig.2.4). This zone extends into the CA PWA where extraction from the T2 aquifer is currently minimal or non-existent.

2.3.4 Golden Grove Embayment GMZs

The depositional environments for sediments in the Golden Grove Embayment (GGE) are different to those for the Adelaide Plains Sub-basin. Consequently, the lithologies of the sedimentary aquifers are also sometimes different. These aquifers are thinner (Fig. 1.2) and more likely to be interconnected than those in the sub-basin. Because of the difference in aquifer characteristics, one regional GMZ for the T1 and T2 aquifers combined is proposed (Fig. 2.5). Another GMZ for the fractured rock aquifers of the GGE is also proposed (Fig. 2.7).

Table 2.1 Proposed groundwater management zones and current consumptive demand

Aquifer grouping	Proposed groundwater management zone	Current consumptive demand		
		Licensed extraction[2]	Non-licensed extraction[3]	Allocation[4]
1. T1 and T2 aquifers, and the fractured rock aquifers of the Golden Grove Embayment	T1 NAP	3199	46	5081
	T1 Dry Creek	2972	0	2972
	T1 Grange	1940	0	1940
	T1 Thebarton	1383	1	1383
	T1 Central Adelaide	1777	4	1777
	T2 NAP	2230	21	4483
	T2 Kangaroo Flat	1321	3	1321
	T2 Virginia	9224	60	14 940
	T2 Regional	103	138	212
	T2 Osborne	1199	7	1199
	T2 Regency Park	1732	0	1732
	T1 and T2 Golden Grove Embayment	1526	44	1601
	Golden Grove Embayment FRAs	14	19	14
2. Quaternary aquifers	Quaternary aquifers	964	1418	1526
3. Quaternary and Tertiary aquifers of the Noarlunga Embayment	Noarlunga Embayment	0	5	0
4. T3 and T4 aquifers	T3 and T4 aquifers	0	0	2300
5. Fractured rock aquifers of the Adelaide Hills face zone	Northern FRAs	960	176	960
	Torrens FRAs	539	214	539
	Patawalonga FRAs	464	239	464
	Southern FRAs	155	573	155

[2] Licensed extraction is the average extraction from metered wells in the NAP PWA for the years 2006 to 2013 inclusive. For the CA PWA extraction was estimated based on the license applications from existing users. See Section 2.5.2 for more details.

[3] Non-licensed extraction is taken from AGT (2011), see Section 2.5.1.2.2 for more details.

[4] Allocation volumes are sourced from a dataset prepared by the AMLR NRM Board and provided to RPS-Aquaterra in 2013, and represent allocation volumes for year 2011 for the NAP PWA and equals the extraction estimated for the CA PWA.

2.3.5 Noarlunga Embayment GMZ

The Noarlunga Embayment, with both the Quaternary and Tertiary aquifers, has been classified as one aquifer grouping and one GMZ is also proposed due to limited extraction and demand because of the highly urbanised nature of the zone (Fig. 2.5).

2.3.6 Fractured rock aquifers GMZs

The fractured rock aquifers (FRAs) of the Adelaide Hills is the fifth aquifer grouping and four GMZs are proposed (Fig. 2.7). The management zones were delineated using the same criteria as those used by Green and Zulfic (2008), that is, surface water sub-catchments and geology. The location of gauging stations with sufficient data recorded to calculate baseflow volumes was also considered.

Because these zones are delineated by geology and gauging station location, the boundaries are slightly different to those devised by SKM (2011a).

The Northern FRA GMZ encompasses the surface water sub-catchments of Smith and Adam Creeks, Little Para River and Dry and Cobbler Creeks. This is because of the similar surface geology and the surface water gauging station that was used for the baseflow calculation by SKM is located in the centre of the GMZ.

The Torrens FRA GMZ encompasses the River Torrens surface water sub-catchment. It also contains the First, Second, Third, Fourth, Fifth and Sixth Creeks sub-catchments.

The Patawalonga FRA GMZ encompasses the Patawalonga Basin and Holdfast Bay sub-catchments.

The Southern GMZ FRA encompasses the Field River, Christie Creek, Curlew Point, Witton Bluff, Hallett Cove and part of the Onkaparinga River sub-catchments. This zone includes the fractured rock aquifers underlying the Tertiary sediments within the Noarlunga Embayment.

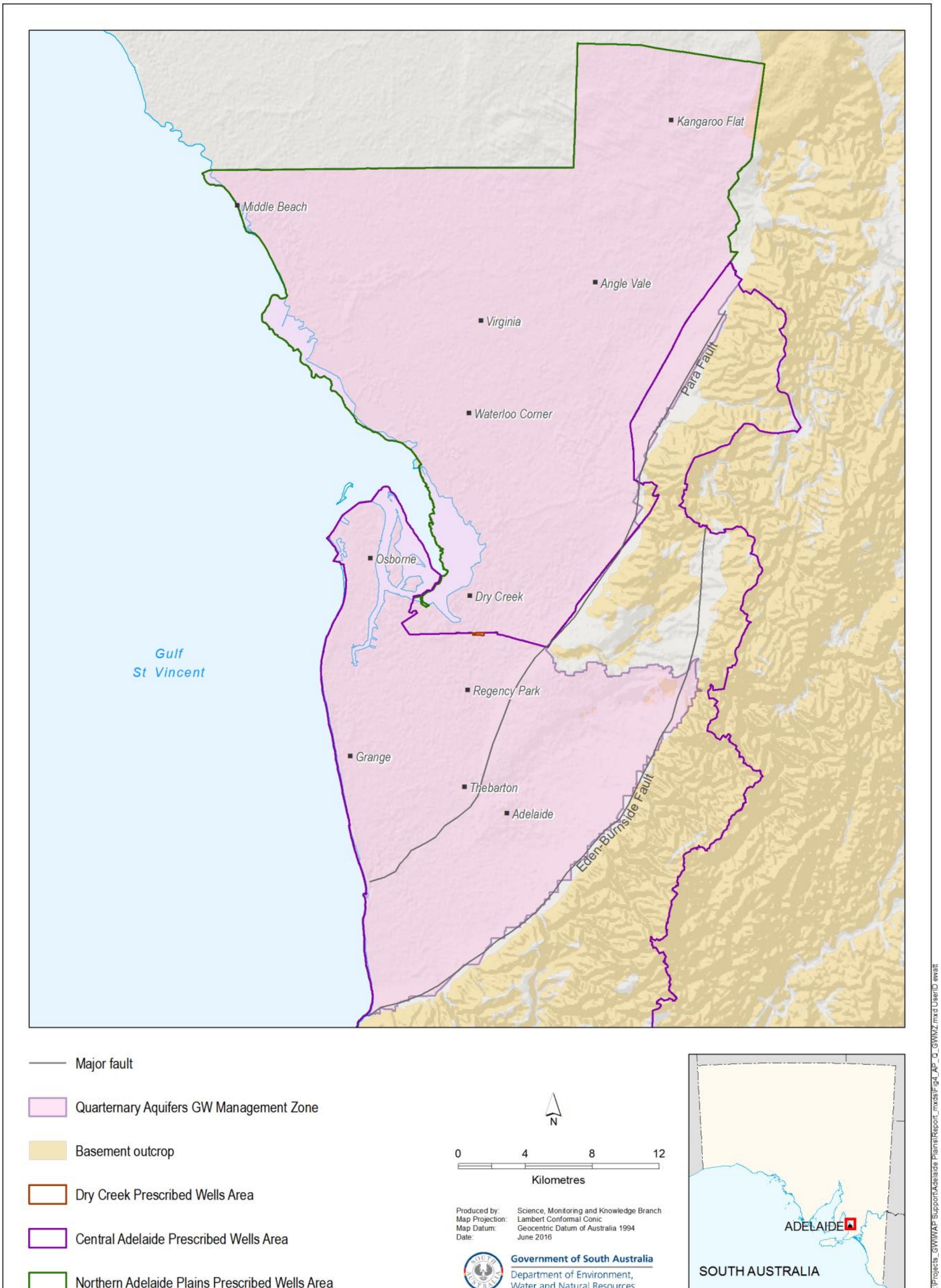

Figure 2.2 Proposed Quaternary aquifers GMZ

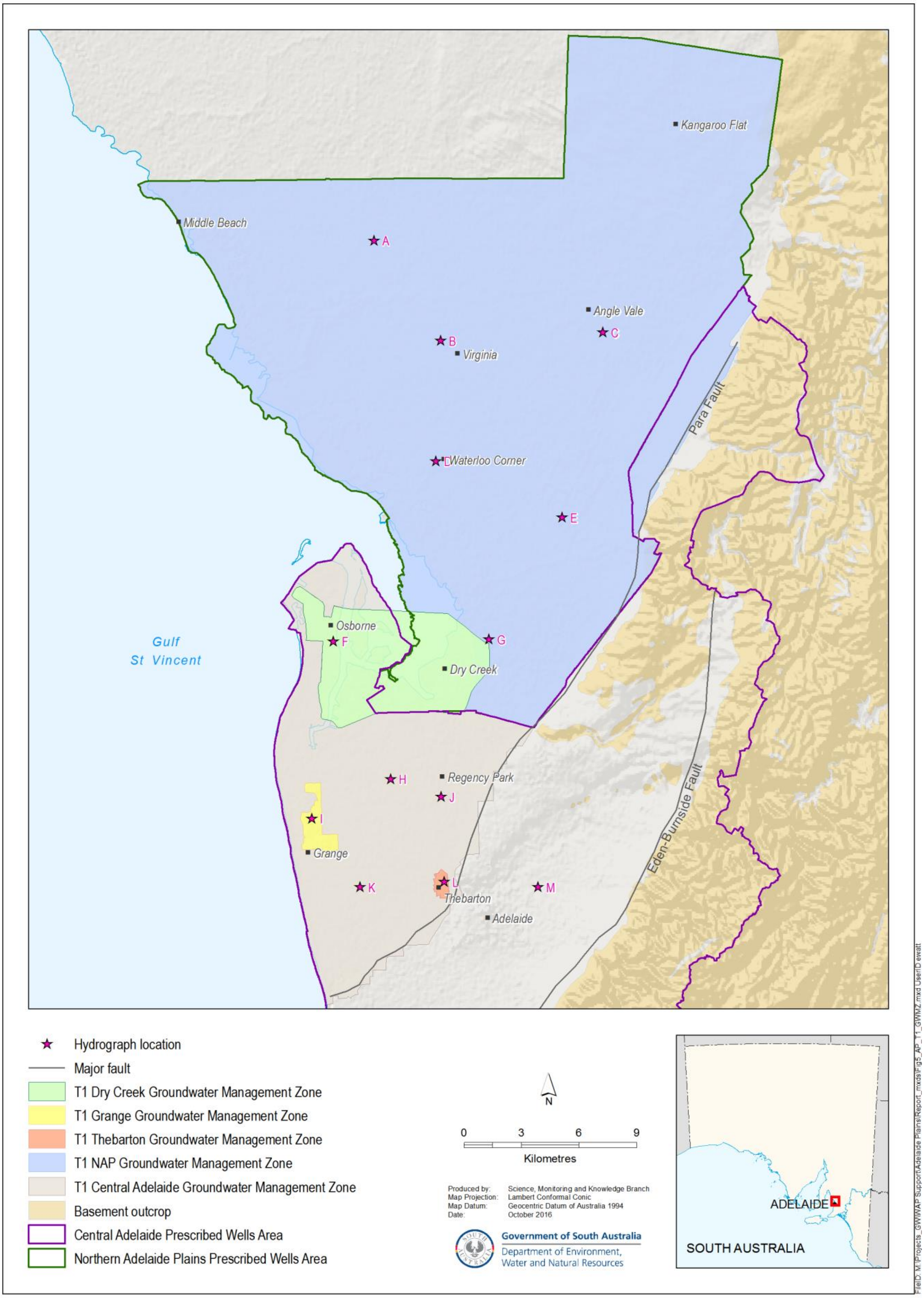

Figure 2.3 Proposed Adelaide Plains T1 aquifer GMZs

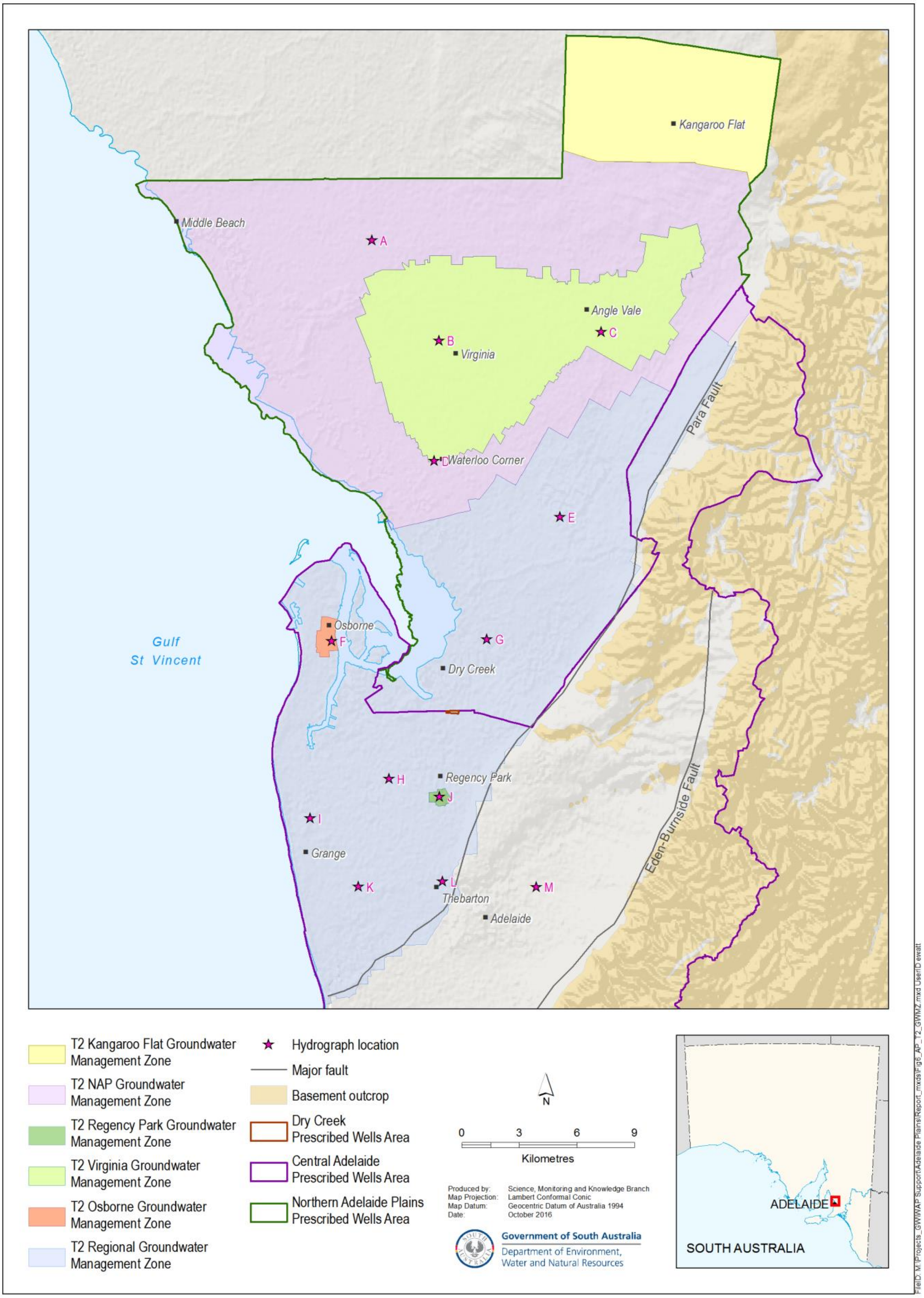

Figure 2.4 Proposed T2 aquifer GMZs

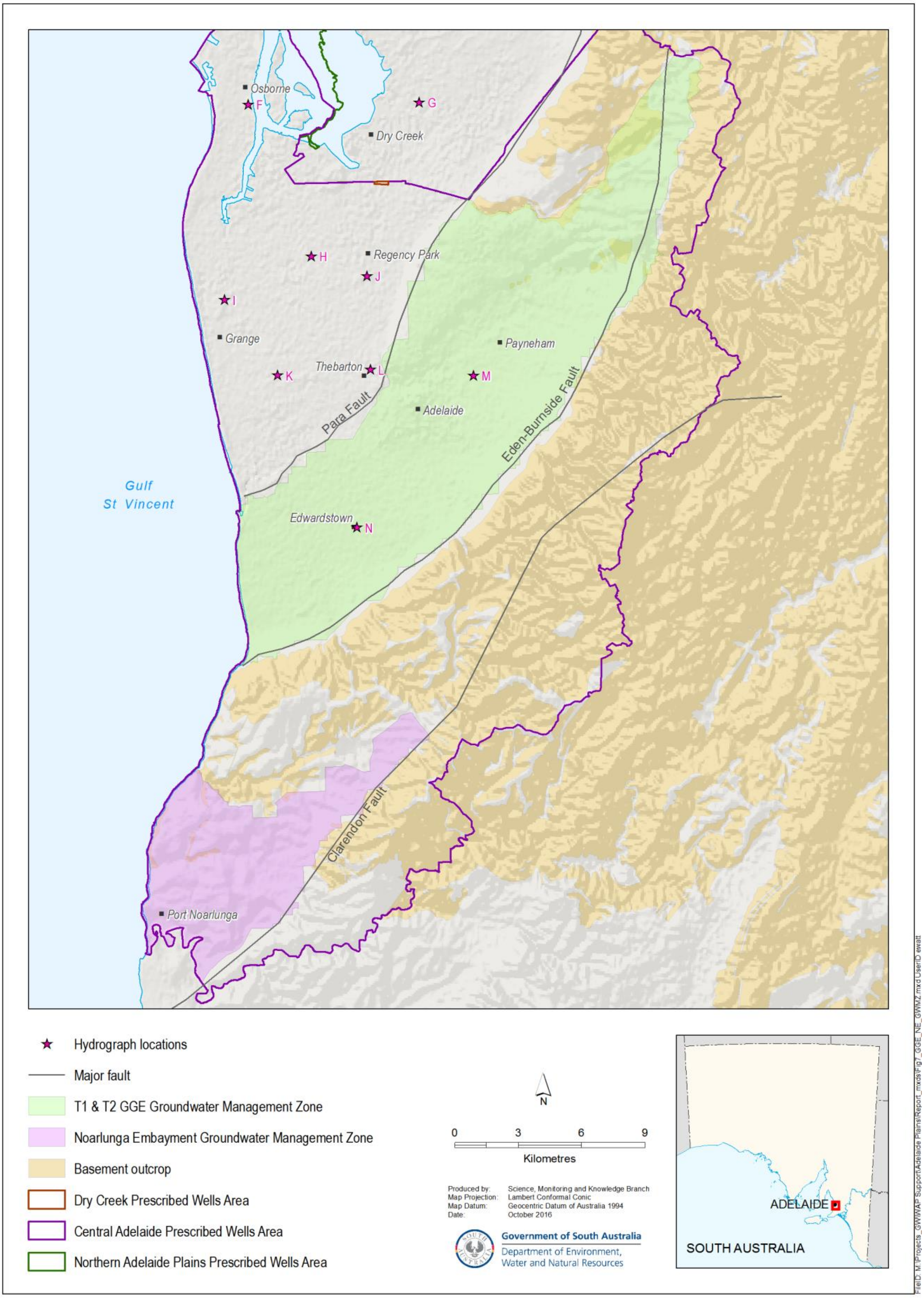

Figure 2.5 Proposed Noarlunga Embayment and Tertiary Golden Grove Embayment GMZs

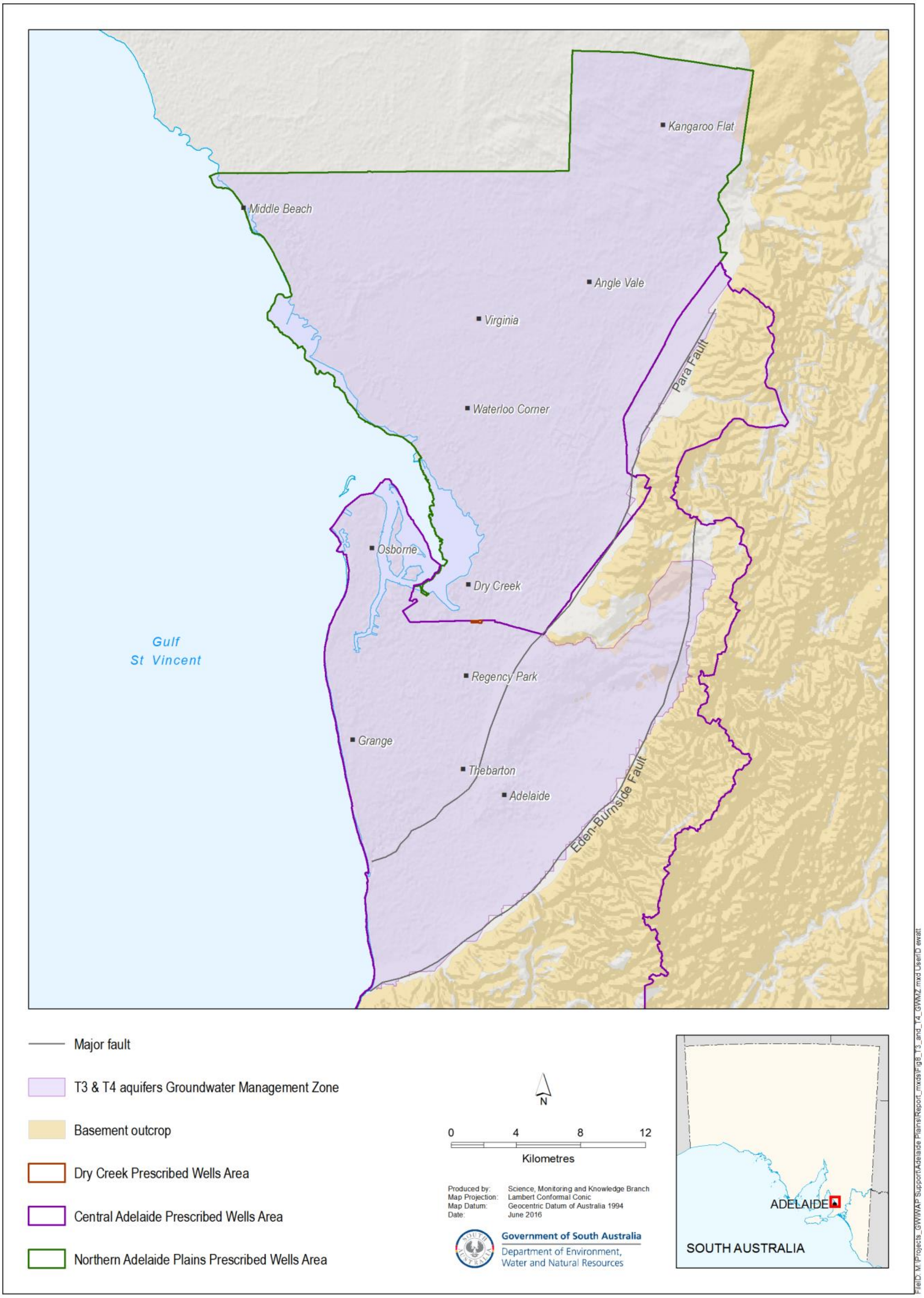

Figure 2.6 Proposed T3 and T4 aquifers GMZ

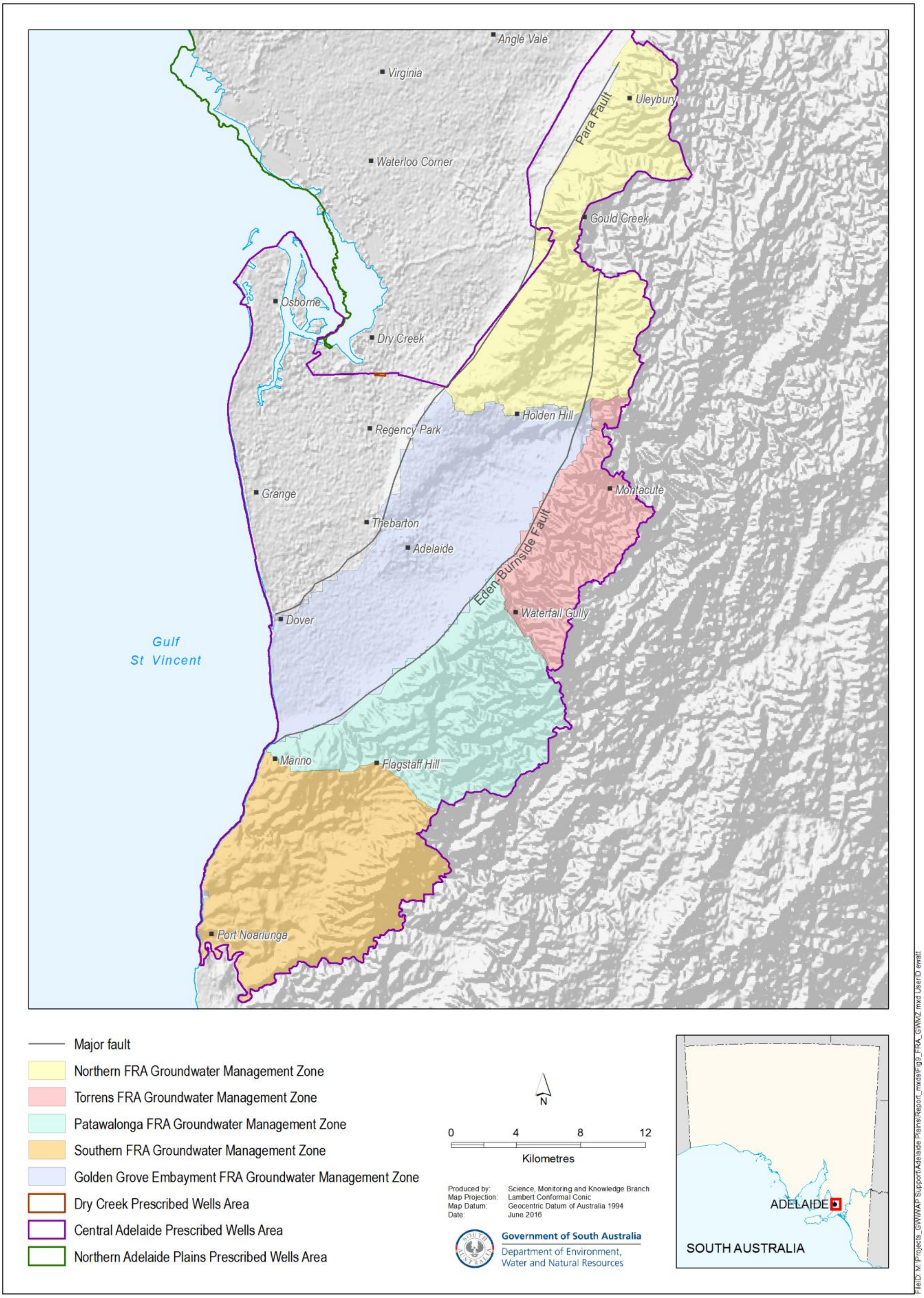

Figure 2.7 Proposed fractured rock aquifers GMZs

2.4 Resource condition indicators and limits

Recommended extraction limits need to be implemented that recognise the sustainable use of the resource. Such limits need to recognise the fundamental properties of the aquifer that need to be protected and the ecosystems that rely on the groundwater resource for their survival. A groundwater 'resource condition indicator' is a measurable groundwater parameter such as groundwater pressure levels, or salinity. A groundwater 'resource condition limit' is the acceptable level of change to the nominated indicators that cannot be exceeded without affecting users of the resource by more than an acceptable or agreed amount. For example, the resource condition indicator may be the aquifer water levels and the resource condition limit may be the drawdown or decline that has occurred by a certain point in time. The groundwater flow model can then be used to estimate the rate of groundwater extraction, or the 'recommended extraction limit', that can occur without the drawdown (resource condition indicator) exceeding this acceptable value (resource condition limit). The setting of resource condition limits enables a discussion of what is an acceptable level of extraction from the resource while aiming to safeguard other desirable values. For example, the T1 and T2 aquifers of the plains have significant cones of depression that may be considered by some as unsustainable. However, as these groundwater pressure levels have been maintained for a long time and are the result of extractions that sustain local industries, the impact on the resources is considered acceptable. Therefore, the recommended extraction limits may be the volumes of water that can be extracted annually while maintaining the cones of depression at or near the current levels over a specified time frame. This would maintain a manageable level of risk to the condition of the resources in the long term while still allowing for economic and social development in the area.

Different resource condition indicators and limits were assigned to the proposed groundwater management zones within the CA and NAP prescribed areas. The resource condition indicators and resource condition limits for the aquifers within the CA and NAP prescribed areas are:

- the volume of water extracted annually from the Quaternary aquifers must not result in unacceptable impacts to GDEs or existing users
- the winter groundwater pressure level (or annual maximum hydraulic head) in the T1 aquifer should not drop below –5 m AHD in the Waterloo Corner area and –15 m AHD in the Central Adelaide PWA by 2040. This is to mitigate the salinity threat from increased downward leakage of salty water from the Q4 aquifer and the encroachment of higher-salinity water from surrounding areas
- the winter groundwater pressure level in the T2 aquifer should not drop below the base of the confining layer separating the T1 and T2 aquifers by 2040 to avoid compromising the structural integrity of the confining layer and the T2 aquifer
- the annual volume of baseflow from the fractured rock aquifers is maintained
- the volume of water extracted annually from the Quaternary and Tertiary aquifers in the Noarlunga Embayment must not result in unacceptable impacts to GDEs or existing users.

Maintaining the lowered groundwater pressure levels in the T1 and T2 aquifers has the potential to cause seawater intrusion, inter-aquifer leakage or the lateral encroachment of higher-salinity groundwater from other areas of the aquifer. This could increase the salinity to a concentration that exceeds the salinity threshold for irrigated crops and cost-effective reverse osmosis, thereby negatively affecting the productivity of the aquifer, especially in the Virginia area. However, the AP2011 model scenarios (RPS Aquaterra 2011) indicated that changes in modelled salinity between March 2010 and 2040 generally show that salinity rarely changes beyond 500 mg/L over the 30 year prediction period, with areas of salinity increase most noticeable within the T1 aquifer at Osborne and various locations in proximity to the coast, and within the T2 aquifer in the area around Virginia, i.e. in areas of concentrated extraction where inter-aquifer leakage is potentially high. Rises in salinity are not necessarily a problem in the T1 aquifer as the largest users outside the NAP employ reverse osmosis desalination to reduce the salinity of extracted groundwater. While the extraction limits recommended in this report are based on maintenance of water levels and avoidance of impacts on users and GDEs, salinity-based resource condition indicators and limits could also be used in the WAP to restrict extractions if it can be shown that extractions are driving salinity increases.

2.5 Determining recommended extraction limits

A water balance approach was used for the Quaternary aquifers, fractured rock aquifers and sedimentary aquifers of the Noarlunga Embayment to estimate the recommended extraction limit that can occur without the resource condition indicators exceeding their limits.

The resource capacity of the Tertiary aquifers could not be estimated using the water balance approach due to the complexity of the recharge mechanisms of these systems, such as throughflow and vertical leakage, and the uncertainty surrounding the estimation of these volumes. This is why the AP2013 groundwater flow model was used to calculate the recommended extraction limits for the Tertiary aquifers GMZs.

It should be noted that the recommended extraction limits for consumptive use in each zone will not necessarily equate to the extraction limits that will be defined in the WAP. Consideration of social and economic factors and what might be considered as acceptable impacts by stakeholders may result in the WAP's extraction limits being different to the extraction limits recommended within this report.

2.5.1 Water balance

In this report, the resource capacity refers to the total volume of groundwater available for all uses, that is, the volume of groundwater available for both consumptive demands (human use) and non-consumptive demands (environmental requirements), or:

Resource capacity = consumptive demand + non-consumptive demand

The volume of water available for consumptive demand is the amount of water (for both licensed and non-licensed purposes) that can be extracted without causing unacceptable long-term declines in groundwater quantity or quality, or unacceptable impacts to GDEs or assets. The water available for licensed demand is calculated as the volume of water available for consumptive demand minus the volume of water represented by non-licensed demand. Therefore, the volume available for consumptive demand would equal the resource capacity minus the non-consumptive demand:

Consumptive demand = resource capacity – non-consumptive demand

or

Licensed extraction + non-licensed extraction = resource capacity – non-consumptive demand

The resource capacity is taken as equal to the recharge to a groundwater system, as the amount of recharge will affect the volume of groundwater held in storage and therefore the volume available for all uses. For example, by using a water balance approach, the storage changes of a groundwater system can be determined by calculating the inputs and outputs of water to the system:

Change in storage = recharge – discharge

So, if recharge exceeds discharge, there is an increase in storage and resource capacity and therefore, more water available for both consumptive and non-consumptive demands. As non-consumptive demand is a fixed volume, this leaves more water available for consumptive demand. Conversely, if there is more discharge than recharge there is a decrease in storage, or the resource capacity, which leads to less water available for consumptive demands. Therefore, the amount of recharge is explicitly linked to the resource capacity:

Licensed extraction + non-licensed extraction = recharge – non-consumptive demand

Therefore, to find the amount available for licensed extraction:

Licensed extraction = recharge – non-consumptive demand – non-licensed extraction.

2.5.1.1 Non-consumptive demand

Non-consumptive demand includes a number of different uses such as:

- the water used by groundwater dependent ecosystems (GDEs) such as vegetation, springs and permanently-flowing stream reaches
- the water required to maintain the integrity of aquifers
- evapotranspiration.

Ecological Associates and SKM (2012) determined that three GDE types in the CA and NAP prescribed areas are relevant to the development of the WAP: fractured rock aquifer springs, groundwater-dependent streams and terrestrial vegetation at the base of the hills.

These ecosystems are associated with shallow groundwater or the discharge of groundwater to the surface from aquifers from which extraction occurs. The threat of current groundwater extraction to these GDEs has been assessed as low to moderate, however there may be sites where local groundwater extraction in close proximity to these GDEs may have an effect. The volume of groundwater required by these GDEs has not been quantified, but their water needs have been considered in the overall water balance.

2.5.1.2 Consumptive demand

Consumptive demand of groundwater includes both licensed (e.g. irrigation, industrial) and non-licensed extraction (e.g. stock and domestic and authorisations under Section 128 of the Act). There are currently around one thousand licensed wells in the NAP PWA, including stock and domestic wells as these are licensed under the current WAP. Although the Central Adelaide PWA is prescribed, licences have not yet been issued and there is currently no comprehensive metering of extractions. Since 1990, about 2600 domestic wells have been drilled in the Adelaide metropolitan area and of these, an estimated 2000 are thought to be operational.

2.5.1.2.1 Licensed extraction

Groundwater extracted for licensed purposes in the NAP PWA is used primarily for irrigation, followed by industrial use, stock and domestic use, recreational use and aquaculture. The annual volumes of licensed groundwater extraction from the NAP PWA from 2006 to 2013 are presented in Figure 2.8. The most recent estimate of current annual extraction in the Adelaide metropolitan area of the CA PWA is about 10 000–12 000 ML/y.

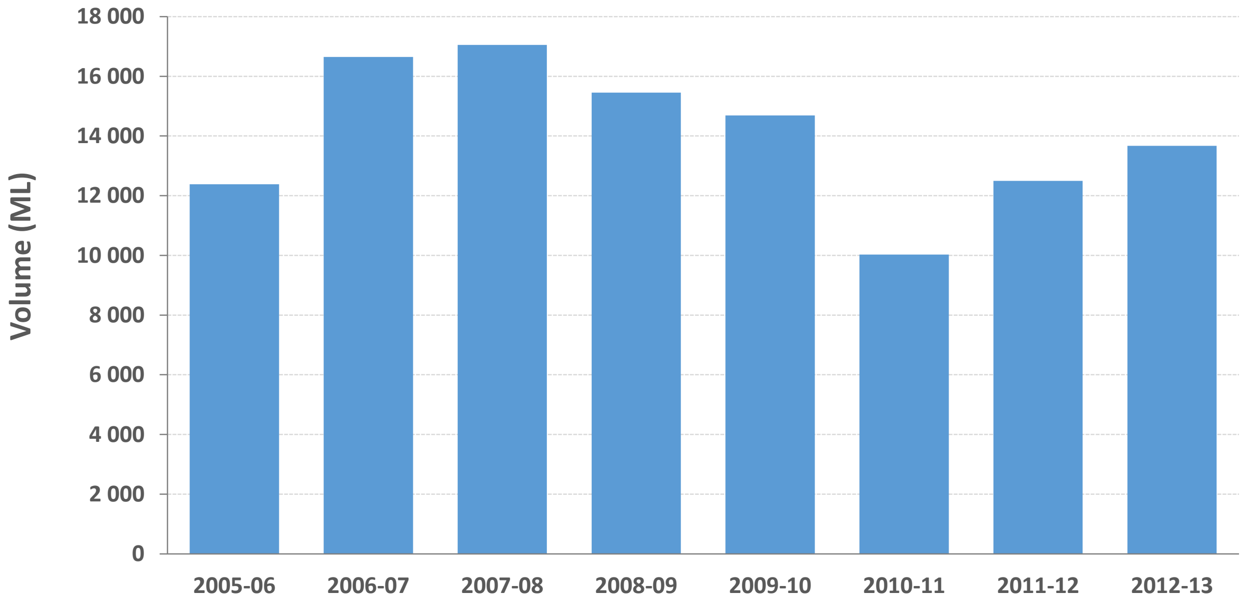

Figure 2.8 Volume of licensed groundwater extraction in the Northern Adelaide Plains PWA from 2006 to 2013

2.5.1.2.2 Non-licensed extraction

AGT (2011) estimated the volume of groundwater extraction by non-licensed users from each major aquifer across the CA and NAP PWAs. Table 2.2 presents a summary of the estimated non-licensed extraction by aquifer as presented in AGT (2011). The total for the fractured rock aquifers and therefore the grand total is slightly different to that presented in the AGT (2011) report due to a calculation error in the AGT report.

Table 2.2 Estimated non-licensed extraction in the Central Adelaide and Northern Adelaide Plains PWAs by aquifer (after AGT 2011)

Aquifer	Estimated extraction (ML/y)					Total (ML/y)
	Domestic	Stock	Forestry	Fire	Roads	
Quaternary	1469.8	1.7	0	0	0	1471.5
T1	106	0.4	0	0	80	186.4
T2	230.6	0.3	0	0	80	310.9
Fractured rock	575	2.2	625	5	160	1367.2
TOTAL	**2381.4**	**4.6**	**625**	**5**	**320**	**3336**

The spatial distribution of this information was used to derive the volumes for each proposed groundwater management zone. (Table 2.3). The 389 ML estimated for hardwood plantation forestry was allocated to the Southern FRA GMZ because of the 214 hectares of blue gums and native forest surrounding the Happy Valley Reservoir (AGT 2011). The 236 ML for softwood plantation forestry was split evenly between the Northern, Torrens, Patawalonga and Southern FRA GMZs due to a lack of spatial information on where the small plantation lots are located. The 5 ML estimated for firefighting was split evenly between the Northern, Torrens, Patawalonga and Southern FRA GMZs as AGT (2011) states that the most likely place where drillholes may be accessed for water to fight fires is in the hills area, fringing the major urban areas. The estimate for roads has not been included as the major projects accounted for in AGT (2011) have been completed or are near completion. A number of wells were found to have been incorrectly assigned to the Tertiary aquifer by AGT. They were reassigned to the fractured rock aquifers as this is the aquifer assigned to them in SA Geodata. One hundred and forty-five wells that AGT have assigned as Quaternary wells are located outside of the proposed Quaternary aquifers GMZ, with 66 of these wells assigned as fractured rock or Tertiary wells in SA Geodata. They have not been included in the non-licensed use estimate for the proposed Quaternary aquifers GMZ.

Table 2.3 Estimated non-licensed extraction in the proposed groundwater management zones (after AGT 2011)

Groundwater management zone	Estimated extraction (ML/y)				Total (ML/y)
	Domestic	Stock	Forestry	Fire	
Quaternary aquifers	1417.45	0.66	0	0	1418.11
T1 NAP	45.54	0.44	0	0	45.98
T1 Dry Creek	0	0	0	0	0
T1 Grange	0	0	0	0	0
T1 Thebarton	0.99	0	0	0	0.99
T1 Central Adelaide	4.12	0	0	0	4.12
T2 NAP	21.09	0.11	0	0	21.2
T2 Kangaroo Flat	2.46	0.11	0	0	2.57
T2 Virginia	59.97	0.11	0	0	60.08
T2 Regional	137.97	0	0	0	137.97
T2 Osborne	6.75	0	0	0	6.75
T2 Regency Park	0	0	0	0	0
Tertiary GGE	43.73	0	0	0	43.73
T3 aquifer	0	0	0	0	0
GGE FRA	19.48	0	0	0	19.48
Noarlunga Embayment	4.93	0.33	0	0	5.26
Northern FRA	114.60	0.88	59	1.25	175.73
Torrens FRA	153.04	0.44	59	1.25	213.73
Patawalonga FRA	178.43	0.33	59	1.25	239.01
Southern FRA	123.09	0.55	448	1.25	572.89
TOTAL	**2333.64**	**3.96**	**625**	**5**	**2967.6**

2.5.2 Groundwater modelling

DEWNR, with RPS Aquaterra, developed the AP2011 groundwater flow and solute transport model that was built upon an understanding of groundwater inflows and outflows, salinity movement and the water budget for the region (RPS Aquaterra 2011). The AP2011 model was peer reviewed by Merrick (2011). An updated version of the AP2011 model, developed by DEWNR and referred to as AP2013, was used for this project. The full modelling report G*roundwater modelling exercise to determine resource capacity* (Peat & Yan 2014) is available in the Appendix in Section 7.

To determine the recommended extraction limit of the T1 and T2 aquifers in the Adelaide Plains Sub-basin and Golden Grove Embayment, a number of scenarios for groundwater extraction were developed as part of the modelling exercise. The aim of these scenarios was to determine the impact of various rates of extraction on the groundwater resource. Solute transport modelling was not carried out due to budgetary and time constraints.

Essentially, a 'base case' scenario was modelled to determine the impact on the potentiometric surface, leakage between aquifers and inflows from the west (i.e. from the ocean). This used the average licensed extractions over a representative eight-year period (2006–13). The period 2006 to 2013 (inclusive) was used for a number of reasons, including:

- higher extraction volumes in earlier years are not considered representative of current conditions or likely future conditions
- quality of data—verified metered data for the NAP PWA is available for these years
- includes wet and dry years
- represents best case for the resource as the current water level equilibrium that has been reached in the T2 aquifer is widely considered an acceptable 'status quo'
- covers a period after installation of the Virginia pipeline, which has eased demand for groundwater.

Metered groundwater extraction data was used for the NAP PWA. As the CA PWA is largely unmetered at present and licences are still to be issued, the extraction within the CA PWA was estimated based on the licence applications from existing users. Therefore, there is a degree of uncertainty in the volumes calculated as they are based on what the existing users estimate they are using now and what they may extract in the future. However, for all of the largest volume users, who collectively extract most of the total volume, the current volumes of use have been verified through land and water-use surveys.

Model scenarios were then run with the extractions increased and the predicted impacts compared to the base case to determine if the higher extraction rates are sustainable and if their impacts are acceptable.

The resource condition indicators and condition limits for the T1 aquifer were that the drawdown should not exceed –5 m AHD in the Waterloo Corner area and –15 m AHD in the Central Adelaide PWA by 2040, to limit the salinity threat from increased downward leakage of salty water from the Q4 aquifer and the encroachment of higher-salinity water from surrounding areas. The extent of the –5 m AHD potentiometric contour was also assessed to gauge the degree of the impact of extractions.

For the T2 aquifer, the resource condition indicator and condition limit are that the winter pressure levels should not exceed the base of the confining layer separating the T1 and T2 aquifers by 2040, to maintain the integrity of the aquifer. The extent of the –30 m AHD potentiometric contour was also assessed to gauge the degree of the impact of extractions.

The –5 m, –15 m and –30 m AHD contours were chosen as they encompass the areas of concentrated extractions.

Table 2.4 briefly summarises the modelling scenarios, with the full modelling report available in the Appendix in Section 7.

The results of the relevant modelling scenarios and the resulting recommended extraction limits for the proposed T1 and T2 aquifer GMZs are discussed in Section 3.2. The results for each modelling scenario are presented in the Appendix in Section 7.

2.5.2.1 Scenario 1 – Base case

This scenario assumes that extraction in the NAP PWA over 30 years (2010–2040) is equivalent to the average extraction over the last eight years, which includes wet and dry climatic periods (2006 to 2013). Wells that have accessed groundwater at any time over those eight years are included in this scenario, including wells that have since been abandoned or backfilled. In the NAP PWA, it is assumed that 80% of the annual usage is extracted in summer and 20% is extracted in winter to meet agricultural and horticultural demand. The average extraction is calculated from data queried from the WILMA database excluding null, anomalous or zero readings.

Existing user demand in the CA PWA has been applied for 30 years (2010 to 2040) in both the T1 and T2 aquifers.

2.5.2.2 Scenario 2 – Worst case

This scenario is based on the assumption that within the NAP PWA, all users will extract their full allocation each year over the 30 years. This scenario is considered to be the "worst case" in terms of relative impact on the groundwater resources. It is assumed that 80% of the annual volume is extracted in summer and 20% is extracted in winter. Allocation volumes are sourced from a dataset prepared by NR AMLR and provided to RPS-Aquaterra in 2013, and represent allocation volumes for year 2011.

This scenario excludes wells for which there has been usage sometime over the last eight years, but no recent allocation. It is assumed that these wells are no longer in use (having been abandoned or backfilled) and their allocation has been transferred. This scenario includes wells that have an allocation but are not currently in use. This is often the case for relatively new wells that have been drilled but there is no meter and no metered data associated with the licence. This scenario considers that these licence holders will take up their allocation sometime in the future.

This scenario assumes that if the average extraction over the eight years is greater than the allocation volume for a given well, then in the future this user is likely to extract groundwater based on the average extraction. This approach is conservative, because it considers existing groundwater users who often use greater than their allocation volume (by transferring in water or paying a penalty for exceeding their allocation) are likely to repeat this behaviour in the future.

Where there are multiple wells associated with a single licence, it is assumed that allocation volumes are evenly distributed, even though extraction is unlikely to be uniform. Therefore, for some licences, the modelled extraction volume may be slightly higher than the allocation volume. This is considered greatly conservative as it is likely to slightly overestimate the impact of groundwater extraction at full allocation.

Existing user demand in the CA PWA has been applied for 30 years in both the T1 and T2 aquifers.

2.5.2.3 Scenario 3 – Mid case

This scenario is based on the assumption that future groundwater extraction is halfway between the average usage over the last eight years and full allocation. In situations where the average usage over the last eight years exceeds allocation, then the average of the last eight years is assumed. It is assumed that 80% of the annual volume is extracted in summer and 20% is extracted in winter.

Existing user demand in the CA PWA has been applied for 30 years in both the T1 and T2 aquifers.

2.5.2.4 Scenario 4 – Base case + 10%

This scenario considers the impacts if all licence holders in the NAP PWA were to extract an extra 10% on top of their average extraction over the last eight years. Existing user demand in the CA PWA west of the Para Fault, i.e. not in the Golden Grove Embayment, also increased by 10%. These increases correspond to an additional 1500 ML/y extraction in NAP PWA and 1000 ML/y in CA PWA. As with the previous scenarios, it is assumed that in the NAP PWA, 80% of the annual volume is extracted in summer and 20% is extracted in winter.

2.5.2.5 Scenario 5 – Base case + 20%

This scenario assumes that groundwater extraction in the NAP PWA over the 30 years is 20% greater than the average extraction over the last eight years. Existing user demand in the CA PWA west of the Para Fault, i.e. not in the Golden Grove Embayment, also increased by 20%. These increases correspond to almost 2800 ML/y additional extraction in the NAP PWA and over 2000 ML/y in the CA PWA. As with the previous scenarios, it is assumed that in the NAP PWA 80% of the annual volume is extracted in summer and 20% is extracted in winter.

2.5.2.6 Scenario 6 – Base case + double in GGE

Currently, about 1600 ML/y is assumed to be extracted from the T1 and T2 aquifers within the Golden Grove Embayment (GGE). To determine the impacts of higher extractions for industrial purposes, Scenario 6 assumes Scenario 1 extractions for the other GMZs, but models double the existing user demand in the T1 and T2 GGE GMZ.

2.5.2.7 Scenario 7 – Scenario 6 + 2000 ML in GGE

As there was little difference in the groundwater pressure levels of the T1 and T2 aquifers in the Golden Grove Embayment between Scenario 1 and Scenario 6, another scenario was run to determine the impacts of higher extractions for industrial purposes and the degree of interference from multiple wells. A hypothetical scenario was run including an additional 24 wells targeting both the T1 and T2 aquifers at a minimum distance of 1.5 km from each other and from existing users. Scenario 7 assumes Scenario 1 extractions for the other GMZs but models an extra 2000 ML/y in addition to double the existing user demand in the GGE (Scenario 6), with each additional well pumping at a constant rate of approximately 2.6 L/s for 30 years. Extraction occurs from both T1 and T2 aquifers in each well.

2.5.2.8 Scenario 8 – Scenario 6 + 1000 ML in GGE

After considering the results of the previous scenario, another hypothetical scenario was run with a reduced increase of 1000 ML/y modelled. This was achieved by reducing the number of wells used in Scenario 7 by 50%, to 12 wells targeting both the T1 and T2 aquifers at a minimum distance of 1.5 km from each other and from existing users. Scenario 8 assumes base case Scenario 1 extractions for the other GMZs but models an extra 1000 ML/y in addition to the doubled existing user demand in the GGE (Scenario 6), with each of the 12 wells pumping at a constant rate of approximately 2.6 L/s for 30 years from both aquifers.

2.5.2.9 Scenario 9 – Base case all GMZs except worst case in T2 NAP and T2 Regional GMZs + 2000 ML in T2 Regional GMZ

As the T2 Regional GMZ covers a large area and contains very few existing users, pumping at full allocation under Scenario 2 is predicted to have minimal impact on the resource and those users. Consequently, new development in the GMZ may be possible with limited resultant impacts. Another hypothetical scenario was therefore run to determine the impacts of higher extractions and the degree of interference from multiple wells. Under Scenario 9, an extra 2000 ML from an additional 134 wells targeting the T2 aquifer at a minimum distance of 1.5 km from each other and from existing users were included, in addition to full allocations from existing users. Each additional well pumped at a seasonal rate of approximately 1 L/s for 30 years.

Running an extra scenario also provided an opportunity to look at the impacts of varying pumping levels in different management zones. Scenario 9 also explores what would happen if base case levels were kept in place in the other GMZs, but full allocation is pumped from the T2 NAP GMZ.

2.5.2.10 Scenario 10 – Base case + 30% with some exceptions

Scenario 10 examined the impacts of varying pumping levels in different management zones. In this scenario, pumping from the T2 Kangaroo Flat GMZ was kept at base case levels (Scenario 1); base case plus an extra 20% (Scenario 2) was pumped from T2 Virginia GMZ; double existing user demand plus an additional 1000 ML/y (Scenario 8) was pumped from the T1 and T2 GGE GMZ; full allocations plus an additional 2000 ML (Scenario 9) was pumped from the T2 Regional GMZ; and an additional 30% on top of base case volumes was pumped from all other GMZs.

Table 2.4 Summary of modelled scenarios

Prediction scenario	Description of scenario
Scenario 1 – Base case	Extraction of average metered extraction from 2006 to 2013 for the NAP PWA; existing user demand for the CA PWA
Scenario 2 – Worst case	Extraction of full allocation volumes for the NAP PWA; existing user demand for the CA PWA
Scenario 3 – Mid case	Extraction of volumes midway between the average metered extraction from 2006 to 2013 and full allocations for the NAP PWA; existing user demand for the CA PWA
Scenario 4 – Base case + 10%	Same as Scenario 1 with an additional 10% extraction from every well west of the Para Fault
Scenario 5 – Base case + 20%	Same as Scenario 1 with an additional 20% extraction from every well west of the Para Fault
Scenario 6 – Base case + double in GGE	Same as Scenario 1, with double the existing user demand extracted from the GGE
Scenario 7 – Scenario 6 + extra 2000 ML in GGE	Same as Scenario 6 with an additional 2000 ML extracted from the GGE
Scenario 8 – Scenario 6 + extra 1000 ML in GGE	Same as Scenario 6 with an additional 1000 ML extracted from the GGE
Scenario 9 – Scenario 1, Scenario 2 in T2 NAP and T2 Regional + extra 2000 ML in T2 Regional	Same as Scenario 1 for all GMZs, except same as Scenario 2 for the T2 NAP and T2 Regional GMZs, with an additional 2000 ML extracted from the T2 Regional GMZ
Scenario 10 – Base case + 30%, Scenario 1 for T2 Kangaroo Flat, Scenario 5 for T2 Virginia, Scenario 9 for T2 Regional and Scenario 8 for T1 and T2 GGE	Same as Scenario 1 with an additional 30% extraction from every well west of the Para Fault, except same as Scenario 1 for the T2 Kangaroo Flat GMZ, same as Scenario 5 for the T2 Virginia GMZ, same as Scenario 9 for the T2 Regional GMZ and the same as Scenario 8 for the T1 and T2 GGE GMZ

2.5.3 Existing work for the proposed Kangaroo Flat GMZ

Barnett (2013) provides an updated assessment of the capacity of the groundwater resources in the Kangaroo Flat area to help determine whether water access entitlements of existing users should be reduced as required by Section 164N of the Act. A Notice of Restriction was first placed over the groundwater resources in the Kangaroo Flat area in March 2000, in response to concerns about the impacts of a significant increase in groundwater pumping in the area. Extractions from the T2 aquifer increased from 330 ML/y in 1997 to over 1000 ML/y in 1998 (Gerges 2000). The Kangaroo Flat area was subsequently incorporated into the NAP PWA by the *Water Resources (Northern Adelaide Plains Prescribed Wells Area) Regulations 2004*.

In the Kangaroo Flat area, the main sustainability issues that need to be considered when determining the resource capacity and recommended extraction limits are the lateral movement of saline groundwater from the north-east, and downward leakage of saline groundwater from the overlying Quaternary aquifers. Monitoring data indicate a strong relationship between irrigation extraction, lowering of hydraulic head elevation, and salinity increases. Salinity increases due to lateral inflows of more saline groundwater from the northeast are a potential problem over the long term, but due to the generally slow rate of groundwater movement, the salinity risk from downward leakage is considered greater and more immediate.

3 Results and analysis

3.1 Quaternary aquifers

While the AP2013 model has not been used to determine the resource capacity for the Quaternary aquifers, the AP2011 model provides some data that is of use in determining the water budget for the Quaternary aquifers GMZ.

Recharge to the Quaternary aquifers is primarily from rainfall, but also includes the application of irrigation water and seepage from streams. Discharge components include groundwater extraction, inter-aquifer leakage, discharge to streams and evapotranspiration and uptake by GDEs.

Recharge to the Quaternary aquifers cannot be easily estimated with any degree of certainty due to the impacts of the dense urbanisation of the area. These include processes that reduce natural recharge from rainfall (large areas of impervious surfaces, stormwater diversion and the concreting of water channels and stream banks) and those that enhance natural recharge (application of irrigation water for horticulture, irrigation of lawns and parks and leaking water mains and sewage pipes).

The calibrated AP2011 model assumes that 5% of annual rainfall (measured at Adelaide Airport) reaches the watertable as recharge and was simulated during winter only. The modelled recharge volume at the end of the history match period (September 2009) was 26.8 GL (RPS Aquaterra 2011). However, there is uncertainty surrounding this rate since it is not directly measureable. To investigate the sensitivity of the model result, the modelled recharge was varied for two sensitivity model runs, with the first run halving the applied recharge and the second doubling the recharge. The lower recharge rate indicated a better overall match between modelled and observed groundwater pressure levels. Additionally, a reduction in recharge did not significantly affect the modelled salinity trends (compared to the base case) and suggests that a reduction in recharge to the model (due to direct infiltration from rainfall) may be warranted. Therefore, if we were to simply halve the modelled recharge volume to get 13.4 GL, this could be used as the resource capacity volume.

RPS Aquaterra (2011) estimated the current recharge to the watertable from irrigation occurring in the NAP PWA, but the volume was not substantial and would apply to a relatively small area so it was not included in the model. Recharge to the Quaternary aquifers from stream discharge is likely to be localised and occur over a long period of time and therefore hard to quantify. Therefore, these two potential sources of recharge have not been included in the calculation of the resource capacity.

The Quaternary Hindmarsh Clay confining layer reduces leakage to or from the underlying Tertiary aquifers in the NAP PWA. However, these confining beds are absent or thin out in some areas, allowing hydraulic connection between aquifers. This can be observed, for example, between the deep Quaternary aquifers in the Little Para area, the Waterloo Corner area (between the Q4 and T1 aquifers) and in an area several kilometres north of the Gawler River. Downwards leakage from the Quaternary aquifers to the underlying T1 aquifer occurs throughout the CA PWA because of the increased hydraulic gradient between Quaternary aquifers and the heavily exploited T1 aquifer in this area. However, the rate of leakage will be affected by the permeability of the confining layer separating the Tertiary and Quaternary aquifers. The amount of leakage occurring from the Quaternary aquifers to the Tertiary aquifers has not been quantified. Loss of water from the Quaternary aquifer to the Tertiary aquifers from leaky wells is also an issue but a volume of water is unknown.

For the Quaternary aquifers, the average annual volume of licensed groundwater extractions from 2006 to 2013 in the NAP PWA and existing user demand in the CA PWA totals 964 ML. Annual non-licensed extraction has been previously estimated at 1418 ML by AGT (2011). Water extracted under authorisation by the Minister under Section 128 of the Act was not included due to a lack of available data.

The volume of water taken up by GDEs has not been quantified but must be accounted for. SKM (2011b) estimated streamflow reductions as a consequence of groundwater extraction to rise to 2281 ML a year by 2100, with the largest reductions in the Gawler River, particularly during low flow periods. This volume is used in the water balance calculation below as a proxy for the volume of water discharged to streams by the Quaternary aquifers. Evapotranspiration was applied over the entire AP 2011 model domain except in areas representing Gulf St Vincent and surface water features. A maximum rate of 300 mm per year was applied to the steady state and the transient history match models. An extinction depth of 1.5 m was applied over the entire model extent. The modelled evapotranspiration volume at the end of the history match periods was 4.4 GL (September 2009) and 2.7 GL (March 2010).

Recalling the water balance equation from Section 2.5.1:

Water available for licensed extraction = recharge – non-consumptive demand – non-licensed extraction

or in this case:

Water available for licensed extraction = recharge – (uptake by GDEs + discharge to streams + evapotranspiration) – non-licensed extraction

and substituting the available data gives us:

= 13 400 – (uptake by GDEs + 2281 + 7100) – 1418

= 2601 – uptake by GDEs

So the water balance has calculated 2601 ML is available for licensed extraction minus the amount taken up by GDEs, which remains unknown. Even though this amount is unknown, it needs to be considered when determining the recommended extraction limit for the Quaternary aquifers. The low demand from the Quaternary aquifers for licensed purposes due to their low yield should also be considered. The estimation of the extraction limit will require some trade-off between the various users of the resource. For example, the amount of discharge to streams could be reduced by an amount considered acceptable to allow more water for licensed extraction.

Monitoring wells within the Quaternary aquifer in the Central Adelaide PWA show generally stable long-term trends that show a broad relationship with rainfall (Fig. 3.1). Decline in groundwater levels due to the 2006 drought and the recovery in recent years due to above-average rainfall are evident.

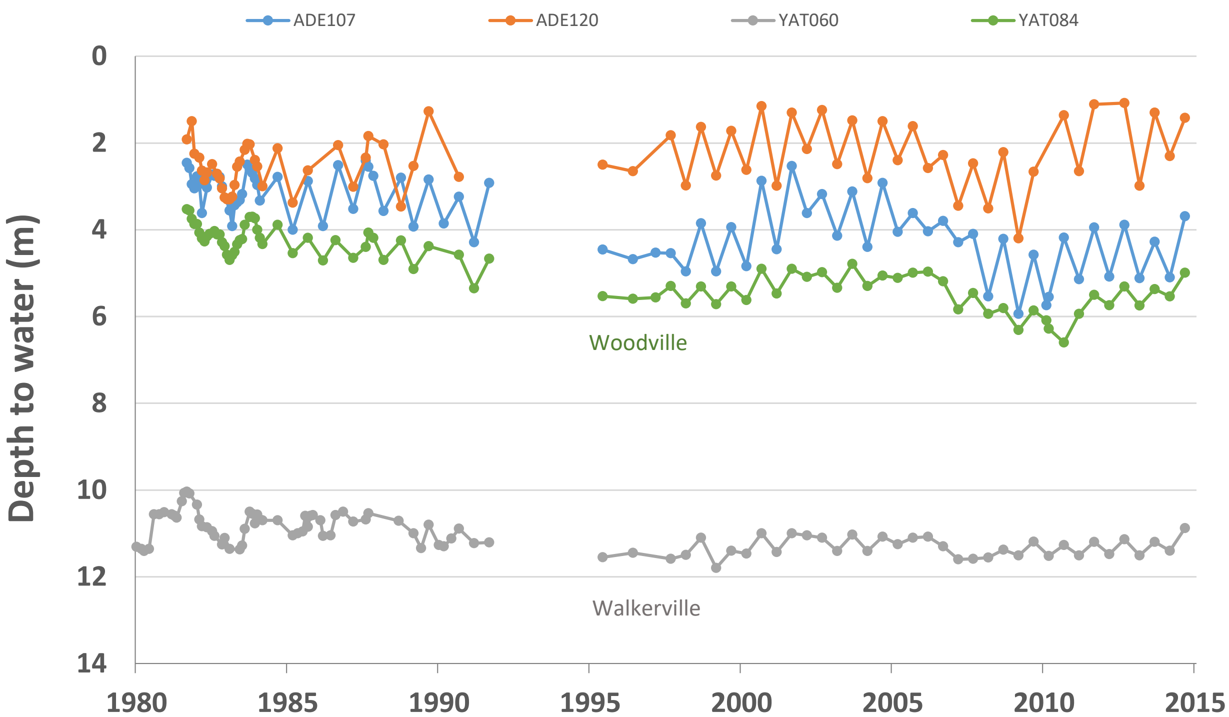

Figure 3.1 Quaternary groundwater level trends in the Central Adelaide Plains PWA

3.1.1 Recommended extraction limit

The recommended extraction limit for the Quaternary aquifers GMZ is the amount of water that can be extracted for licensed extraction without unacceptable impacts to GDEs or existing users. As requested by the Board, a range for the recommended extraction limit has been suggested. The recommended extraction limit for the proposed Quaternary aquifers GMZ is 1600–2000 ML/y. This range was chosen based on the water balance calculation that determined the volume of water available for licensed extraction of 2601 ML/y. However, this amount includes water taken up by GDEs, which has not been quantified. It also includes the current licensed extractions from the Quaternary aquifers of 964 ML/y and current allocations of 1526 ML/y. Therefore, setting the recommended extraction limit at 1600–2000 ML/y covers existing licensed holders, allows further development of the aquifer, but also 'reserves' some water for GDEs as well.

3.2 T1 and T2 aquifers

The results from each modelling scenario for the T1 and T2 aquifers in the CA and NAP prescribed areas are discussed in the Appendix in Section 7. The results for each groundwater management zone are discussed in the following section. The volumes extracted from each GMZ under each scenario are presented in Table 3.1.

Table 3.1 Scenario extraction volumes (ML/y)

GMZ	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1 NAP	3199	5091	3953	3519	3839	3199	3199	3199	3199	4159
T1 Dry Creek	2972	2972	2972	3270	3567	2972	2972	2972	2972	3864
T1 Grange	1940	1940	1940	2134	2328	1940	1940	1940	1940	2522
T1 Thebarton	1383	1383	1383	1521	1660	1383	1383	1383	1383	1798
T1 Central Adelaide	1777	1777	1777	1955	2132	1777	1777	1777	1777	2310
T2 NAP	2230	4483	3322	2453	2676	2230	2230	2230	4483	2899
T2 Kangaroo Flat	1321	1321	1321	1453	1585	1321	1321	1321	1321	1321
T2 Virginia	9224	14917	11921	10146	11068	9224	9224	9224	9224	11068
T2 Regional	103	212	157	113	124	103	103	103	2212	2212
T2 Osborne	1199	1199	1199	1319	1439	1199	1199	1199	1199	1559
T2 Regency Park	1732	1732	1732	1905	2078	1732	1732	1732	1732	2252
T1 and T2 GGE	1526	1526	1526	1526	1526	3052	5052	4052	1526	4052
Total	**28 606**	**38 554**	**33 204**	**31 315**	**34 023**	**30 132**	**32 132**	**31 132**	**32 968**	**40 016**

3.2.1 T1 Northern Adelaide Plains GMZ

Scenario results for the proposed T1 NAP GMZ were analysed at Waterloo Corner (Location D; Fig. 3.2; Table 3.2) as this is the location of the most concentrated extraction from the T1 aquifer in the NAP PWA. If future annual groundwater extraction is equivalent to the average annual extraction over the nominated eight years (2006–2013), it is predicted that groundwater levels in the T1 aquifer will remain relatively stable over the long term. Under Scenario 1, both the winter and summer groundwater pressure levels decline by about 2 m after 30 years. Summer levels nearly reach the resource condition limit of –5 m AHD after 30 years, but levels recover to 1 m AHD in winter.

If all licence holders in the NAP PWA were to extract groundwater at their full allocation, a significant decline in the groundwater pressure levels in the T1 aquifer is predicted. Under Scenario 2, after 30 years the cone of depression deepens by around 6 m (relative to Scenario 1) to about −11 m AHD in summer, and the winter pressure level reaches –5 m AHD, thereby exceeding the resource condition limit. The area covered by the –5 m AHD potentiometric contour totals approximately 40 km^2. There is no indication of an equilibrium being reached, with ongoing decline due to downward leakage into the underlying, heavily-pumped T2 aquifer.

Under Scenario 3, the cone of depression reaches −5 m AHD at the end of summer after 30 years, but recovers to –1 m AHD in winter. The –5 m AHD potentiometric contour covers an area of about 4 km^2.

Scenario 4 results are similar to Scenario 1, with an increase in summer and winter groundwater pressure levels after 30 years of 3 m, and the –5 m AHD potentiometric contour covering a very small area of just 0.04 km^2. Levels drop by another metre under Scenario 5 and the area of the –5 m AHD contour covers 3 km^2.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented as extraction volumes were kept the same as Scenario 1 for all proposed groundwater management zones, except for the T1 and T2 GGE GMZ. Declines in levels caused by pumping in the Golden Grove Embayment is unlikely to travel across a complex fault system such as the Para Fault and affect pressure levels in the adjoining aquifers of the Adelaide Plains Sub-basin.

Scenario 9 extraction volumes for the proposed T1 NAP GMZ were kept the same as Scenario 1, but a decline of around 3.5 m is predicted to occur in both winter and summer after 30 years. This is likely due to the increased volume of extraction from the underlying T2 NAP GMZ under Scenario 9 causing increased downward leakage.

Pumping under Scenario 10 results in declines of 5 to 6 m relative to Scenario 1 and the -5 m AHD contour covers an area of 6 km^2.

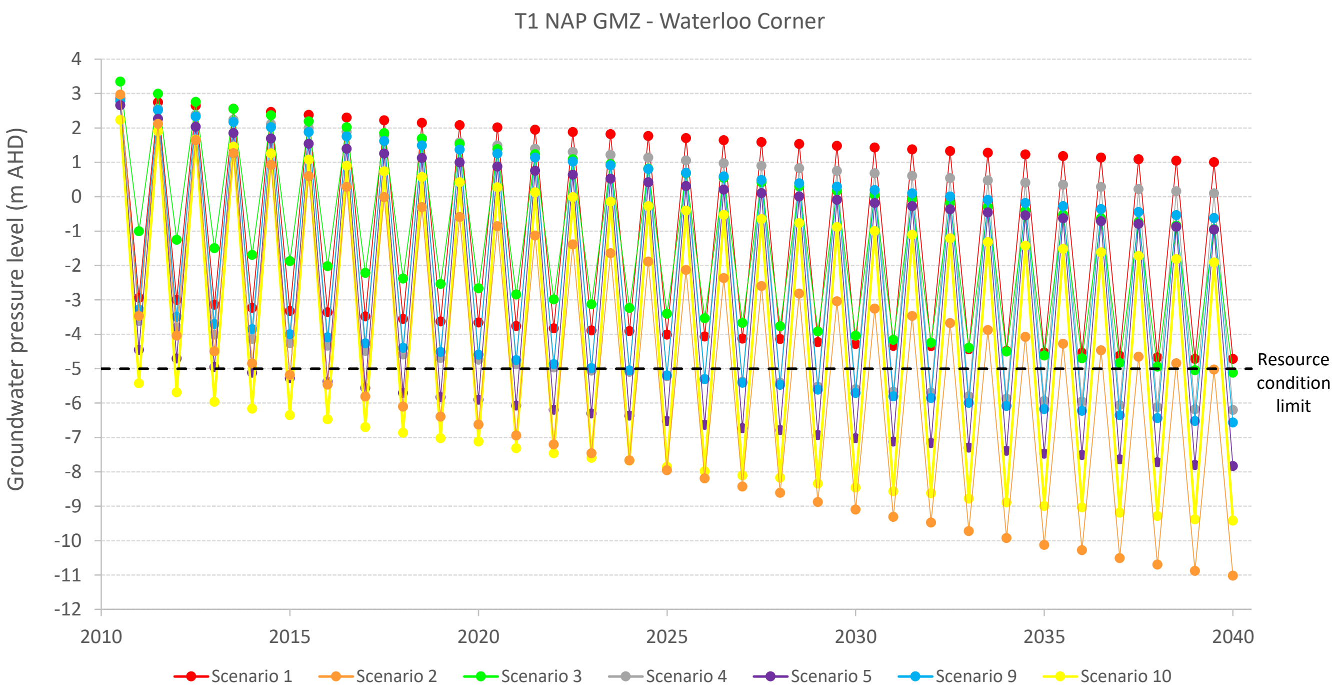

Figure 3.2 Predicted T1 aquifer pressure levels for relevant scenarios in the proposed T1 Northern Adelaide Plains GMZ (Location D, Waterloo Corner)

3.2.2 T1 Dry Creek GMZ

Scenario results for the proposed T1 Dry Creek GMZ were analysed at Osborne (Location F; Fig. 3.3; Table 3.2) as this is the location of the most concentrated extraction from the T1 aquifer in this area. Under Scenario 1, both the winter and summer groundwater pressure levels decline by only 0.2 m after 30 years, and are well above the –15 m AHD resource condition limit. The –5 m AHD contour covers an area of 6 km^2.

Groundwater pressure levels for Scenarios 2 and 3 are not presented for the T1 Dry Creek GMZ as extraction volumes were kept the same as Scenario 1. The extraction within the CA PWA was estimated based on the licence applications from existing users and future allocations are likely to reflect these numbers also.

Scenario 4 results are similar to Scenario 1, with an increase in summer and winter levels after 30 years of 1–1.5 m and the –5 m AHD potentiometric contour covering an area of 10 km^2. Groundwater pressure levels drop by another 1–1.5 m under Scenario 5 and the area of the –5 m AHD contour covers 17 km^2.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented for the T1 Dry Creek GMZ as extraction volumes were kept the same as Scenario 1, as mentioned in Section 3.2.1.

Scenario 9 extraction volumes were kept the same as Scenario 1, but a drawdown of around 0.5–1 m is predicted to occur after 30 years and the area covered by the –5 m AHD contour reaches 18 km^2. This is likely due to the increased volume of extraction from the underlying T2 Regional GMZ under Scenario 9 causing increased downward leakage.

Pumping under Scenario 10 results in declines of 4 to 5 m relative to Scenario 1. The –5 m AHD contour expands to cover an area of 148 km^2,stretching from Outer Harbor and Dry Creek in the north down to Adelaide Airport.

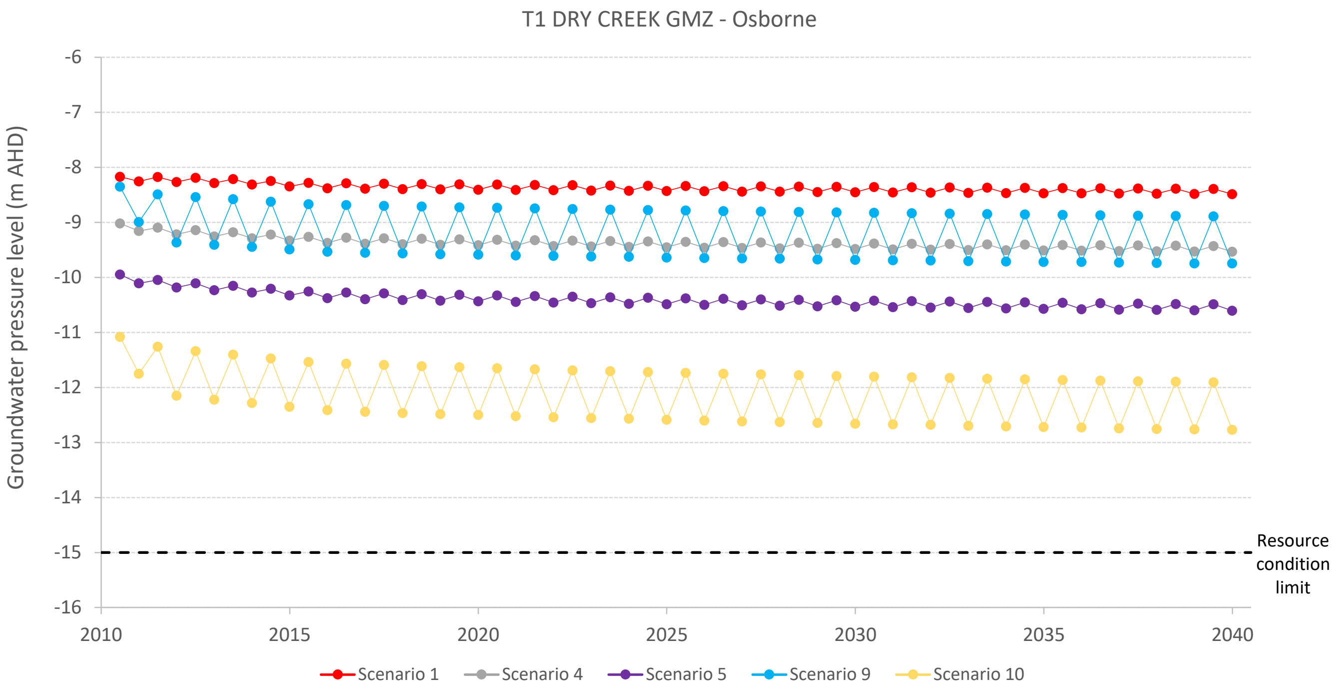

Figure 3.3 Predicted T1 aquifer pressure levels for relevant scenarios in the proposed T1 Dry Creek GMZ (Location F, Osborne)

3.2.3 T1 Grange GMZ

Groundwater extracted from the T1 aquifer in the proposed T1 Grange GMZ is used extensively for the irrigation of golf courses in West Lakes, Grange and Seaton. Scenario results for the T1 Grange GMZ were analysed at Grange (Location I; Fig. 3.4; Table 3.2) as this is the location of the most concentrated extraction from the T1 aquifer in these areas. Under Scenario 1, both the winter and summer groundwater pressure levels decline by about 0.5 m after 30 years and are well above the –15 m AHD resource condition limit. The –5 m AHD contour covers an area of 9 km^2.

Groundwater pressure levels for Scenarios 2 and 3 are not presented for the T1 Grange GMZ as extraction volumes were kept the same as Scenario 1 as mentioned in Section 3.2.1.

Scenario 4 results are similar to Scenario 1, with an increase in summer and winter levels after 30 years of 1.5 m. The –5 m AHD potentiometric contour area increases to 15 km^2. Groundwater pressure levels drop by another 1–2 m under Scenario 5 and the area of the –5 m AHD contour expands eastwards to Thebarton, covering 38 km^2.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented for the T1 Grange GMZ as extraction volumes were kept the same as Scenario 1, as mentioned in Section 3.2.2.

Scenario 9 extraction volumes were kept the same as Scenario 1, but a decline in levels of around 0.5 m is predicted to occur after 30 years and the area covered by the –5 m AHD contour reaches 17 km^2. This is likely due to the increased volume of extraction from the underlying T2 Regional GMZ under Scenario 9 causing increased downward leakage.

Pumping under Scenario 10 results in declines of 4–5 m relative to Scenario 1. The –5 m AHD contour expands to cover an area of 148 km^2, stretching from Outer Harbor and Dry Creek in the north down to Adelaide Airport.

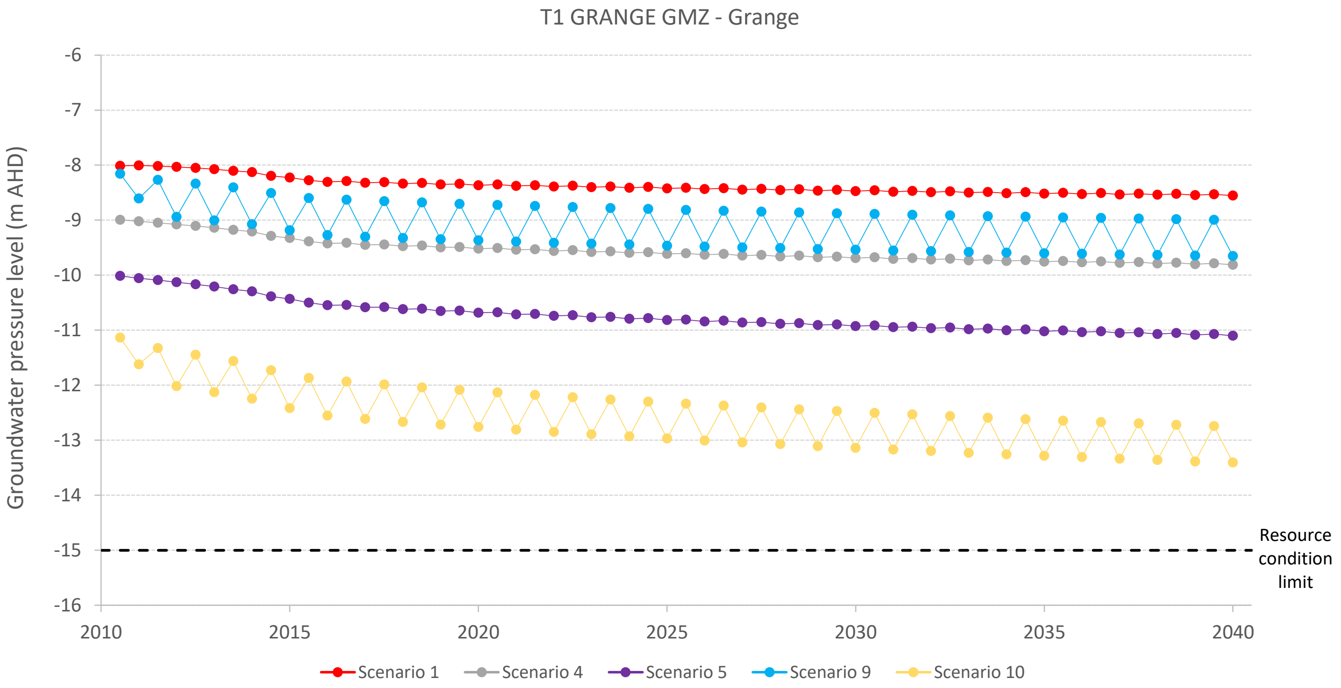

Figure 3.4 Predicted T1 aquifer pressure levels for relevant scenarios in the proposed T1 Grange GMZ (Location I, Grange)

3.2.4 T1 Thebarton GMZ

Groundwater extracted from the T1 aquifer in the proposed T1 Thebarton GMZ is used for beverage production. Scenario results were analysed at Thebarton (Location L; Fig. 3.5; Table 3.2). Extractions were predicted to increase over five years and this was simulated in the model. Under Scenario 1, both the winter and summer groundwater pressure levels decline by about 2 m after 30 years and are well above the –15 m AHD resource condition limit. The –5 m AHD contour covers an area of about 1 km^2.

Groundwater pressure levels for Scenarios 2 and 3 are not presented for the T1 Thebarton GMZ as extraction volumes were kept the same as Scenario 1, as mentioned in Section 3.2.2.

Scenario 4 results are similar to Scenario 1, with an increase in summer and winter levels of 1.5 m after 30 years. The –5 m AHD potentiometric contour area increases to 15 km^2. Groundwater pressure levels drop by another 1–2 m under Scenario 5 and the area of the –5 m AHD contour expands eastwards to Thebarton, covering 38 km^2.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented for the T1 Grange GMZ as extraction volumes were kept the same as Scenario 1, as mentioned in Section 3.2.1.

Scenario 9 extraction volumes were kept the same as Scenario 1, but a decline in levels of around 0.5–2 m is predicted to occur after 30 years and the area covered by the –5 m AHD contour reaches 4 km^2. This is likely due to the increased volume of extraction from the underlying T2 Regional GMZ under Scenario 9 causing increased downward leakage.

Pumping under Scenario 10 results in declines of 7–8 m relative to Scenario 1 and is approaching the resource condition limit of –15 m AHD. The –5 m AHD contour expands to cover an area of 148 km^2, stretching from Outer Harbor and Dry Creek in the north down to Adelaide Airport.

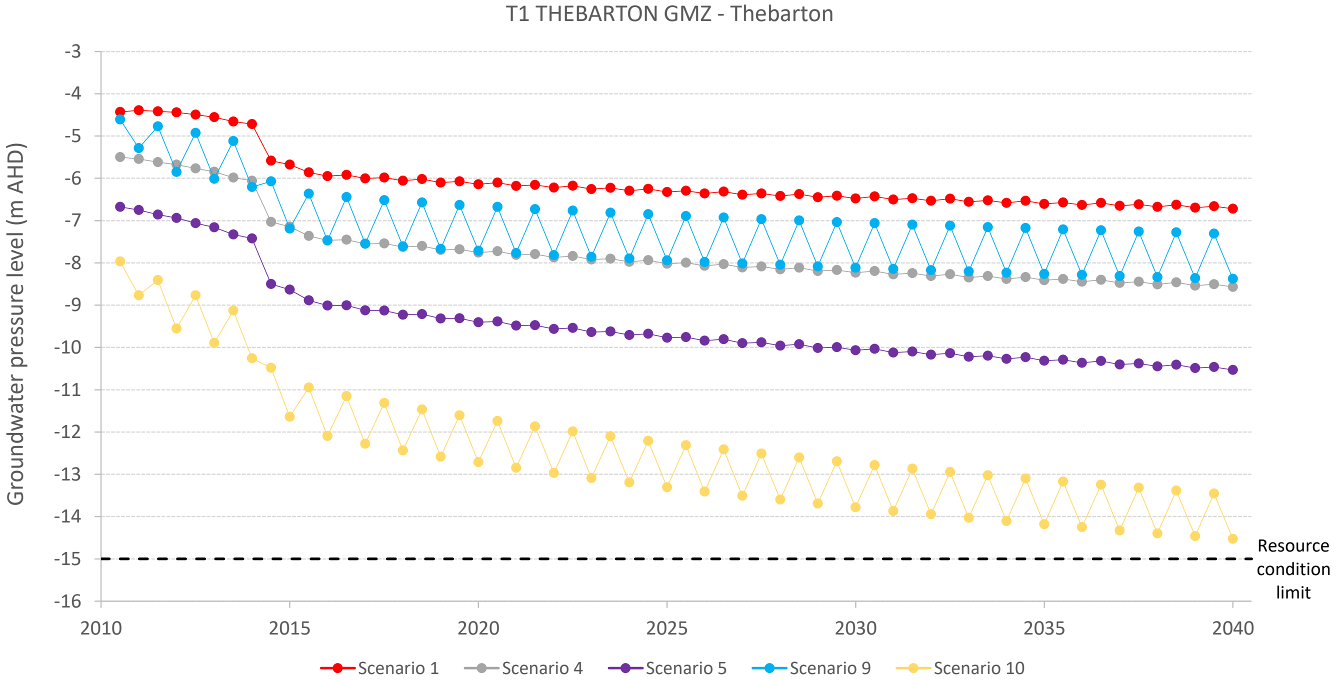

Figure 3.5 Predicted T1 aquifer pressure levels for relevant scenarios in the proposed T1 Thebarton GMZ (Location L, Thebarton)

3.2.5 T1 Central Adelaide GMZ

Scenario results for the proposed T1 Central Adelaide GMZ were analysed at Woodville North (Location H; Fig. 3.6; Table 3.2) and Kidman Park (Location K; Fig. 3.7) because of their central locations in the GMZ and proximity to other proposed groundwater management zones. Under Scenario 1, both the winter and summer groundwater pressure levels decline by 0.6–0.8 m after 30 years and are well above the –15 m AHD resource condition limit.

Groundwater pressure levels for Scenarios 2 and 3 are not presented for the T1 Central Adelaide GMZ as extraction volumes were kept the same as Scenario 1, as mentioned in Section 3.2.2.

Scenario 4 results are similar to Scenario 1, with an increase in summer and winter levels after 30 years of 1–1.5 m. A small cone of depression at –5 m AHD develops at the Kooyong Golf Course. Groundwater pressure levels drop by 2–2.5 m under Scenario 5 and the cone of depression at Kooyong Golf Course merges with those surrounding the T1 Grange and T1 Thebarton GMZs.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented for the T1 Grange GMZ as extraction volumes were kept the same as Scenario 1, as mentioned in Section 3.2.1.

Scenario 9 extraction volumes were kept the same as Scenario 1, but declines in water levels are more similar to Scenarios 4 and 5. This is likely due to the increased volume of extraction from the underlying T2 Regional GMZ under Scenario 9 causing increased downward leakage.

Pumping under Scenario 10 results in declines in levels of 3–4 m relative to Scenario 1. The –5 m AHD contour expands to cover an area of 148 km^2, stretching from Outer Harbor and Dry Creek in the north down to Adelaide Airport.

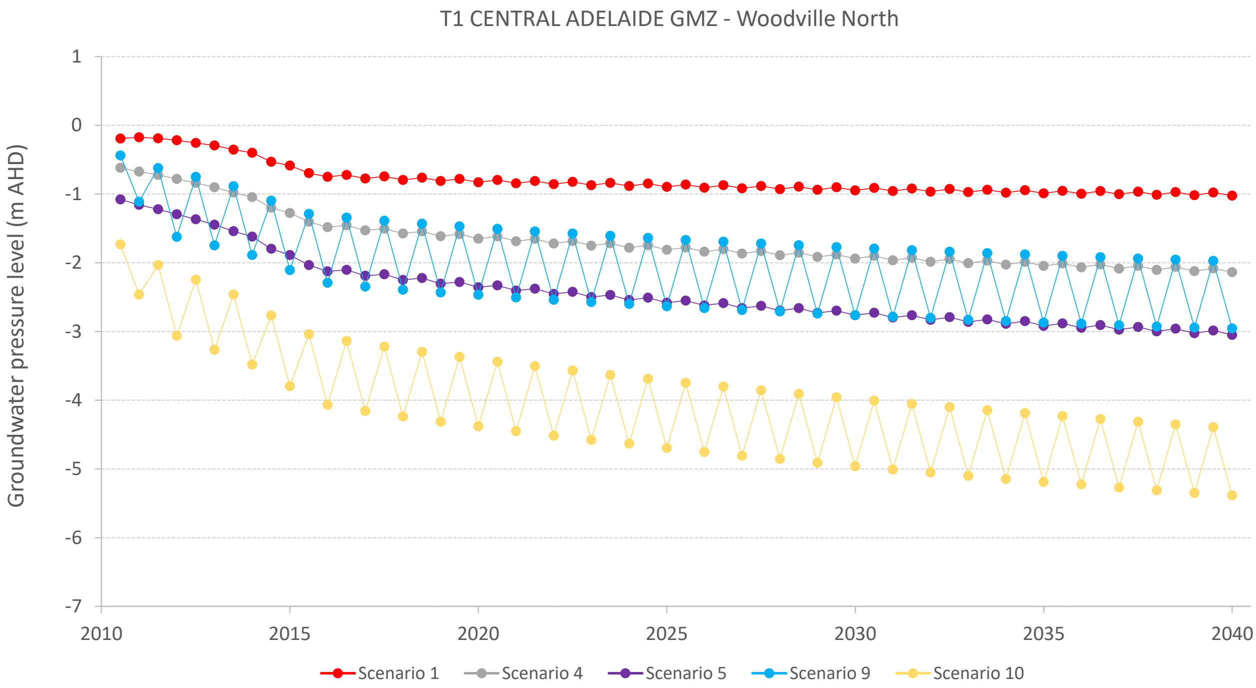

Figure 3.6 Predicted T1 aquifer pressure levels for relevant scenarios in the T1 Central Adelaide GMZ (Location H, Woodville North)

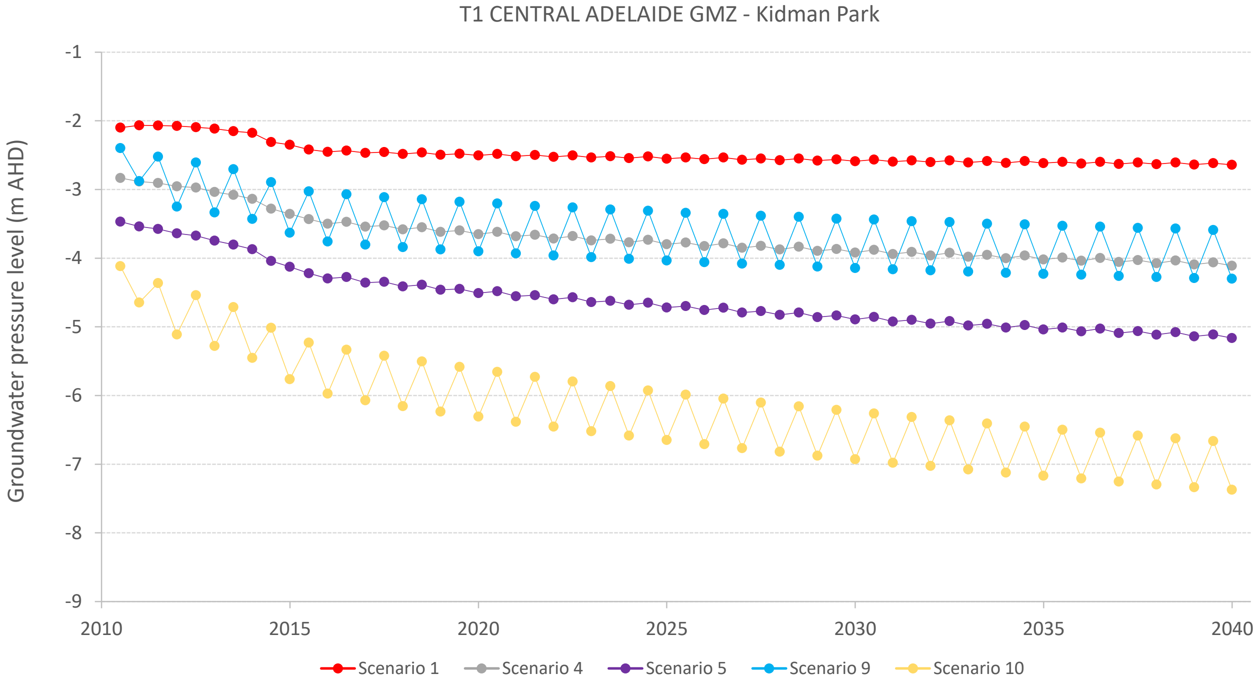

Figure 3.7 Predicted T1 aquifer pressure levels for relevant scenarios in the T1 Central Adelaide GMZ (Location K, Kidman Park)

3.2.6 T2 Northern Adelaide Plains GMZ

Scenario results for the T2 NAP GMZ were analysed at Two Wells (Location A; Fig. 3.8) as this is the location of the most concentrated extraction from the T2 aquifer in this GMZ. If future annual groundwater extraction is equivalent to the average annual extraction over the nominated eight years (2006–2013), it is predicted that groundwater levels in the T2 aquifer will remain relatively stable over the long term. Under Scenario 1, both the winter and summer groundwater pressure levels decline by about half a metre after 30 years, and are well above the resource condition limit.

If all licence holders in the NAP PWA were to extract groundwater at their full allocation, a significant decline in the groundwater pressure levels in the T2 aquifer is predicted. Under Scenario 2, at the end of summer 2040 the pressure level lowers by around 21 m (relative to Scenario 1) to about −27.5 m AHD, and the winter water level elevation reaches –12 m AHD, but the resource condition limit is not exceeded.

After 30 years of pumping volumes mid-way between base case and worst case under Scenario 3, winter levels decline by 5 m relative to Scenario 1 and the summer drawdown increases by nearly 11 m.

Scenario 4 results are similar to Scenario 1, with a decline in summer and winter groundwater pressure levels of 1–2 m after 30 years. Levels drop by 2–4 m under Scenario 5.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented as extraction volumes were kept the same as Scenario 1 as mentioned in Section 3.2.1.

Scenario 9 extraction volumes were increased to full allocations, with a decline in winter levels of 5 m and an increase in summer levels of 13 m relative to Scenario 1.

Pumping under Scenario 10 results in drawdowns of 2–3 m relative to Scenario 1, somewhere between Scenarios 4 and 5.

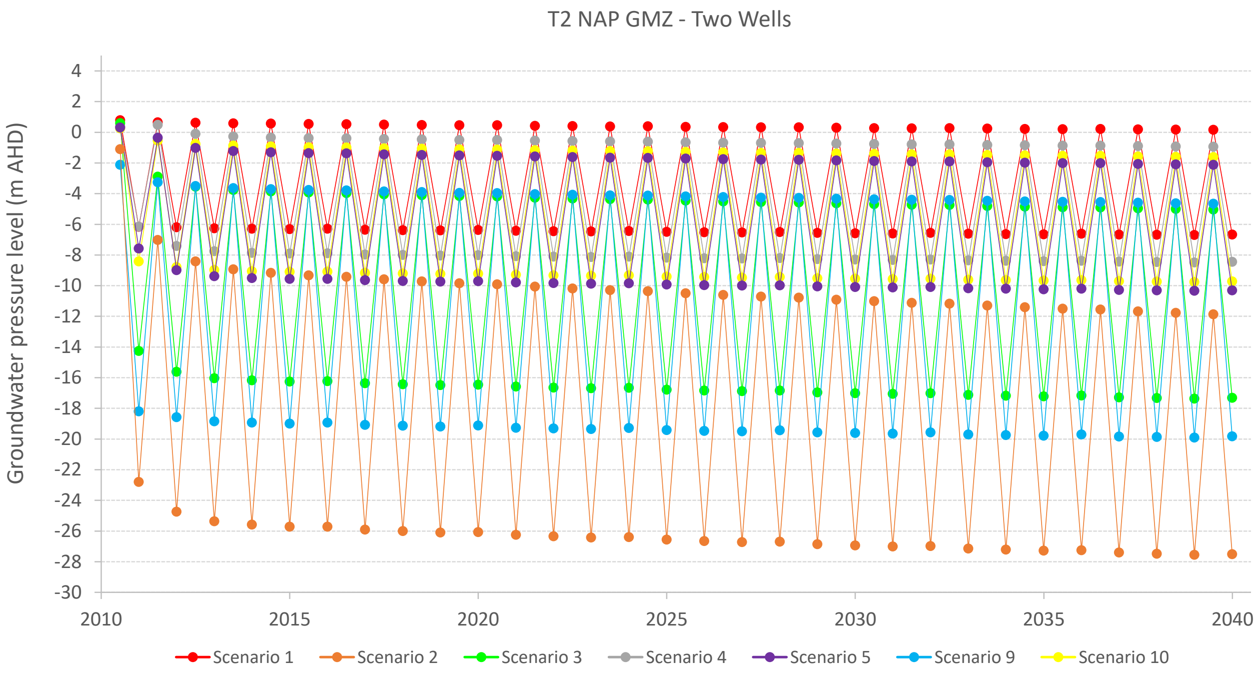

Figure 3.8 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T2 Northern Adelaide Plains GMZ (Location A, Two Wells)

3.2.7 T2 Virginia GMZ

Scenario results for the proposed T2 Virginia GMZ were analysed at Virginia (Location B; Fig. 3.9; Table 3.2) as this is the location of the most concentrated extraction from the T2 aquifer. Under Scenario 1, both the winter and summer groundwater pressure levels decline by about 1–2 m after 30 years, and the –30 m AHD contour covers an area of 54 km^2.

If all licence holders in the NAP PWA were to extract groundwater at their full allocation, a significant decline in the groundwater pressure levels in the T2 aquifer is predicted. Under Scenario 2 at the end of summer 2040, the cone of depression deepens by around 31 m (relative to Scenario 1) to about −85 m AHD, and the winter levels decline by 36 m to reach –60 m AHD, thereby exceeding the resource condition limit. The area covered by the –30 m AHD potentiometric contour expands to cover an area of 201 km^2, and there is no indication of an equilibrium being reached.

Under Scenario 3, the cone of depression reaches −75 m AHD at the end of summer after 30 years, with levels remaining below the top of the T2 aquifer for 7–8 months of the year. However groundwater pressure levels recovers to –37 m AHD in winter, indicating that the resource condition limit is not breached. The –30 m AHD potentiometric contour covers an area of 132 km^2.

Compared to Scenario 1, Scenario 4 results in an increase in summer and winter levels of 6.5 m and 4 m, respectively, after 30 years. The –30 m AHD potentiometric contour covers 80 km^2. Groundwater pressure levels are 13.5 m lower in summer and 8 m lower in winter under Scenario 5 relative to Scenario 1 and the area of the –30 m AHD contour covers 109 km^2.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented as extraction volumes in the T2 Virginia GMZ were kept the same as Scenario 1 as mentioned in Section 3.2.1.

Scenario 9 extraction volumes are kept the same as Scenario 1, but the groundwater pressure level is predicted to decline by 6 m to –30 m AHD in winter and –61 m AHD in summer after 30 years. The –30 m AHD contour doubles in size to 108 km^2. This is due to the adjacent T2 NAP GMZ pumping at full allocation and the T2 Regional GMZ pumping an additional 2000 ML under Scenario 9.

Scenario 10 results are similar to Scenario 9. A decline in levels of 6 m in winter and 8.5 m in summer relative to Scenario 1 is predicted, with the –30 m AHD contour covering an area of 106 km^2.

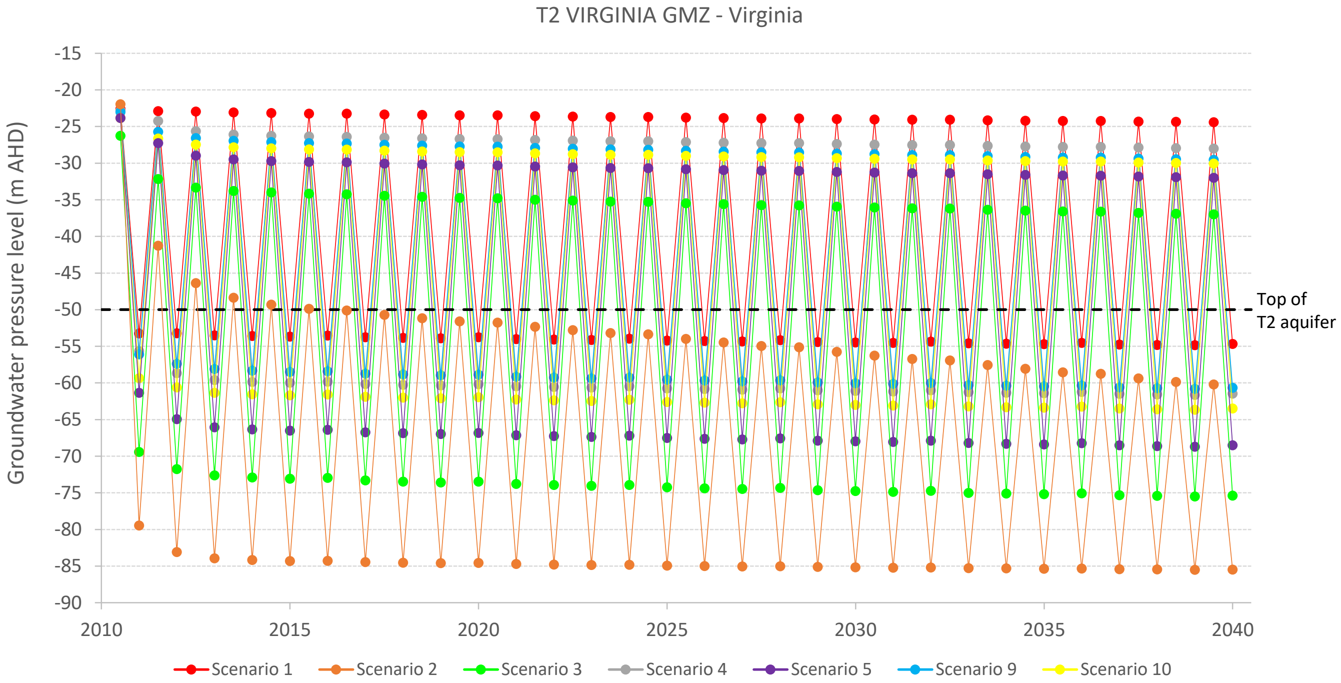

Figure 3.9 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T2 Virginia GMZ (Location B, Virginia)

3.2.8 T2 Regional GMZ

Scenario results for the T2 Regional GMZ were analysed at Edinburgh (Location E; Fig. 3.10), Green Fields (Location G; Fig. 3.11), Woodville North (Location H; Fig. 3.12) and Kidman Park (Location K; Fig. 3.13) because of the large spatial extent of the GMZ. Under Scenario 1, after 30 years, both the winter and summer groundwater pressure levels decline by about 2 m at Edinburgh, 1 m at Green Fields, 4 m at Woodville North and 1.5 m at Kidman Park, and are tens of metres above the proposed resource condition limit which is located at roughly -100 m AHD in the north of the GMZ, and lower than -200 m AHD in the south of the GMZ.

The effect of pumping at full allocation in the T2 Regional GMZ is quite variable because of the distribution of existing users. Most are located near Edinburgh and Green Fields, and as such, the decline in groundwater pressure levels under Scenario 2 is greater at these two locations. After 30 years, levels at Edinburgh are 11 m lower in winter and 13 m lower in summer, relative to Scenario 1. At Green Fields they are 4 m lower in winter and 5 m lower in summer, relative to Scenario 1. At Woodville North and Kidman Park, declines are up to one metre in both summer and winter.

After 30 years of pumping under Scenario 3, winter groundwater pressure levels are 4.5 m lower at Edinburgh and nearly 2 m lower at Green Fields relative to Scenario 1. The summer level is 5.6 m at Edinburgh and just over 2 m lower at Green Fields. Both winter and summer groundwater pressure levels are 0.6 m lower than Scenario 1 at Woodville North and Kidman Park.

Compared to Scenario 1, an increase in extraction by 10% and 20% under Scenarios 4 and 5 results in small declines in levels after 30 years. Declines range between 1 and 2 m under Scenario 4 and between 2 and 4 m under Scenario 5.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented in this report as extraction volumes in the T2 Regional GMZ are kept the same as Scenario 1 as mentioned in Section 3.2.1.

Because of the small number of existing users over such a large area, extraction volumes were heavily increased under Scenario 9 to determine the effect of further development of the T2 aquifer in the GMZ. When compared to Scenario 1 after 30 years, groundwater pressure levels at Edinburgh are 6 m lower in winter and 13 m lower in summer. At Green Fields they are 5 m lower in winter and nearly 14 m lower in summer. At Woodville North water levels are 3 m lower in winter and 10.5 m lower in summer, and in Kidman Park they are 2 m lower in winter and 6.5 m lower in summer.

Scenario 10 extraction volumes were kept the same as Scenario 9, but were increased by 30% in most of the surrounding GMZs. Groundwater pressure levels from Scenario 10 are less than a metre lower than Scenario 9 pressure levels at Edinburgh and nearly 2 m lower at Green Fields. At Woodville North, levels are 5 m lower than Scenario 9 and 3 m lower at Kidman Park, relative to Scenario 9.

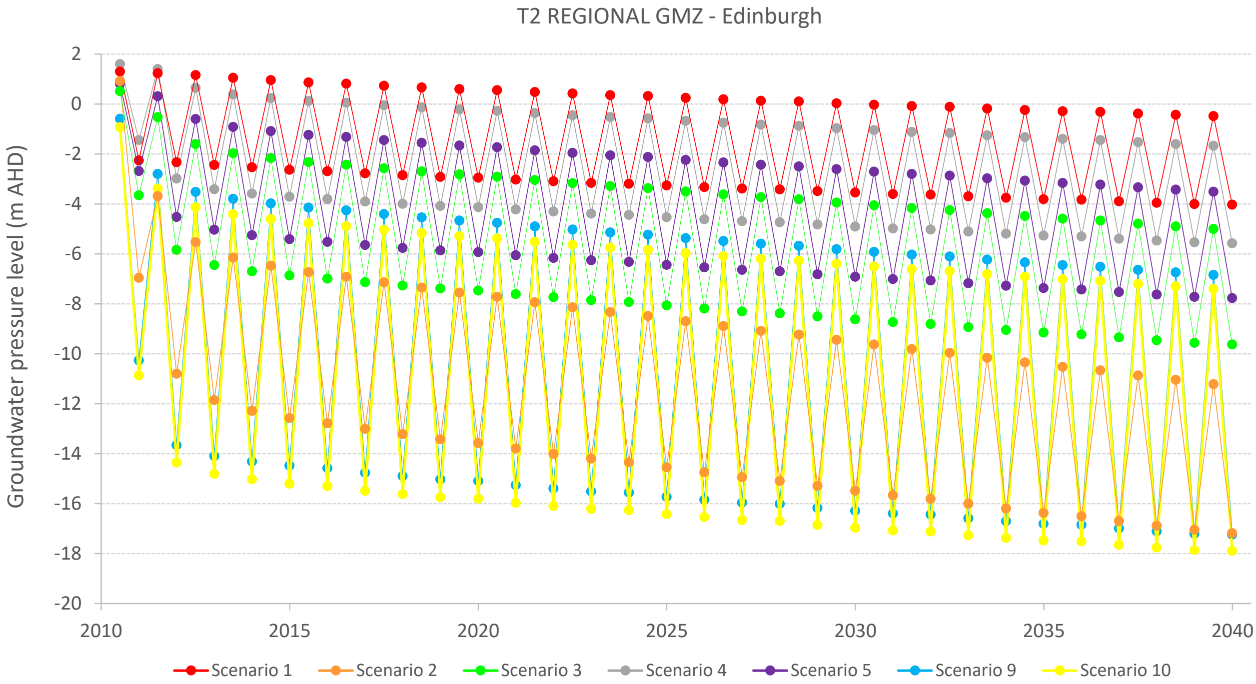

Figure 3.10 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T2 Regional GMZ (Location E, Edinburgh)

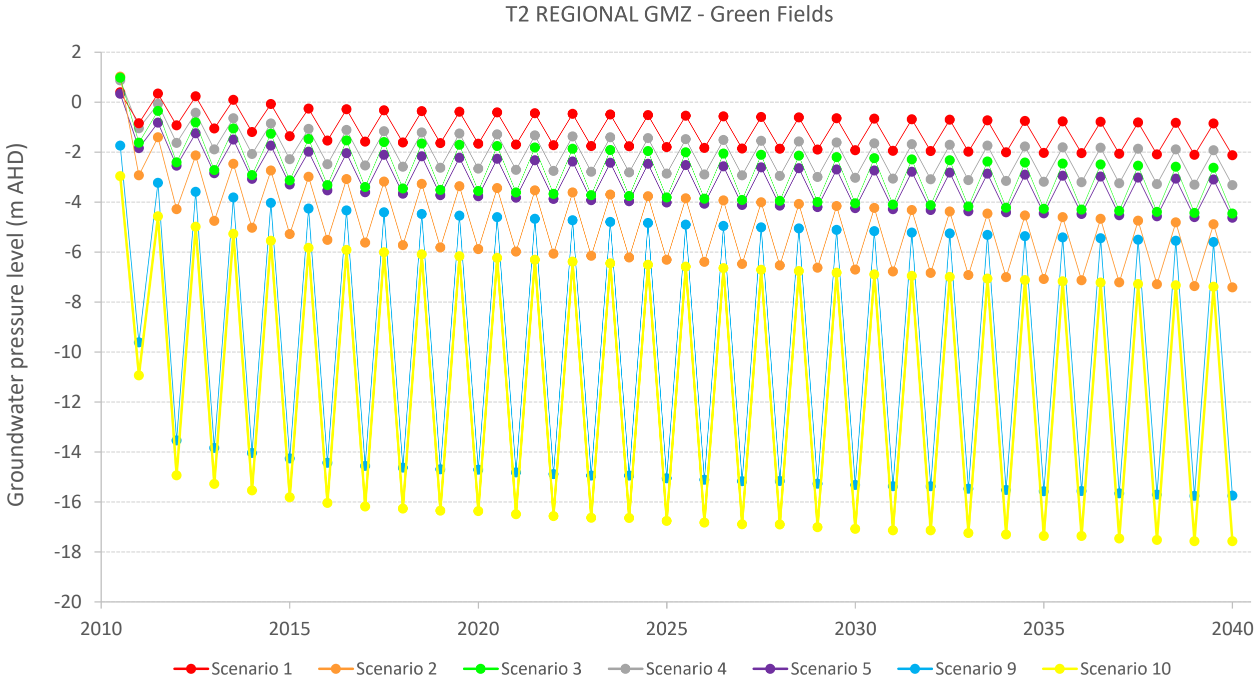

Figure 3.11 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T2 Regional GMZ (Location G, Green Fields)

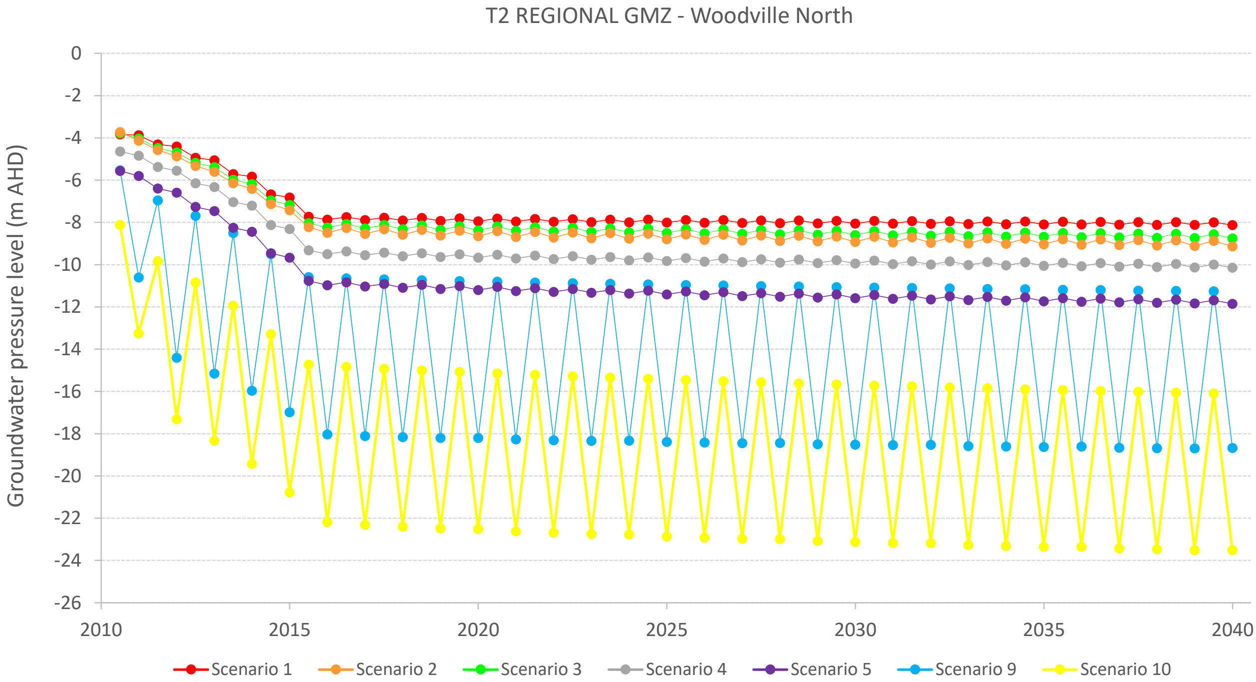

Figure 3.12 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T2 Regional GMZ (Location H, Woodville North)

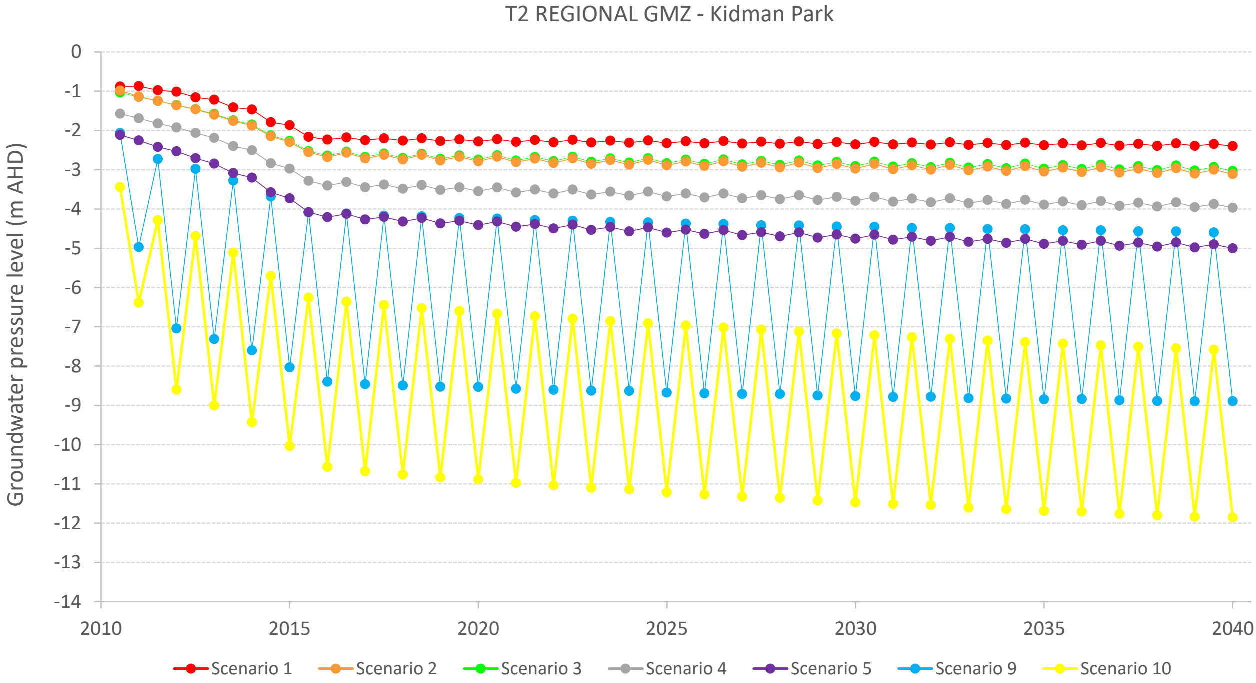

Figure 3.13 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T2 Regional GMZ (Location K, Kidman Park)

3.2.9 T2 Osborne GMZ

Scenario results for the T2 Osborne GMZ were analysed at Osborne (Location F; Fig. 3.14; Table 3.2). Under Scenario 1, both the winter and summer groundwater pressure levels decline by about 0.8 m after 30 years and are well above the resource condition limit. The –30 m AHD contour covers an area of just 0.6 km^2.

Groundwater pressure levels for Scenarios 2 and 3 are not presented for the T2 Osborne GMZ as extraction volumes were kept the same as Scenario 1, as mentioned in Section 3.2.2.

Pumping at an additional 10% under Scenario 4 results in levels that are 4 m lower than Scenario 1. This increases to 8 m with additional 20% under Scenario 5. The –30 m AHD contour expands to around 1 km^2 under Scenario 4 and nearly 2 km^2 under Scenario 5.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented for the T1 Osborne GMZ as extraction volumes were kept the same as Scenario 1, as mentioned in Section 3.2.1.

Scenario 9 extraction volumes from the proposed T2 Osborne GMZ were kept the same as Scenario 1, but a decline in levels of around 3 m in winter and 9.5 m in summer is predicted to occur after 30 years, and the area covered by the –30 m AHD contour reaches 4 km^2. This is likely due to the increased volume of extraction from the surrounding T2 Regional GMZ under Scenario 9.

Increasing average extractions by 30% under Scenario 10 results in groundwater pressure level declines of 15 m in winter and 21 m in summer relative to Scenario 1 and the –30 m AHD contour expands to cover an area of 10 km^2.

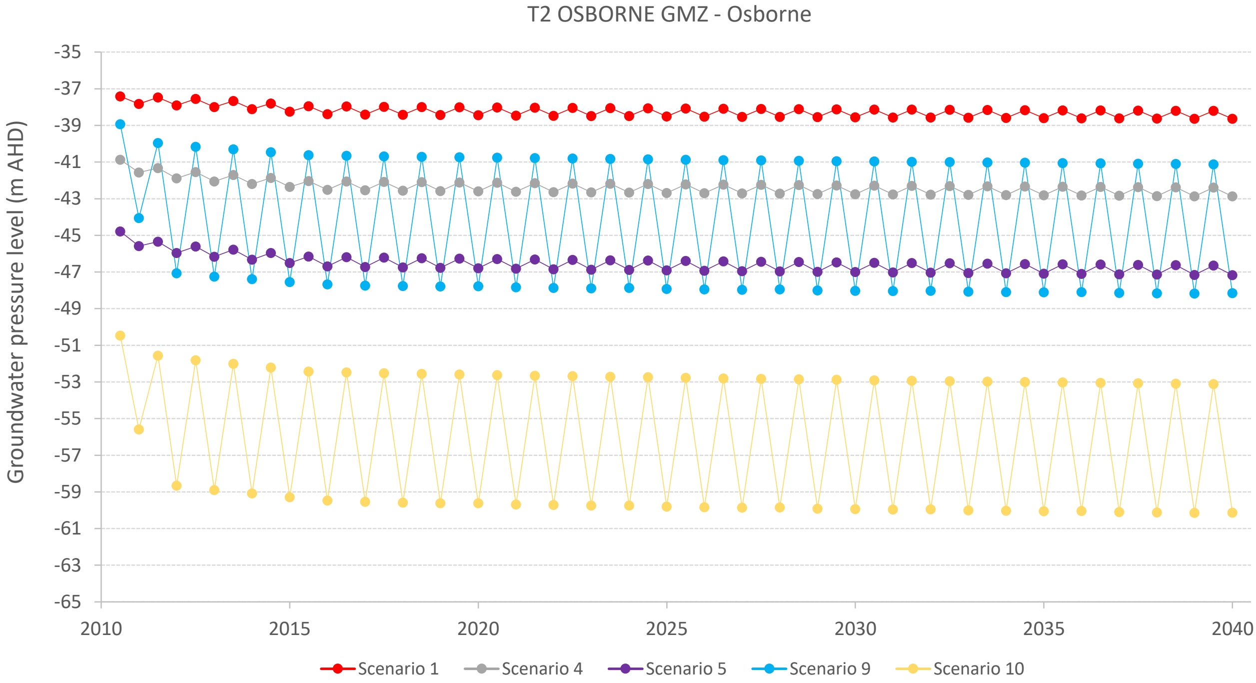

Figure 3.14 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T2 Osborne GMZ (Location F, Osborne)

3.2.10 T2 Regency Park GMZ

Groundwater extracted from the T2 aquifer in the proposed T2 Regency Park GMZ is used for beverage production and scenario results were analysed at Regency Park (Location J; Fig. 3.15; Table 3.2). Extractions were predicted to increase over five years and this was simulated in the model. Under Scenario 1, both the winter and summer groundwater pressures levels decline by about 17 m after five years and then remain stable over the remaining 25 years, but are well above the resource condition limit. The –30 m AHD contour covers an area of just 0.13 km^2.

Groundwater pressure levels for Scenarios 2 and 3 are not presented for the T2 Osborne GMZ as extraction volumes were kept the same as Scenario 1 as mentioned in Section 3.2.2.

Pumping at an additional 10% under Scenario 4 results in levels that are nearly 5 m lower than Scenario 1. This increases to 9 m with additional 20% under Scenario 5. The –30 m AHD contour expands to just 0.3 km^2 under Scenario 4 and 0.5 km^2 under Scenario 5.

Groundwater pressure levels for Scenarios 6, 7 and 8 are not presented for the T1 Grange GMZ as extraction volumes were kept the same as Scenario 1, as mentioned in Section 3.2.1.

Scenario 9 extraction volumes were also kept the same as Scenario 1, but a decline of around 3 m in winter and 8 m in summer is projected to occur after 30 years, and the area covered by the –30 m AHD contour reaches 0.5 km^2. This is likely due to the increased volume of extraction from the surrounding T2 Regional GMZ under Scenario 9.

Increasing average extractions by 30% under Scenario 10 results in declines of 15 m in winter and 20 m in summer relative to Scenario 1 and the –30 m AHD contour expands to cover an area of 3 km^2.

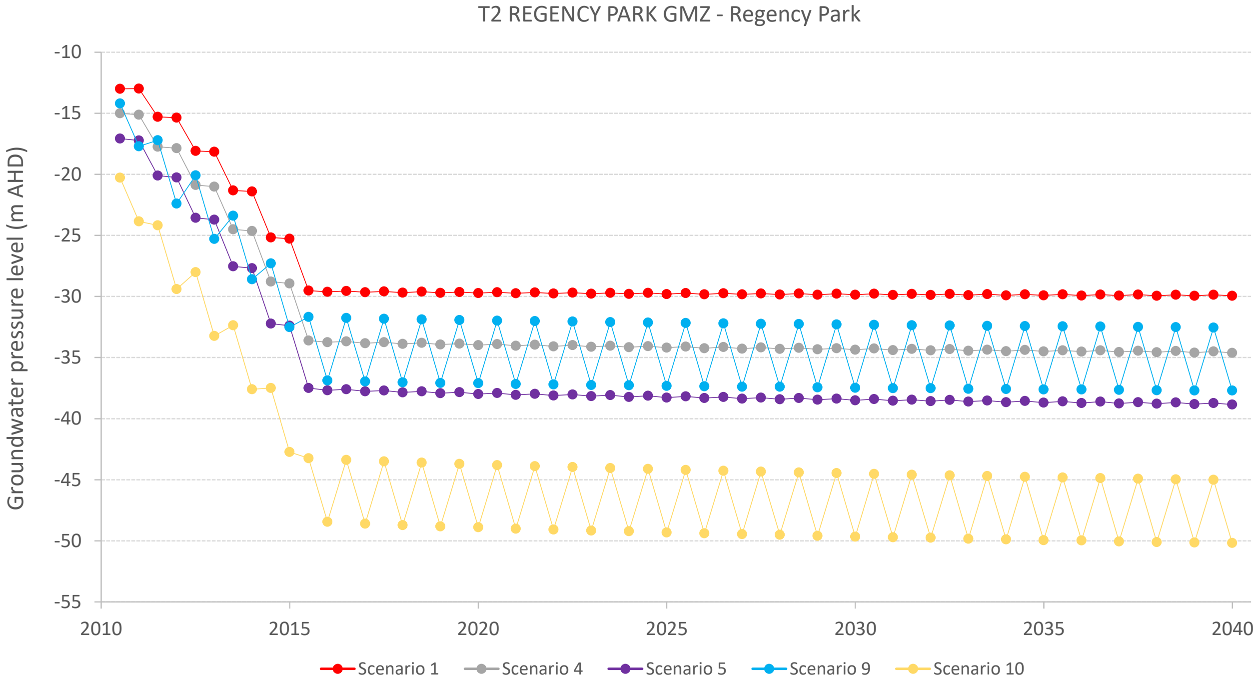

Figure 3.15 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T2 Regency Park GMZ (Location J, Regency Park)

3.2.11 T1 and T2 Golden Grove Embayment GMZ

Scenario results for the T1 and T2 GGE GMZ were analysed at Stepney (Location M; Fig. 3.16; Table 3.2) and Edwardstown (Location N; Fig. 3.17; Table 3.2) because of their central locations in the GMZ. The modelled groundwater pressure level response from both aquifers is very similar, suggesting a high degree of connectivity between them and as such, scenario results for the T2 aquifer alone are presented in the graphs for display purposes.

Under Scenario 1, both the winter and summer levels decline by less than 0.2 m after 30 years, and are well above the resource condition limit at both locations.

Groundwater pressure levels for Scenarios 2, 3, 4 and 5 are not presented for the T1 and T2 GGE GMZ as extraction volumes were kept the same as Scenario 1. Drawdown caused by increased pumping in the Adelaide Plains Sub-basin under these scenarios is unlikely affect pressure levels in the aquifers of the Golden Grove Embayment on the uplifted side of the Para Fault.

Pumping at double the average extraction volume under Scenario 6 results in a decline in pressure levels of around 1–1.5 m after 30 years, relative to Scenario 1. Pressure level declines increase to 3.5–5 m after 30 years of pumping an additional 2000 ML (compared to Scenario 6) under Scenario 7. Reducing the additional pumping to 1000 ML (compared to Scenario 6) under Scenario 8 results in pressure levels that are 2.5–3 m lower than Scenario 1.

Pressure levels for Scenarios 9 and 10 are not presented for the T1 and T2 GGE GMZ as extraction volumes were kept the same as Scenario 1 and Scenario 8, respectively and are pressure levels are unlikely to be affected by changes to pumping volumes on the downthrown side of the Para Fault.

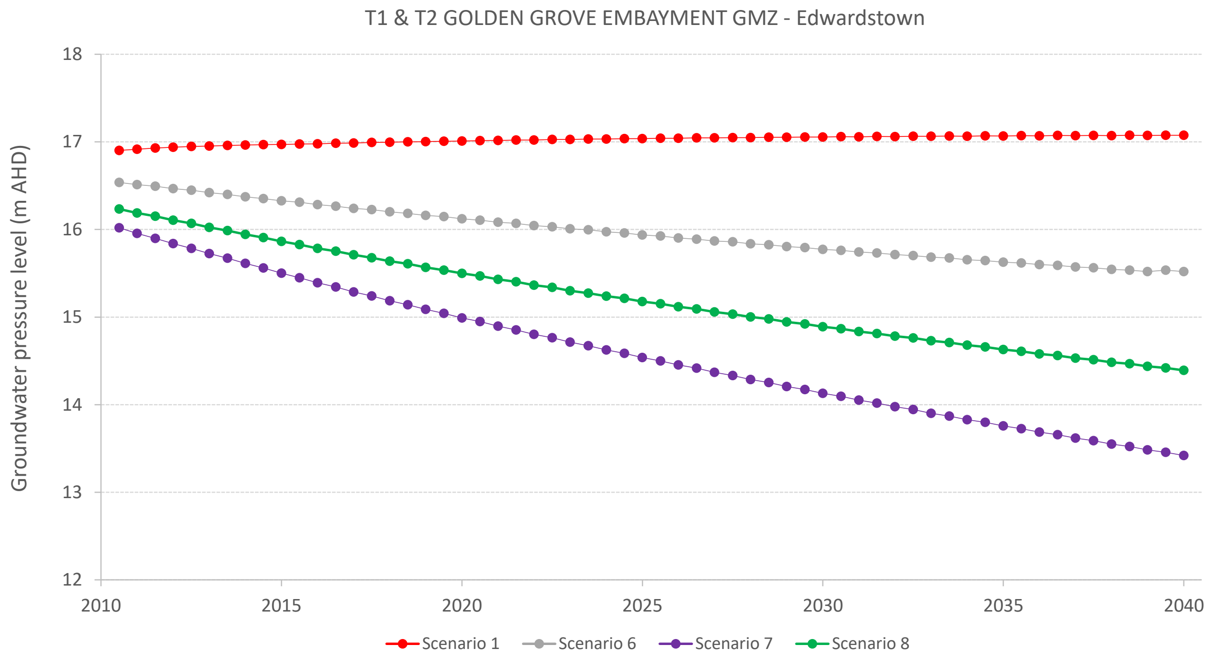

Figure 3.16 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T1 and T2 Golden Grove Embayment GMZ (Location M, Stepney)

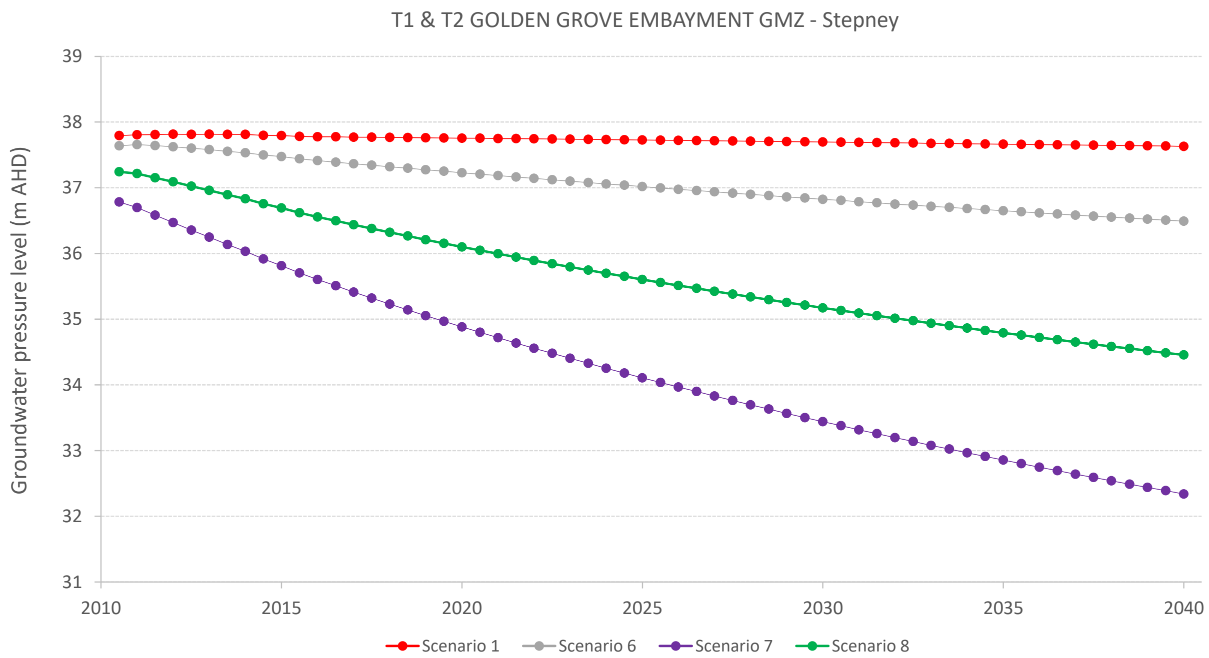

Figure 3.17 Predicted T2 aquifer pressure levels for relevant scenarios in the proposed T1 and T2 Golden Grove Embayment GMZ (Location N, Edwardstown)

Table 3.2 Summary of model scenario results

	Scenario										Current[5]
Reportable measure	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**conditions**
T1 Waterloo Corner winter water level 2040 (m AHD)	1	-5	-1	0	-1	1	1	1	-0.5	-2	2.6
T1 Waterloo Corner summer water level 2040 (m AHD)	-5	-11	-5	-6	-8	-5	-5	-5	-6.5	-9	-3.6
T1 Waterloo Corner -5 m AHD contour area (km^2) summer 2040	0	40	4	0.04	3	0	0	0	0.6	6	23
T1 Dry Creek winter water level 2040 (m AHD)	-8	-8	-8	-9	-10.5	-8	-8	-8	-9	-12	-7
T1 Grange winter water level 2040 (m AHD)	-8.5	-8.5	-8.5	-10	-11	-8.5	-8.5	-8.5	-9	-13	-3
T1 Thebarton winter water level 2040 (m AHD)	-7	-7	-7	-8.5	-10.5	-7	-7	-7	-7	-13.5	-8
T1 Dry Creek -5 m AHD contour area (km^2) summer 2040	6	6	6	10	17	6	6	6	18		
T1 Grange -5 m AHD contour area (km^2) summer 2040	9	9	9	15	38	9	9	9	17	148	207
T1 Thebarton -5 m AHD contour area (km^2) summer 2040	1	1	1	3		1	1	1	4		
T2 Virginia winter water level 2040 (m AHD)	-24	-60	-37	-28	-32	-24	-24	-24	-30	-30	-22
T2 Virginia summer water level 2040 (m AHD)	-55	-85.5	-75	-61.5	-68.5	-55	-55	-55	-61	-63.5	-46
T2 Virginia -30 m AHD contour area (km^2) summer 2040	54	201	132	80	109	54	54	54	108	106	25
T2 Regency Park winter water level 2040 (m AHD)	-30	-30	-30	-34.5	-39	-30	-30	-30	-32.5	-45	-8
T2 Regency Park -30 m AHD contour area (km^2) summer 2040	0.13	0.13	0.13	0.3	0.5	0.13	0.13	0.13	0.5	3	-
T2 Osborne winter water level 2040 (m AHD)	-38	-38	-38	-42	-47	-38	-38	-38	-41	-53	-4
T2 Osborne -30 m AHD contour area (km^2) summer 2040	0.6	0.6	0.6	1.1	1.8	0.6	0.6	0.6	4	10	-
T2 and T1 Stepney (GGE) winter water level (m AHD)	38	38	38	38	38	36.5	32	34.5	38	35	26
T2 and T1 Edwardstown (GGE) winter water level (m AHD)	17	17	17	17	17	15.5	13	14	17	17	10
Resource condition limits exceeded Y/N	N	Y	N	N	N	N				N	NA
Total Tertiary extractions	28 418	38 641	33 530	31 100	33 781	30 019	32 019	31 019	33 046	39 863	NA

[5] Groundwater pressure levels measured in monitored wells in 2015.

3.3 Recommended extraction limits for T1 and T2 aquifers

The recommended extraction limits for the T1 and T2 aquifers GMZs are the volumes of water that can be extracted for licensed use without causing unacceptable long-term declines in groundwater pressure levels. They do not include water for stock and domestic use or water authorised by the Minister for Water under Section 128 of the Act.

For the T1 aquifer, the winter groundwater pressure levels should not exceed –5 m AHD in the Waterloo Corner area and –15 m AHD in the Central Adelaide PWA by 2040. For the T2 aquifer, the winter levels should not exceed the base of the confining layer separating the T1 and T2 aquifers by 2040.

As requested by the Board, a range of recommended extraction limits for each GMZ have been proposed. An upper limit is proposed for the GMZs where a range of volumes is not practicable. Under Scenario 2, the resource condition limits for the proposed T1 NAP GMZ (Waterloo Corner area) and T2 Virginia GMZ are exceeded, and this scenario is therefore considered unsustainable for these zones (Table 3.2). The significant declines in groundwater pressure levels which result in an area where depressurisation of the T2 aquifer occurs, significantly increases the risk of not only salinity rises due to downward leakage and lateral inflows of more saline groundwater, but also the risk of structural damage to the confining layer above the T2 aquifer. The assessment of the likelihood of these increases in extraction and the associated consequences is beyond the scope of this report.

Model scenarios suggest increases in extraction of 20–30% would have tolerable impacts on the T1 and T2 aquifers in most of the proposed groundwater management zones. Therefore, the range of recommended extraction limits for most zones are based on the volumes modelled in Scenarios 5 and 10.

The recommended extraction limit for the proposed T2 Virginia GMZ has been kept at in the range of 10–20% increase on current average extractions to limit major increases in the existing cone of depression in this area of intensive extraction.

The recommended extraction limit for the proposed T2 NAP GMZ is the current allocation volume of 4483 ML (which is more than double current extractions). Although this amount has not been modelled in the same scenario as the base case + 20% volume that is the upper recommended limit for the adjacent T2 Virginia GMZ, this volume seems reasonable based on outcomes from other scenarios. The total volume extracted from these two GMZs under the mid case scenario (Scenario 3), equals 15 323 ML. The total volume extracted from the T2 NAP GMZ under full allocation and T2 Virginia GMZ under base case + 20% equals 15 555 ML. Therefore, it is suggested that the groundwater pressure level response will be similar to the Scenario 3 results, which is where the levels are predicted to come close to the resource condition limit. The risk of structural damage to the confining layer above the T2 aquifer and the risk of ingress of higher salinity water in the medium term under this scenario are considered acceptable. Monitoring wells in the vicinity show that historical pressure levels have approached the resource condition limit in times of low rainfall and increased extractions, but the levels have quickly recovered when wetter conditions resume and extractions decrease.

As the T2 Regional GMZ covers a large area and contains very few existing users, pumping at full allocation under Scenario 2 is predicted to have minimal impact on the resource and those users. Consequently, new development in the GMZ may be possible with limited resultant impacts. A recommended extraction limit of 2212 ML is therefore suggested for the T2 Regional GMZ. Although this volume is much higher than the current extraction in this area, additional modelling (Scenarios 9 and 10) suggests the impact of extracting this increased volume from the GMZ does not exceed the proposed resource condition limits and would have acceptable impacts on existing users. Given that this GMZ underlies suburban areas, the likelihood of such an increase in extraction is low. The recommended extraction limit of 2212 ML should be accompanied with a proviso that any application over 250 ML/y should provide a hydrogeological investigation that determines the impact on the resource and other users.

Because of the highly urbanised nature of the proposed T1 and T2 Golden Grove Embayment GMZ, there is unlikely to be a significant increase in demand. However, scenario modelling has shown that an increase of double the amount of existing user demand may cause drawdown of only 1 to 1.5 m. An increase of 2000 ML/y on top of the doubled existing user demand may not be sustainable, but an increase of 1000 ML/y is not likely to be detrimental to the resource. Therefore, the recommended extraction limit range is based on the doubling of existing user demand and the additional 1000 ML. Similar conditions to the T2 Regional GMZ that any application over 250 ML/y should conduct a hydrogeological investigation to determine the impact on the resource and other users is suggested.

An earlier assessment of the T2 aquifer in the Kangaroo Flat region of the NAP PWA (Barnett 2013) confirmed 1500 ML/y as an initial recommended limit for allocations. A reduction in extractions since 2008–09 to below 1500 ML have led to a reduction in seasonal drawdown, a rise in the maximum recovered groundwater level, and a reduction in salinity in four of the six monitored irrigation wells in the two areas of concentrated extraction. However some irrigation wells are showing an ongoing rising salinity trend, with half of those sampled still recording values over 1500 mg/L (the maximum salinity tolerance for most crop types). A process to determine existing user requirements in this area is in development at the time of writing. The social and economic importance of groundwater extractions in the Kangaroo Flat region were outside the scope of the Barnett (2013) report, and will be considered during the formulation of the water allocation plan.

Again, it should be noted that the extraction limits recommended for consumptive use in each proposed management zone do not necessarily equate to the recommended extraction limits that will be defined in the WAP. Consideration of social and economic factors and what might be considered by stakeholders to be acceptable impacts may result in the allocated volumes being different to the recommended extraction limits.

It should also be noted that the extraction limits have been set based on the assessment that impacts to water quality due to extraction pose a low risk to the resource in the short to medium term. While the groundwater pressure levels in the T1 and T2 aquifers remain tens of metres below pre-development levels, there will be an ongoing salinity threat from increased downward leakage of salty water from the Q4 aquifer (particularly in the Waterloo Corner area where the Hindmarsh Clay confining layer is thin or absent, and in the Kangaroo Flat area) and the lateral encroachment of higher-salinity water from surrounding areas. Therefore, despite what is suggested as the recommended extraction limit, a resource salinity limit trigger could also be used in the WAP to restrict extractions, and a program of work undertaken in the future to evaluate more fully the longer-term salinity impacts likely to arise from the using the recommended extraction limits.

3.4 T3 and T4 aquifers

There is currently no extraction from these aquifers and further development is likely to be limited by the depth of the aquifers and the poor water quality of the resource. As such, the current allocation volume of 2300 ML as the lower range volume for the recommended extraction limit and a nominal figure of 4000 ML as the maximum recommended extraction limit is suggested. A condition that any application over 250 ML/y should conduct a hydrogeological investigation to determine the impact on the resource and other users is also suggested. Any further increase to extraction above the 4000 ML limit should be assessed on a case-by-case basis.

3.5 Fractured rock aquifers

For the Northern, Torrens, Patawalonga and Southern FRA GMZs, the volume of groundwater available for licensed allocation has been derived using a water balance approach according to the equation set out in Section 2.5.1:

Water available for licensed extraction = recharge – non-consumptive demand – non-licensed extraction

or in the case of the MLR fractured rock aquifers, where dominant non-consumptive discharge is observed in the form of surface stream baseflow:

Water available for licensed extraction = recharge – baseflow – non-licensed extraction.

A methodology consistent with that used for the water allocation plans for both the Eastern and Western Mount Lofty Ranges (EMLR and WMLR) was used to determine the net annual recharge volume for the FRA GMZs. The recharge to the fractured rock aquifers is calculated by applying hydrochemical methods to data from field investigations conducted in locations with a variety of geology types. Recharge fluxes are aggregated according to the proportion of each geology type in each management zone and scaled according to rainfall differences. These are then multiplied by the area of the management zone to derive a recharge volume. The details of this method are described in Green *et al.* (2006). As there are no recharge investigation sites within the CA PWA, it has been necessary to use the recharge rate estimates from nearby sites with similar geology in the neighbouring WMLR. These were then extrapolated over the appropriate management zones.

The recharge volume (resource capacity) is then compared to the sum of the total annual baseflow and the non-licensed groundwater extractions. For each fractured rock aquifer GMZ, the upper recommended extraction limit volume, which is the uppermost limit of the total volume of groundwater that can be made available for licensed purposes, is derived from these parameters (Table 3.3). So, the water balance becomes:

Upper recommended extraction limit = recharge – baseflow – non-licensed extraction.

Table 3.3 Water balance and recommended extraction limits for the fractured rock aquifers GMZs (all volumes in ML)

FRA GMZ	Recharge	Baseflow	Non-licensed extraction	Upper recommended extraction limit
Northern	6352	2697	176	3479
Torrens	4502	2651	214	1637
Patawalonga	5223	4734	239	250
Southern	2560	2368	573	-381

These initial calculations highlighted some discrepancies in the Patawalonga and Southern FRA GMZs (Table 3.3), wherein the baseflow estimates are almost as high as the recharge estimates. While this situation might be expected in a highly permeable catchment with high rates of throughflow (such as the Tookayerta underground water management zone in the EMLR, which is infilled with Permian sands), it is unusual for fractured rock aquifers which typically have a much lower permeability.

In cases where the hydrochemical investigations estimate groundwater recharge to be significantly less than the sum of groundwater discharges, some degree of uncertainty in the accuracy of the hydrochemical methodology must be assumed, particularly if the available monitoring data indicate that groundwater levels are not showing any sustained decline. In these instances, the approximation of recharge from the sum of all groundwater discharges (baseflow, non-licensed extraction and existing user demand) is the preferred methodology and was applied to the Patawalonga and Southern FRA GMZs (Table 3.4). A guideline condition that the resulting recharge must not exceed 12% of the annual rainfall in the GMZ and that monitored wells in the GMZ must not show a decline in groundwater levels, were fulfilled for these two zones.

In this situation, as the upper recommended extraction limit (UREL) is calculated as the recharge minus the sum of baseflow and non-licensed extraction, the UREL equals the volume of existing user demand (EUD) for these two GMZs. For the Patawalonga FRA GMZ this would be 464 ML and for the Southern FRA GMZ 155 ML. These volumes are quite small and should be considered the minimum recommended extraction limit as this approach is quite conservative. Nevertheless, considering that the proposed resource condition limits have been set in order to maintain current annual average baseflow levels, it would not be possible to recommend a higher extraction limit without further scientific studies.

It should be noted that there is a significant potential for error in these recharge estimates. The reference recharge estimates are subject to error in their derivation by hydrochemical models, and the process of extrapolation to other sub-catchments is likely to compound these errors. The method of extrapolation described above takes no account of differences in vegetation coverage, soil type or slope, which may differ markedly between the location of a recharge investigation site and the sub-catchment in which the recharge rate derived at that site is applied. However, as the chloride mass balance method has been very influential in deriving these estimates, they are likely to err towards being too low rather than too high.

The recharge figures were subsequently reduced to reflect the reduction in recharge under plantation forest. It has been assumed here that 85% of potential recharge is lost via interception under plantation forests. To accommodate this, the areas of plantation forests identified by AGT (2011) within each GMZ were calculated and recharge was reduced accordingly. Due to the widely variable nature of recharge under urban areas, the effect of urbanisation has been disregarded here.

Where the available groundwater level data show no sustained decline, it is assumed the annual total of groundwater discharging within the management zone is in balance with the annual total of groundwater recharging. In these conditions, annual recharge can also be approximated from the sum of groundwater extractions and baseflow.

Baseflow separation techniques use the time-series record of stream flow to derive the baseflow signature, which is assumed to be groundwater discharge. SKM (2011a) conducted baseflow separation analysis for selected stream gauges within the study area that had adequate periods of record. The locations of the stream gauges are rarely in the ideal location for calculating baseflows for the selected sub-catchments and consequently, the simplifying assumptions applied may lead to errors.

Non-licensed water extraction includes stock and domestic use and water authorised by the Minister under Section 128 of the Act, e.g. water used for firefighting and public road making. AGT (2011) developed a systematic methodology for querying the SA Geodata drillhole database in order to determine the number of operational, non-licensed drillholes within the NAP and CA prescribed areas. Various assumptions about typical rates of extraction were used to estimate the non-licensed extraction for each major aquifer and the spatial distribution of this information was used to derive the volumes for each groundwater management zone. The estimate for roads has not been included as the major projects accounted for in AGT (2011) have been completed or are near completion.

There is the potential for error in the estimates for non-licensed extraction, with the stock and domestic use for fractured rock aquifers likely to be overestimated by up to 20% (AGT 2011). The estimates for forestry also include land parcels designated as forestry that remain unplanted as of January 2011, so the volume of recharge adjustment for forestry may be overestimated. The 236 ML of groundwater extraction for softwood plantation forestry was split between the Northern, Torrens, Patawalonga and Southern FRA GMZs due to lack of detail of location of land parcels where the watertable is considered to be within 6 m of the ground surface and therefore accessible to the trees. The 389 ML of groundwater extraction for hardwood plantation forestry was allocated to the Southern FRA GMZ because of the 214 ha of hardwood (blue gums and native forest) surrounding the Happy Valley Reservoir. The 5 ML estimated for firefighting was split evenly between the Northern, Torrens, Patawalonga and Southern FRA GMZs as AGT (2011) state that the most likely place where drillholes may be accessed for water to fight fires is in the hills area fringing the major urban areas.

As the CA PWA is largely unmetered at present and licences are still to be issued, the extraction within the prescribed area was estimated based on the licence applications from existing users. Therefore, there is a degree of uncertainty in the volumes calculated as they are based on what the existing users estimate they are using now and what they may extract in the future. However, for all of the largest volume users who collectively extract most of the total volume, the current usage has been verified through land and water-use surveys.

Throughflow from the fractured rock aquifers is thought to be an important source of recharge to the sedimentary aquifers beneath the plains. It has not been explicitly accounted for in the water balance methodology because of the large uncertainties in knowledge of the flow mechanism and volumes of groundwater flux across the major fault zones. Estimates have ranged from 5000–10 000 ML/y. Throughflow volumes will only change if the hydraulic gradient driving flow across the faults also changes. Because of the steep terrain, there are currently no extractions for licensed purposes within one kilometre of these faults and there is a low risk of increases in extraction. It is reasonable to assume that throughflow (whatever volume it may be) will not be significantly affected by licensed extraction because the zone of influence of the extraction wells is highly unlikely to extend beyond one kilometre to the fault zone.

There is insufficient information to use the water balance method for the fractured rock aquifers beneath the Golden Grove Embayment. Current extractions are primarily located in the northern half of the GMZ where overlying Tertiary sediments are thin and probably dry. Non-licensed use and existing user demand is relatively low at about 19 and 14 ML/y respectively, with a low risk of significant demand in the future because of the urbanised nature of the GGE and relatively high salinities. Therefore, a nominal figure of 500 ML/y is suggested for the recommended extraction limit, but a caveat that any application over 50 ML requires a hydrogeological investigation to determine the impact on the resource and other users is also suggested.

3.6 Noarlunga Embayment

The Noarlunga Embayment GMZ is heavily urbanised and is the equivalent of Zones 4 (Quaternary) and 5 (Tertiary) in SKM (2011a). Therefore, the net annual recharge volume of 2479 ML and the annual baseflow volume of 757 ML calculated by SKM for Zone 4 have been used. The spatial distribution of non-licensed extraction estimated by AGT (2011) indicates 5 ML of groundwater is used for these purposes in the NE GMZ. The upper recommended extraction limit volume for the Noarlunga Embayment GMZ has been derived from the formula used for the fractured rock aquifers, that is:

Upper recommended extraction limit = recharge – baseflow – non-licensed extraction

Using the volumes available:

Upper recommended extraction limit = 2479 – 757 – 5 = 1717 ML

The resulting upper recommended extraction limit volume for the Noarlunga Embayment GMZ is 1717 ML/y. There is no existing user demand for licensed purposes. Throughflow from the adjacent fractured rock aquifers across the Clarendon Fault provides a recharge mechanism for the Noarlunga Embayment GMZ sedimentary aquifers, but due to the large uncertainties associated with calculating throughflow, this has not been included. Therefore, the allocation volume is a conservative estimate. However, as there are limited monitoring data available for the Noarlunga Embayment GMZ, the condition of the resource is not known with certainty but the risk of over-extraction is very low.

4 Assessment of the effects on other water resources

Section 76(4)(a)(ii) of the Act requires a water allocation plan to assess whether the taking or use of water from the resource will have a detrimental effect on the quantity or quality of water that is available from any other water resource. This includes water resources in neighbouring prescribed and non-prescribed areas.

It must be recognised that climatic influences (such as below-average rainfall) will affect water resources throughout the region and such influences should not wholly be attributed to the taking of water.

4.1 Impacts caused by groundwater extraction

The extraction of groundwater will always have an impact on the groundwater resource and it is the role of the WAP to ensure that these impacts on the resource itself, other groundwater users and groundwater-dependent ecosystems (GDEs) are within acceptable limits.

Around each point of extraction, there will be a zone of influence where drawdown of groundwater pressure levels will be observed. Outside of this zone, the impact on water levels and groundwater flow will be insignificant, not only within the same aquifer from which the extraction is occurring, but also in nearby aquifers that may or may not have a hydraulic connection.

Because the water level declines due to extraction in confined aquifers is a pressure response, the resultant zones of influence are established more quickly, and are more widespread than those that occur in unconfined aquifers.

4.1.1 Inter-aquifer leakage

Before development, the confined Tertiary aquifer systems of the Adelaide Plains were artesian, with pressure levels up to 10 m above ground level. However, since intensive groundwater extraction began in the 1960s, the groundwater pressure levels in the T1 and T2 aquifers declined in some areas to 15 and 50 m below sea level, respectively.

Where these large cones of depression in groundwater pressure level developed, the vertical hydraulic gradients have been reversed, resulting in the potential for downward leakage from the Quaternary aquifer and leakage between the Tertiary aquifers themselves. The rate and volume of flow between them are controlled by permeability of the materials that separate them and the differences in their groundwater levels (i.e. the nature of the hydraulic gradient that exists between them).

4.1.2 Marine salt/fresh groundwater interface

Under natural conditions, coastal aquifers with hydraulic connectivity to the sea typically form a marine salt/fresh groundwater interface. The shape and location of this interface is governed by natural processes that include tidal action and climate driven seasonal or annual changes in aquifer discharge to the sea. These changes are believed to be minor and of short duration with low risk to the groundwater resource.

Only the shallow Quaternary aquifers of the Adelaide Plains have a hydraulic connection with the sea. At the coast, the deeper T1 and T2 aquifers lie beneath 50 and 100 m of Hindmarsh Clay and therefore have no connection with the sea. However, the offshore extent and thickness of the Hindmarsh Clay is unknown and hence the location of the marine salt/fresh groundwater interfaces in the deeper Tertiary aquifers is also unknown.

4.2 Impact of taking from one resource on another

4.2.1 Surface water

Groundwater extraction may have an impact on surface water resources in two ways. Where groundwater discharge occurs from unconfined aquifers to gaining streams in the form of baseflow, extractions may reduce the hydraulic gradient toward the stream and hence reduce the volume of baseflow. If these extractions occur close to the streams, the hydraulic gradient may be altered sufficiently to induce discharge from the stream to the groundwater. This can occur to both gaining and losing streams.

There is widespread connection between groundwater and surface water in the CA PWA, particularly in the unconfined fractured rock aquifers in the Mount Lofty Ranges, where baseflow can be vital in supporting ecosystems during summer. SKM (2011b) identified that the headwaters of the following streams are likely to be affected by current groundwater extractions:

- Cobbler Creek
- Dry Creek
- River Torrens
- First Creek
- Fourth Creek
- Fifth Creek
- Sturt River
- Field River
- Christie Creek.

On the plains, current extractions from unconfined Quaternary aquifers are relatively small and are likely to have only a small potential to affect streamflow in the lower reaches of the River Torrens. Extractions from deeper confined aquifers are considered to have no significant direct impacts on streams in current planning timeframes.

In order to protect streamflow from the impacts of future licensed extractions, buffer zones around streams in the hills zone of the CA PWA are recommended so that no new wells may be constructed within them for licensed purposes. The width of these buffer zones are suggested to be a distance of 100 m on each side of the centre line for all other third order (and above) watercourses to be consistent with the WMLR WAP. For the lower yielding Quaternary sediments on the plains, a buffer zone of 50 m is suggested where some connection to streams is recognised (i.e. the lower reaches of the River Torrens and the foothills). Other GDEs identified in previous studies (SKM 2012) occurring within the CA PWA will also be protected by these buffer zones.

In reality, the streams within the Mount Lofty Ranges portion of the CA PWA are strongly incised with steep valley sides which are often vegetated. This terrain presents a low risk for increases in extraction for licensed purposes. It must be stressed that these buffer zones will not protect streamflow or GDEs from the impacts of drought-induced declines in groundwater level and natural discharge.

4.3 Water resources in adjacent non-prescribed wells areas

The groundwater resources in the adjacent non-prescribed areas to the north of the NAP PWA are generally of poor quality and low yielding. The taking and use of water from the Quaternary, Tertiary and fractured rock aquifers in the NAP and CA prescribed areas is not expected to detrimentally affect these resources. Minor impacts could occur in the area near the NAP PWA boundary if the zone of influence due to extraction extends outside the PWA.

5 Impacts of climate change

The Tertiary aquifers of the NAP and CA prescribed areas are not significantly affected by direct recharge from rainfall occurring over the sedimentary aquifers. Rather, recharge to these aquifers is sustained by the difference in elevation between the aquifers beneath the Adelaide Plains and the connected aquifers of the Mount Lofty Ranges. A further consideration is how a drier, warmer future climate may increase demand for irrigation water over the whole region and whether such an increase in demand could be sustained by the region's groundwater resources (in combination with additional sources of water).

DEWNR has undertaken investigations into the potential impacts of climate change on groundwater resources beneath the Adelaide Plains. These investigations are in addition to an evaluation of the potential impacts of climate change and limited water availability on the irrigated horticulture industry of the NAP, using projections of future climate from a suite of Global Climate Models (Pitt *et al.* 2013). The key findings of the former are:

- projected reductions in rainfall in the Western Mount Lofty Ranges will likely lead to moderate reductions in recharge to the unconfined fractured rock aquifers in the Ranges, and a decline in groundwater levels
- any sustained future decline in groundwater levels in the Western Mount Lofty Ranges will, after a time delay of several decades, result in a small decline in groundwater levels in the major Tertiary aquifers, in addition to any existing decline that may result from groundwater extraction for irrigation
- any sustained future decline in groundwater levels in the Western Mount Lofty Ranges will, after a time delay of several decades, result in a reduction in groundwater flow from the WMLR to the sedimentary aquifers
- if land use patterns and horticultural practices remain the same, there may be an increase in demand for irrigation water due to projected increases in temperature, and hence increases in crop water use for the same area of crop.

Given the uncertainties in how and when climate will change in the future, an adaptive management approach will allow sufficient flexibility to change management responses as new information arises. This can be achieved through the implementation of resource condition limits that could be used to vary allocations should it be deemed necessary, consistent monitoring of the condition of the groundwater resource, and regular reviews of the water allocation plan.

6 Conclusions and recommendations

Ranges of recommended extraction limits for the proposed GMZs in the CA and NAP PWAs have been estimated (Table 6.1) by using either a water balance approach or scenario modelling in combination with an assessment of resource condition indicators and limits. These recommended extraction limits have been made based on the groundwater technical assessments described in this report, but will require social and economic perspectives to be considered before a final decision can be made on the volumes to be allocated.

The resource condition indicator and resource condition limit for the Quaternary aquifers is that the volume of water extracted annually must not result in unacceptable impacts to GDEs or existing users. The recommended extraction limit proposed for the proposed Quaternary aquifers GMZ is 1600–2000 ML/y (Table 6.1). This range was estimated based on the water balance calculation that determined the volume of water available for licensed extraction of 2601 ML/y. However, this amount includes water taken up by GDEs, which has not been quantified. It also includes the current licensed extractions from the Quaternary aquifers of 964 ML/y and current allocations of 1526 ML/y. Therefore, setting the recommended extraction limit at 1600–2000 ML/y allows for existing licensed users as well as some further development of the aquifer, but also 'reserves' some water for GDEs.

The recommended extraction limits for the T1 and T2 aquifers GMZs are the amount of water that can be extracted for licensed use without causing unacceptable long-term declines in groundwater pressure levels. They do not include water for stock and domestic use or water authorised by the Minister for Water under Section 128 of the Act. For the T1 aquifer, the winter groundwater pressure levels should not exceed –5 m AHD in the Waterloo Corner area and –15 m AHD in the Central Adelaide PWA by 2040. For the T2 aquifer, the winter groundwater pressure levels should not exceed the base of the confining layer separating the T1 and T2 aquifers by 2040.

For the T1 and T2 aquifers, a recommended extraction limit equal to a 20–30% increase from the current average extraction is proposed for most T1 and T2 GMZs (Table 6.1). This range of limits was derived from modelling Scenarios 5 and 10 that show increases in the amount of drawdown were within the resource condition limits set for the aquifers and any unacceptable impacts on existing users should be limited. These volumes still allow some development of the aquifers.

The recommended extraction limit for the proposed T2 Virginia GMZ has been kept at the lower range of 10-20% increase on current average extractions to limit major increases in the existing cone of depression in this area of intensive extraction (Table 6.1).

The recommended extraction limit for the proposed T2 NAP GMZ is the current allocation volume of 4483 ML (Table 6.1). The risk of structural damage to the confining layer above the T2 aquifer and the risk of ingress of higher salinity water in the medium term under this scenario is considered acceptable.

A recommended extraction limit of 2212 ML is suggested for the proposed T2 Regional GMZ (Table 6.1). This volume is much more than the current extraction in this area, but additional modelling suggests the impact of this additional extraction on pressure levels in this GMZ does not exceed the proposed resource condition limits. The recommended extraction limit of 2212 ML is accompanied with the proviso that any application over 250 ML/y should conduct a hydrogeological investigation to determine the impact on the resource and other users.

Scenario modelling for the T1 and T2 Golden Grove Embayment GMZ has shown that doubling the estimated existing user demand has only a minor impact on groundwater pressure levels within the GMZ and extracting an extra 1000 ML/y is likely to have an acceptable impact (Table 6.1). A condition that any application over 250 ML/y should conduct a hydrogeological investigation to determine the impact on the resource and other users is also suggested.

An assessment of the T2 aquifer in the Kangaroo Flat region of the NAP PWA confirmed 1500 ML/y as an initial limit for allocations (Table 6.1).

There is currently no extraction from the T3 and T4 aquifers and further development is likely to be limited by the depth of the aquifers and the poor quality of the resource. As such, the current allocation volume of 2300 ML as the lower range volume for the recommended extraction limit and a nominal figure of 4000 ML as the maximum recommended extraction limit is suggested (Table 6.1). A condition that any application over 250 ML/y should require a hydrogeological investigation to determine the impact on the resource and other users is also suggested. Any further increase to extraction above the 4000 ML limit should be assessed on a case-by-case basis.

The volume of groundwater available for licensed extraction from the fractured rock aquifer GMZs was derived using a water balance approach. The resource condition indicators and resource condition limits for these GMZs are that the annual volume of baseflow is maintained assuming a continuation of current climatic conditions. Due to the uncertainties in the water balance calculations for the fractured rock aquifers, the lower range recommended extraction limits for the fractured rock aquifer GMZs are based on maintaining current extractions. The higher recommended extraction limits in the proposed range are based on the calculations of water available while still maintaining baseflow and accounting for current allocations (Table 6.1).

There is insufficient information to use the water balance method for the proposed FRA GGE GMZ. Non-licensed use and existing user demand is relatively low at about 19 and 14 ML/y respectively, with a low risk of significant demand in the future because of the urbanised nature of the GGE and relatively high salinities. Therefore, a nominal figure of 500 ML/y is suggested for the recommended extraction limit (Table 6.1), but a caveat that any application over 50 ML requires a hydrogeological investigation to determine the impact on the resource and other users is also suggested.

The resource condition indicators and resource condition limits for the Noarlunga Embayment are that the volume of water extracted annually from the Quaternary and Tertiary aquifers must not result in unacceptable impacts to GDEs or existing users. The upper recommended extraction limit for the Noarlunga Embayment GMZ is 1717 ML/y (Table 6.1). There is no existing user demand for licensed purposes and throughflow from the adjacent fractured rock aquifers has not been included. Therefore, the recommended extraction limit is a conservative estimate. However, as there are limited monitoring data available for the NE GMZ, the condition of the resource is not known with certainty but the risk of over-extraction is very low.

Table 6.1 Recommended extraction limit and current extraction and allocation volumes for all groundwater management zones (all volumes in ML)

GMZ	Current licensed extraction[6]	Current allocation[7]	Recommended extraction limit
Quaternary aquifers	964	1526	1600–2000
T1 NAP	3199	5081	3839–4159
T1 Dry Creek	2972	2972	3566–3864
T1 Grange	1940	1940	2328–2522
T1 Thebarton	1383	1383	1660–1798
T1 Central Adelaide	1777	1777	2132–2310
T2 NAP	1994	4483	2592–4483
T2 Kangaroo Flat	1321	1321	≤1500
T2 Virginia	9227	14 940	10 150–11 072

[6] Licensed extraction is the average extraction from metered wells in the NAP PWA for the years 2006 to 2013 inclusive. For the CA PWA extraction was estimated based on the license applications from existing users. See Section 2.5.2 for more details.

[7] Allocation volumes are sourced from a dataset prepared by the AMLRNRMB and provided to RPS-Aquaterra in 2013, and represent allocation volumes for year 2011 for the NAP PWA and equals the extraction estimated for the CA PWA.

GMZ	Current licensed extraction[6]	Current allocation[7]	Recommended extraction limit
T2 Regional	73	212	≤2212
T2 Osborne	1199	1199	1439–1559
T2 Regency Park	1732	1732	2078–2252
T1 and T2 GGE	1526	1526	3052–4052
T3 and T4 aquifers	0	2300	2300–4000
FRA GGE	14	14	≤500
FRA Northern	960	960	960–3479
FRA Torrens	539	539	539–1637
FRA Patawalonga	464	464	464
FRA Southern	155	155	155
Noarlunga Embayment	0	0	≤1717

6.1 Recommendations for resource management

It is important that resource condition indicators and proposed limits are agreed to by stakeholders, for example irrigators and stock and domestic users. The resource condition limits must reflect a balance of economic development, protection of the resource and rights of stock and domestic users. Consideration also needs to be given to the issue of how to deal with the variability that will occur due to long-term climate variability and to anticipated climate change.

It should be noted that the recommended extraction limits for each zone do not necessarily equate to the recommended extraction limits that will be defined in the WAP. Consideration of social and economic factors and what might be considered as acceptable impacts by stakeholders may result in the allocated volumes being different to the extraction limit.

It should also be noted that impacts to water quality due to extraction have been assessed to pose a low level of risk in the short to medium term and therefore resource condition limits based on salinity have not been set. Nevertheless, as a precautionary approach, a salinity resource trigger could also be used in the WAP to restrict extractions. This warrants consideration as there may be a salinity threat from increased downward leakage of salty water from the Q4 aquifer (particularly in the Waterloo Corner area where the Hindmarsh Clay confining layer is thin or absent, and in the Kangaroo Flat area) and the encroachment of higher-salinity water from surrounding areas.

The volumetric extraction limits proposed here are based on the approach of maintaining the groundwater resource condition within identified acceptable limits. Resource condition indicators (groundwater pressure levels) would therefore be monitored on an ongoing basis and management actions taken based on how close the system is to going beyond its agreed limits. For example, water level thresholds could be set to trigger reductions to allocations or directly to use. If the situation arises where the recommended extraction limits of a GMZ are exceeded without the resource condition limits being at risk of being breached, then the WAP should have the flexibility to not impose unnecessary management responses (such as use restrictions).

7 Appendix

Groundwater modelling exercise to determine recommended extraction volumes

Introduction

The Department of Environment, Water and Natural Resources (DEWNR) are assisting the Adelaide and Mount Lofty Ranges Natural Resources Management Board (AMLRNRMB) in the development of a water allocation plan (WAP) for the Northern Adelaide Plains (NAP) and Central Adelaide (CA) PWAs.

A modified version of the Adelaide Plains (AP2011) model was used as a tool for estimating changes in groundwater levels in sedimentary aquifers within the NAP and CA regions under several scenarios of groundwater extraction. The purpose of this scenario modelling exercise is to use the model as a tool to assist in the determination of recommended extraction limits for the various sedimentary groundwater management zones (GMZs).

History of model development for Adelaide Plains

A numerical groundwater model for the Adelaide Plains region (AP2011) was developed by RPS Aquaterra (RPS Aquaterra, 2011). The objective was to develop a tool to assist in better understanding of the groundwater system and for future management of the groundwater resources in the Adelaide Plains. Some modifications, simplifications and changes in model settings have recently been undertaken:

- the General Head Boundary (GHB) has been modified to increase the volume of lateral inflow into the sedimentary aquifers from the Mount Lofty Ranges (MLR)
- rainfall recharge in the plains area was simplified by representing it as a long-term average condition
- the Munno Para Clay was extended to the western model boundary under the coast, which is supported by borehole data

These changes improve the ability of the model to simulate the Adelaide Plains groundwater system, whilst still achieving an adequate match to groundwater levels within the CA and NAP areas as per AP2011 model. This model version is referred to as the AP2013 model which has been used for this scenario modelling exercise and has been amended to simulate a future period of 30 years.

Modelling scenarios

Table 7.1 summarises each of the eight modelling scenarios and the conditions that were applied to various areas within the NAP and CA prescribed areas, which are discussed in further detail in the following sections. Table 7.2 gives the volume of groundwater extracted for each scenario from each groundwater management zone. Managed aquifer recharge (MAR) schemes are excluded from scenarios.

Table 7.1 Summary of modelled scenarios and conditions

Prediction scenario	Region	Description of groundwater extraction
Scenario 1 – Base case	North Adelaide Plains	Average metered usage 2006 to 2013. Seasonal split in extraction (80% in summer; 20% in winter)
	Central Adelaide	As per AP2011 model (extraction non-seasonal as largest users are industrial)
	Kangaroo Flat	As per AP2011 model (extraction is seasonal)
	Dry Creek	Average metered usage 2006 to 2013 (extraction non-seasonal as largest users are industrial)
Scenario 2 – Worst case	North Adelaide Plains	Extraction of full allocation for 2011, with additional extraction if average extraction exceeds allocation
	Central Adelaide	Same as Scenario 1
	Kangaroo Flat	Same as Scenario 1
	Dry Creek	Same as Scenario 1
Scenario 3 – Mid case	North Adelaide Plains	Extraction of volumes midway between the average of metered usage 2006 to 2013 and full allocation
	Central Adelaide	Same as Scenario 1
	Kangaroo Flat	Same as Scenario 1
	Dry Creek	Same as Scenario 1
Scenario 4 – Base case + 10%	North Adelaide Plains	Averaged metered usage 2006 to 2013 with an additional 10% extraction
	Central Adelaide	As per AP2011 model with an additional 10% extraction
	Kangaroo Flat	Same as Scenario 1
	Dry Creek	Averaged metered usage 2006 to 2013 with an additional 10% extraction
Scenario 5 – Base case + 20%	North Adelaide Plains	Averaged metered usage 2006 to 2013 with an additional 20% extraction
	Central Adelaide	As per AP2011 model with an additional 20% extraction
	Kangaroo Flat	Same as Scenario 1
	Dry Creek	Averaged metered usage 2006 to 2013 with an additional 20% extraction
Scenario 6 – Base case + double in GGE	Central Adelaide	Same as Scenario 1 with double the amount east of Para Fault in Golden Grove Embayment
	North Adelaide Plains	Same as Scenario 1
	Kangaroo Flat	Same as Scenario 1
	Dry Creek	Same as Scenario 1
Scenario 7 – Scenario 6 + extra 2 GL in GGE	Central Adelaide	Same as Scenario 6 with extra 2000 ML east of Para Fault in Golden Grove Embayment
	North Adelaide Plains	Same as Scenario 1
	Kangaroo Flat	Same as Scenario 1
	Dry Creek	Same as Scenario 1

Prediction scenario	Region	Description of groundwater extraction
Scenario 8 – Scenario 6 + extra 1 GL in GGE	Central Adelaide	Same as Scenario 6 with extra 1000 ML east of Para Fault in Golden Grove Embayment
	North Adelaide Plains	Same as Scenario 1
	Kangaroo Flat	Same as Scenario 1
	Dry Creek	Same as Scenario 1
Scenario 9 – Base case all GMZs except Worst case in T2 NAP and T2 Regional GMZs + 2000 ML in T2 Regional GMZ	Northern Adelaide Plains	Same as Scenario 1, except same as Scenario 2 in T2 NAP and T2 Regional GMZs, with extra 2000 ML in T2 Regional
	Central Adelaide	Same as Scenario 1, except same as Scenario 2 with extra 2000 ML in T2 Regional GMZ
	Kangaroo Flat	Same as Scenario 1
	Dry Creek	Same as Scenario 1
Scenario 10 – Base case + 30%, Scenario 1 for T2 Kangaroo Flat, Scenario 5 for T2 Virginia, Scenario 9 for T2 Regional and Scenario 8 for T1 and T2 GGE	Northern Adelaide Plains	Same as Scenario 1 with an additional 30% extraction from every well west of the Para Fault, except same as Scenario 1 for the T2 Kangaroo Flat GMZ, same as Scenario 5 for the T2 Virginia GMZ
	Central Adelaide	Same as Scenario 1 with an additional 30% extraction from every well west of the Para Fault, except same as Scenario 9 for the T2 Regional GMZ and the same as Scenario 8 for the T1 and T2 GGE GMZ
	Kangaroo Flat	Same as Scenario 1
	Dry Creek	Same as Scenario 1 with an additional 30% extraction

Table 7.2 Scenario extraction volumes (ML/y)

GMZ	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T1 NAP	3199	5091	3953	3519	3839	3199	3199	3199	3199	4159
T1 Dry Creek	2972	2972	2972	3270	3567	2972	2972	2972	2972	3864
T1 Grange	1940	1940	1940	2134	2328	1940	1940	1940	1940	2522
T1 Thebarton	1383	1383	1383	1521	1660	1383	1383	1383	1383	1798
T1 Central Adelaide	1777	1777	1777	1955	2132	1777	1777	1777	1777	2310
T2 NAP	2230	4483	3322	2453	2676	2230	2230	2230	4483	2899
T2 Kangaroo Flat	1321	1321	1321	1453	1585	1321	1321	1321	1321	1321
T2 Virginia	9224	14917	11921	10146	11068	9224	9224	9224	9224	11068
T2 Regional	103	212	157	113	124	103	103	103	2212	2212
T2 Osborne	1199	1199	1199	1319	1439	1199	1199	1199	1199	1559
T2 Regency Park	1732	1732	1732	1905	2078	1732	1732	1732	1732	2252
T1 and T2 GGE	1526	1526	1526	1526	1526	3052	5052	4052	1526	4052
Total	**28 606**	**38 554**	**33 204**	**31 315**	**34 023**	**30 132**	**32 132**	**31 132**	**32 968**	**40 016**

Scenario 1 – Base case

This scenario assumes that extraction in the NAP region over the following 30 years is equivalent to the average condition over the last eight years, which includes wet and dry climatic periods (2006 to 2013). Wells which have accessed groundwater at any time over the last eight years are included in this scenario, to include those wells that have recently been abandoned or backfilled. In the NAP, it is assumed that 80% of the annual usage is extracted in summer and 20% is extracted in winter to meet agricultural demand. The average usage is calculated from data queried from the WILMA database excluding null, anomalous or zero readings.

Existing user demand in the CA PWA has been applied for 30 years in both the T1 and T2 aquifers.

Groundwater level contours at the end of summer after 30 years are given for the T1 aquifer (Figure 7.1) and the T2 aquifer (Figure 7.2). Hydrographs from both aquifers at six locations at various extraction centres are given in Figures 7.3 and 7.4. The locations of the hydrographs are shown in Figures 7.1 and 7.2.

If groundwater extraction is equivalent to the average condition over the last eight years, it is predicted that groundwater levels in both the T1 and T2 aquifers will remain relatively steady over the long-term and the cone of depression will not widen greatly. Over the summer period when demand is high, it is predicted that the seasonal change in water level is about 6 m in the T1 aquifer and more than 30 m in the T2 aquifer in the centre of the cone of depression at Virginia.

<u>T1 aquifer</u> – Existing user demand in the CA PWA has resulted in small cones of depression of between -7 and −9 m AHD in the T1 aquifers in the Osborne, Grange and Thebarton areas at the end of summer after 30 years. In the NAP PWA, current extraction has also lead to levels of −5 m AHD in the Waterloo Corner area at the end of summer in 2040.

<u>T2 aquifer</u> – At the centre of the cone of depression in the T2 aquifer in the NAP, the groundwater level is approximately −55 m AHD at the end of summer. Stratigraphic data indicates that the top of the T2 aquifer is approximately −50 m AHD, which suggests the T2 aquifer may become unconfined and depressurised in the centre of the cone of depression during the summer months. Water level recovery is expected during winter when confined conditions would resume. Within the CA PWA, cones of depression at -35 and -38 m AHD have formed in the Regency Park and Osborne areas respectively, due to industrial extractions.

At the end of summer in the 30th year, the groundwater level in the T2 aquifer that is at or below -30 m AHD covers an area of more than 50 km^2 centred on Virginia. The total volume of groundwater pumped from the T2 aquifer in this area is more than 5000 ML/y, with most users extracting groundwater at a rate of 10 ML/y or less.

The water balance for the NAP area suggests that there is only minor inflow into the T1 and T2 aquifers from beneath the sea bed. Vertical flux downward from the Quaternary sediments may dominate in the centre of the cone area in the NAP.

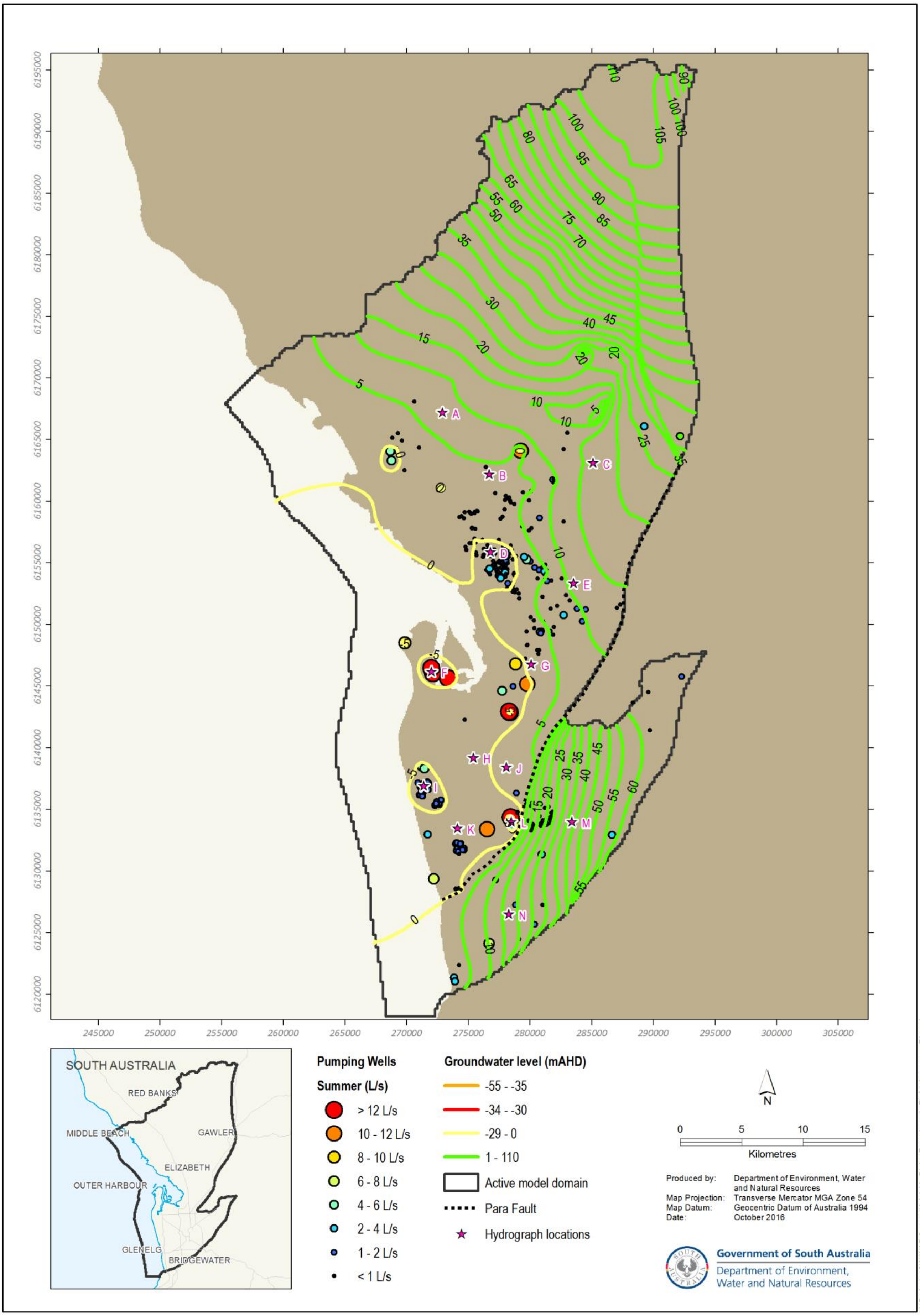

Figure 7.1 Scenario 1 – Maximum groundwater pressure levels after 30 years – T1 aquifer

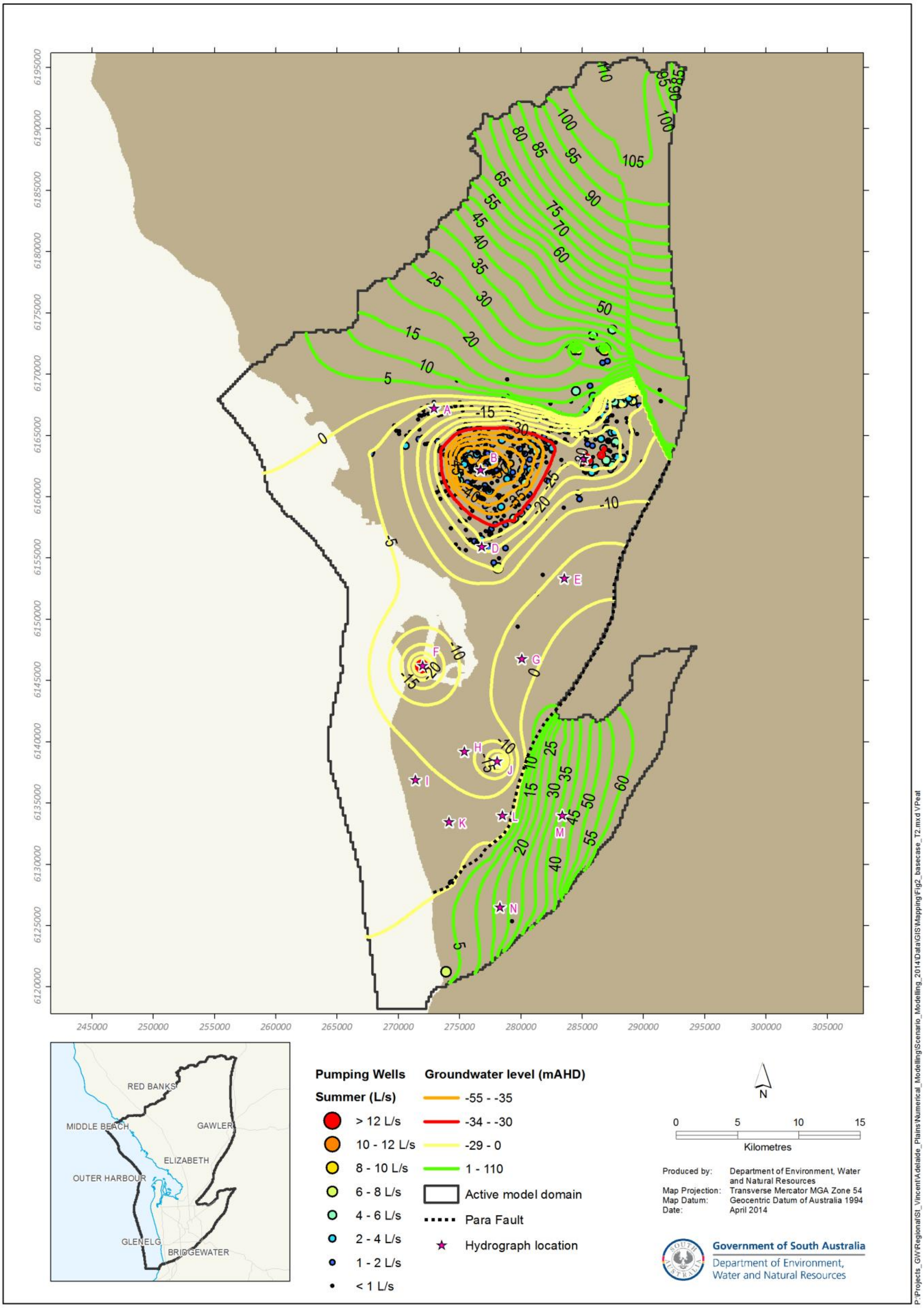

Figure 7.2 Scenario 1 – Maximum groundwater pressure levels after 30 years – T2 aquifer

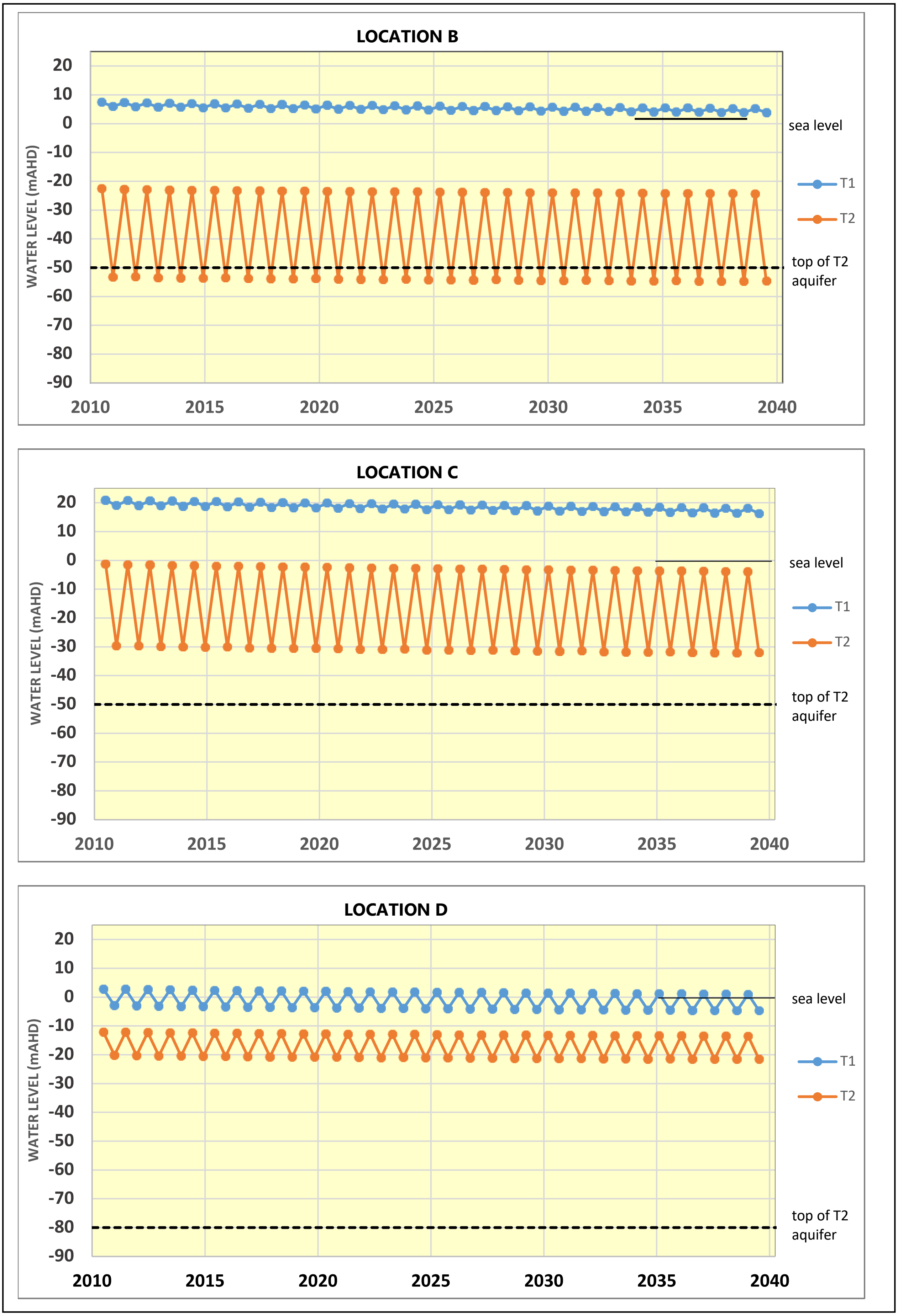

Figure 7.3 Scenario 1 – Selected hydrographs in the NAP PWA

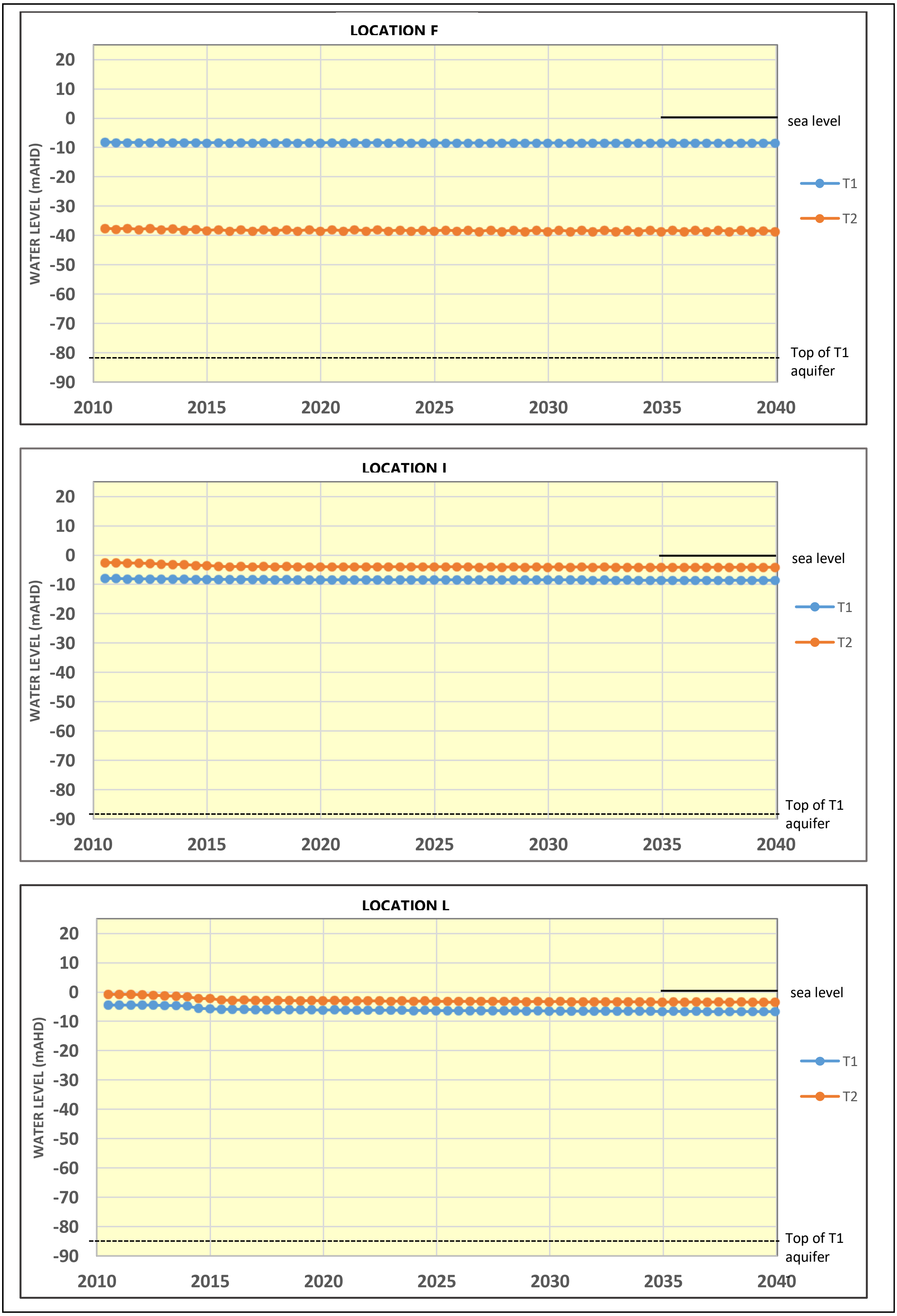

Figure 7.4 Scenario 1 – Selected hydrographs in the CA PWA

Scenario 2 – Worst case

This scenario is based on the assumption that within the NAP region, all users will extract at their full allocation over the next 30 years. This scenario is considered to be the "worst case" in terms of relative impact on the groundwater resource. It is assumed that 80% of the annual volume is extracted in summer and 20% is extracted in winter. Allocation volumes are sourced from a dataset prepared by the AMLRNRMB and provided to RPS-Aquaterra in 2013, and represent allocation volumes for year 2011.

This scenario excludes wells for which there has been usage sometime over the last eight years, but no recent allocation. It is assumed that these wells are no longer in use (having been abandoned or backfilled) and their allocation has been transferred. This scenario includes wells that have an allocation but are not currently in use. This is often the case for relatively new wells which have been drilled but there is no meter and no metered data associated with the licence. This scenario considers that these licence holders will take up their allocation sometime in the future.

This scenario assumes that if the average usage over the last eight years is greater than the allocation volume for a given well, then in the future this user is likely to extract groundwater based on the average usage. This approach is conservative, because it considers existing groundwater users who often use greater than their allocation volume (by transferring in water or paying a penalty for exceeding their allocation) are likely to repeat this behaviour in the future.

Where there are multiple wells associated with a single licence, it is assumed that allocation volumes are evenly distributed, even though usage is unlikely to be uniform. Therefore, for some licences, the modelled extraction volume may be slightly higher than the allocation volume. This is considered greatly conservative as it is likely to slightly overestimate the impact of groundwater extraction at full allocation.

There is no change in extraction volumes in the CA PWA in this scenario and hence there will be no change in the predicted water levels. No hydrographs are presented for this area.

Groundwater level contours at the end of summer after 30 years for the T1 aquifer and T2 aquifer are presented in Figures 7.5 and 7.6 respectively. Hydrographs at the three NAP locations are given in Figure 7.7.

<u>T1 aquifer</u> – The long-term decline in groundwater level of the T1 aquifer is predicted to be 5 m lower than Scenario 1, with a small cone of depression forming in the Waterloo Corner area at -10m AHD. There is no indication of equilibrium being reached with ongoing decline due to downward leakage into the underlying heavily used T2 aquifer.

<u>T2 aquifer</u> - The cone of depression in the T2 aquifer centred on Virginia is expected to widen significantly, with the long-term groundwater level decline estimated to be more than 20 m below current levels at the centre of the cone. In winter, groundwater levels of the T2 aquifer would not recover to a level above the top of the aquifer, leading to long-term and widespread depressurization of the T2 aquifer. At the end of summer in the year 2040, water levels of −30 m AHD or deeper is predicted across most of the NAP PWA and encompasses the majority of groundwater users.

In summer, water level of -30 m AHD or deeper is predicted across most of NAP and encompasses most groundwater users. The total volume of groundwater pumped from the T2 aquifer in this area is more than 17 000 ML/y.

The water balance for the NAP area suggests that although the volume of groundwater extracted in NAP is significantly higher, there is still only minor inflow into the T1 and T2 aquifers from beneath the sea bed to the west. Vertical flux downward from the Quaternary sediments may dominate in the centre of the cone.

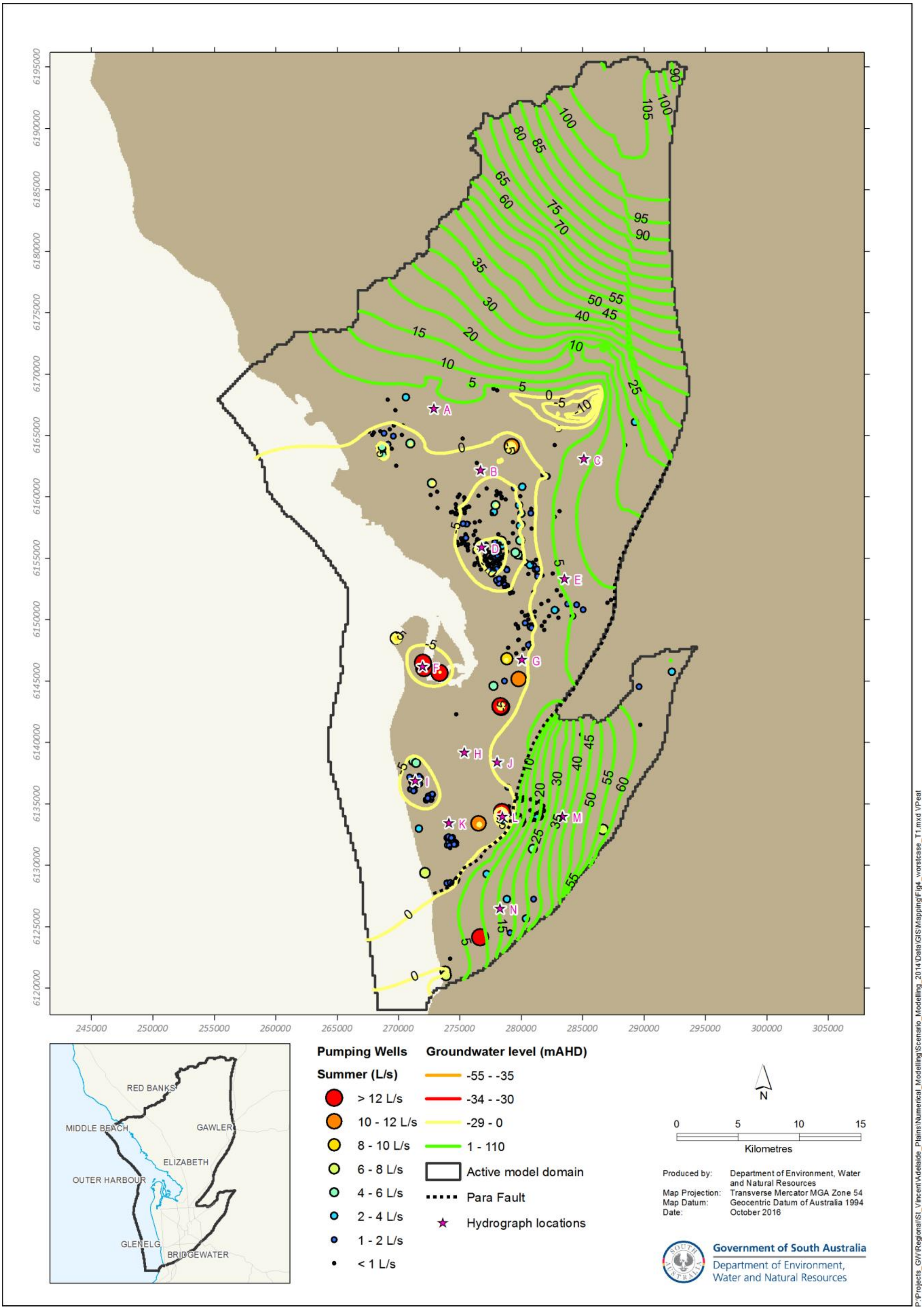

Figure 7.5 Scenario 2 – Maximum groundwater pressure levels after 30 years – T1 aquifer

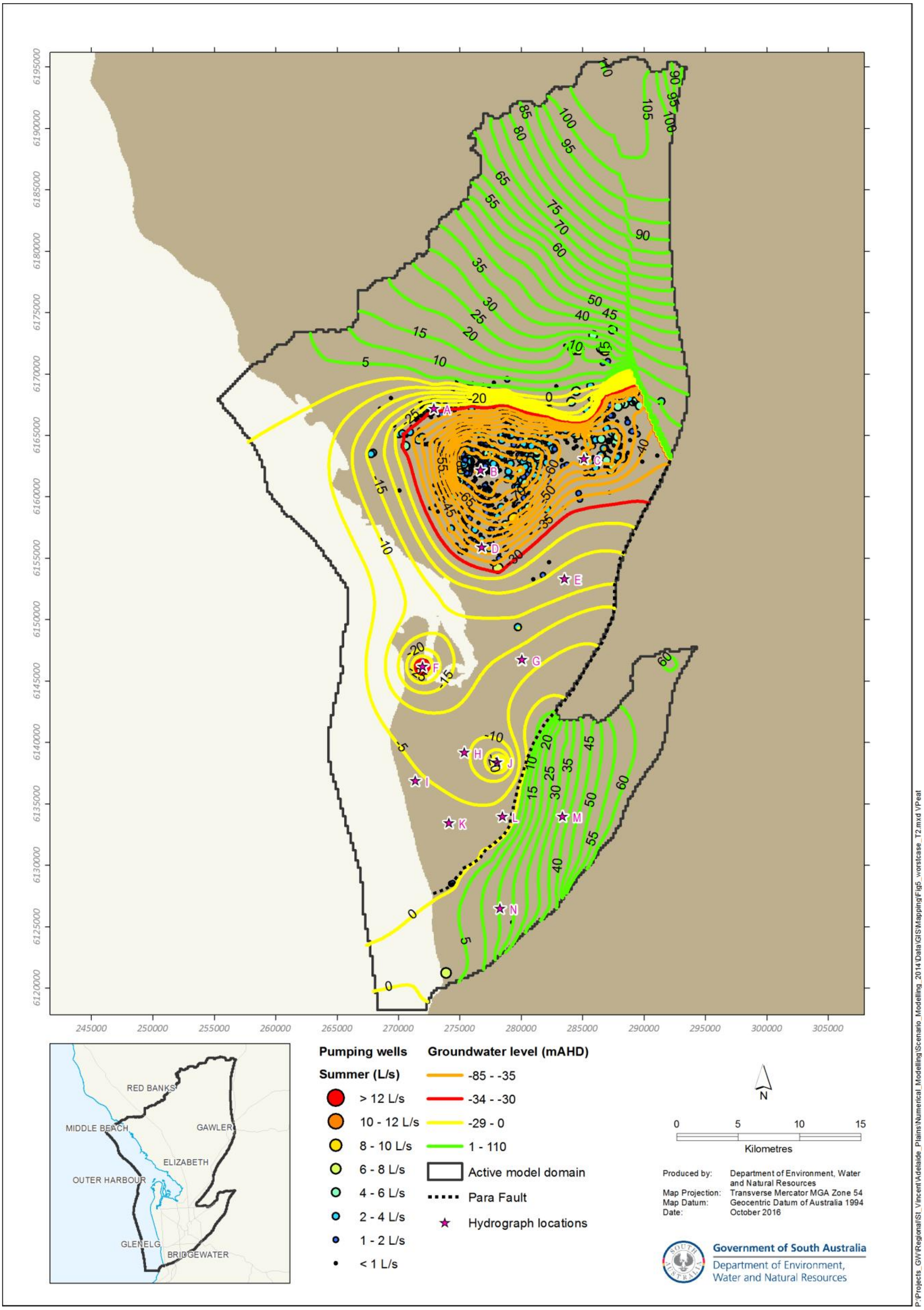

Figure 7.6 Scenario 2 – Maximum groundwater pressure levels after 30 years – T2 aquifer

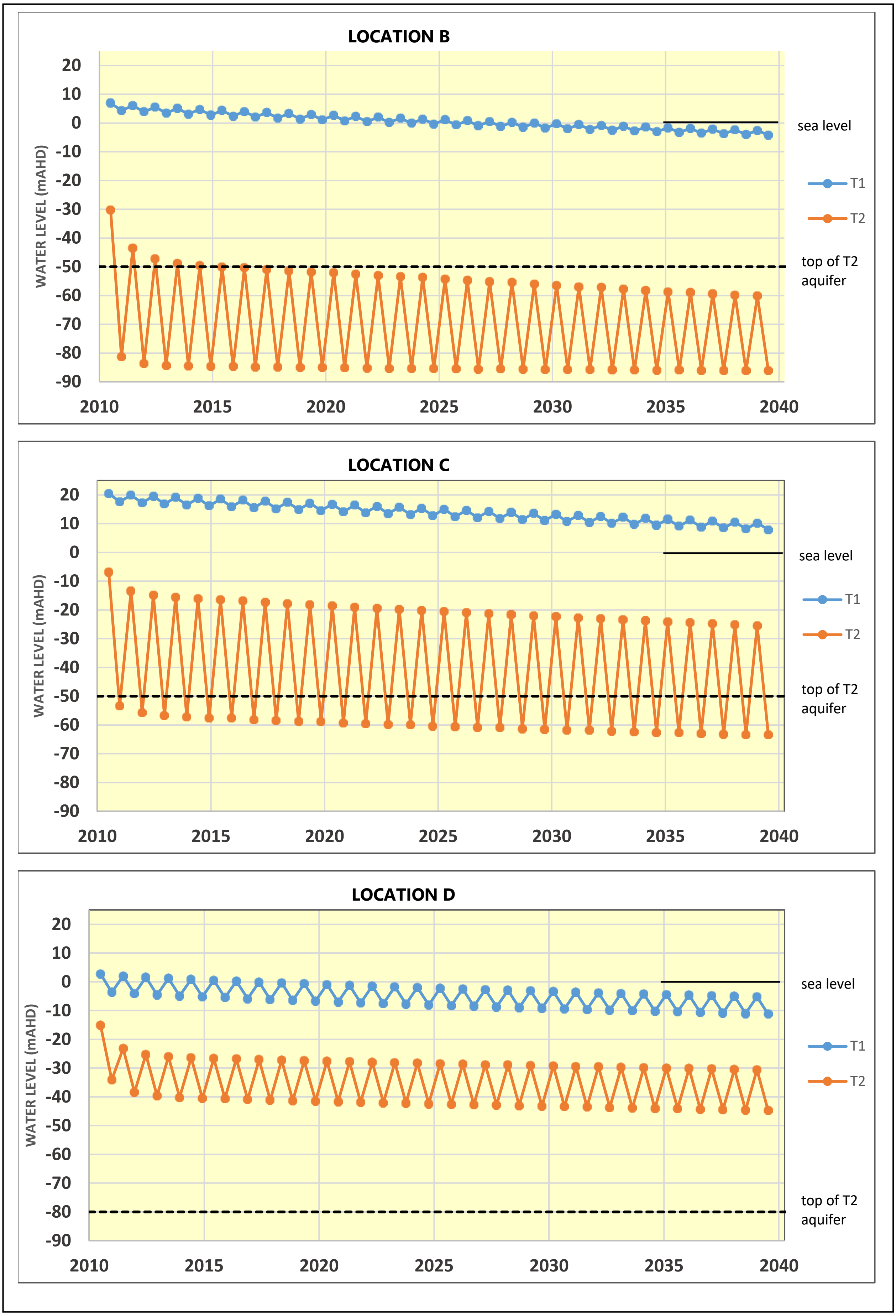

Figure 7.7 Scenario 2 – Selected hydrographs for the NAP PWA

Scenario 3 – Middle case

This scenario is based on the assumption that future groundwater extraction is halfway between the average usage over the last eight years and full allocation. In situations where the average usage over the last eight years exceeds allocation, then the average of the last eight years is assumed. It is assumed that 80% of the annual volume is extracted in summer and 20% is extracted in winter.

There is no change in extraction volumes in the CA PWA in this scenario and hence there will be no change in the predicted water levels. No hydrographs are presented for this area.

Groundwater level contours at the end of summer after 30 years for the T1 aquifer (Fig. 7.8) and T2 aquifer (Fig. 7.9) are presented. Hydrographs at the three locations in the NAP are given in Figure 7.10. A cross-section from the coast to the hills through the cone of depression shows the water level after 30 years in summer (Fig. 7.11) for Scenarios 1, 2 and 3.

T1 aquifer – A gradual long-term groundwater level decline in the T1 aquifer is evident in the Waterloo Corner area which is identical to the Scenario 1 prediction.

T2 aquifer - A long-term groundwater level decline of more than 10 m below current levels in the T2 aquifer is predicted for the Virginia and Angle Vale areas. Unconfined and depressurized conditions would be expected for the T2 aquifer during summer, with some water level recovery expected during winter when confined conditions would temporarily resume. At the end of summer in the year 2040, the groundwater level in the T2 aquifer is at or below −30 m AHD over a considerable area of more than 130 km^2 centred on Virginia.

At the end of summer, the groundwater level in the T2 aquifer is at or below -30 m AHD over a considerable area of more than 130 km^2 centred on Virginia. The total volume of groundwater pumped from the T2 aquifer in this area is more than 12 000 ML/y. The water balance suggests that the volume of water drawn from aquifers beneath the sea is minor.

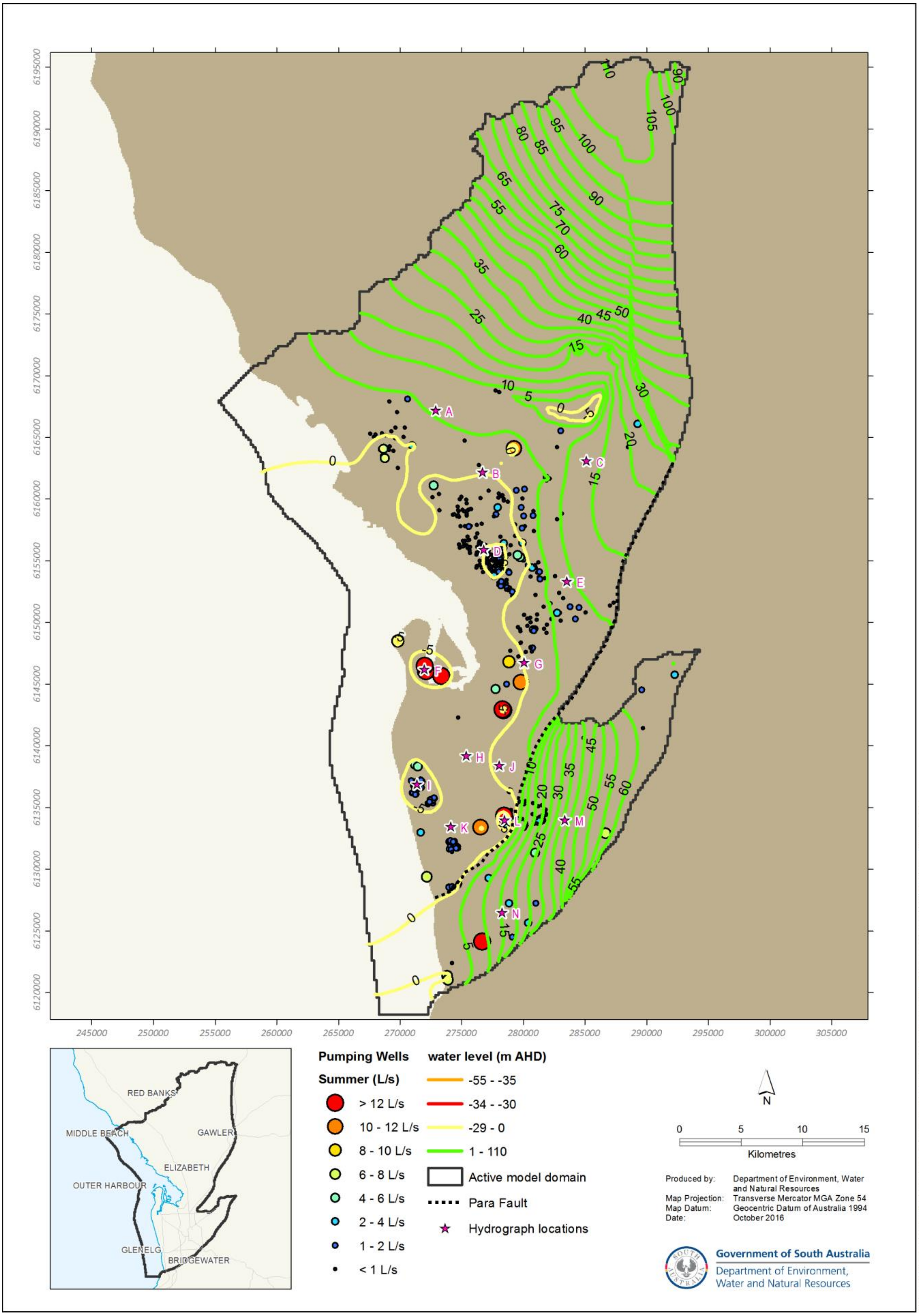

Figure 7.8 Scenario 3 – Maximum groundwater pressure levels after 30 years – T1 aquifer

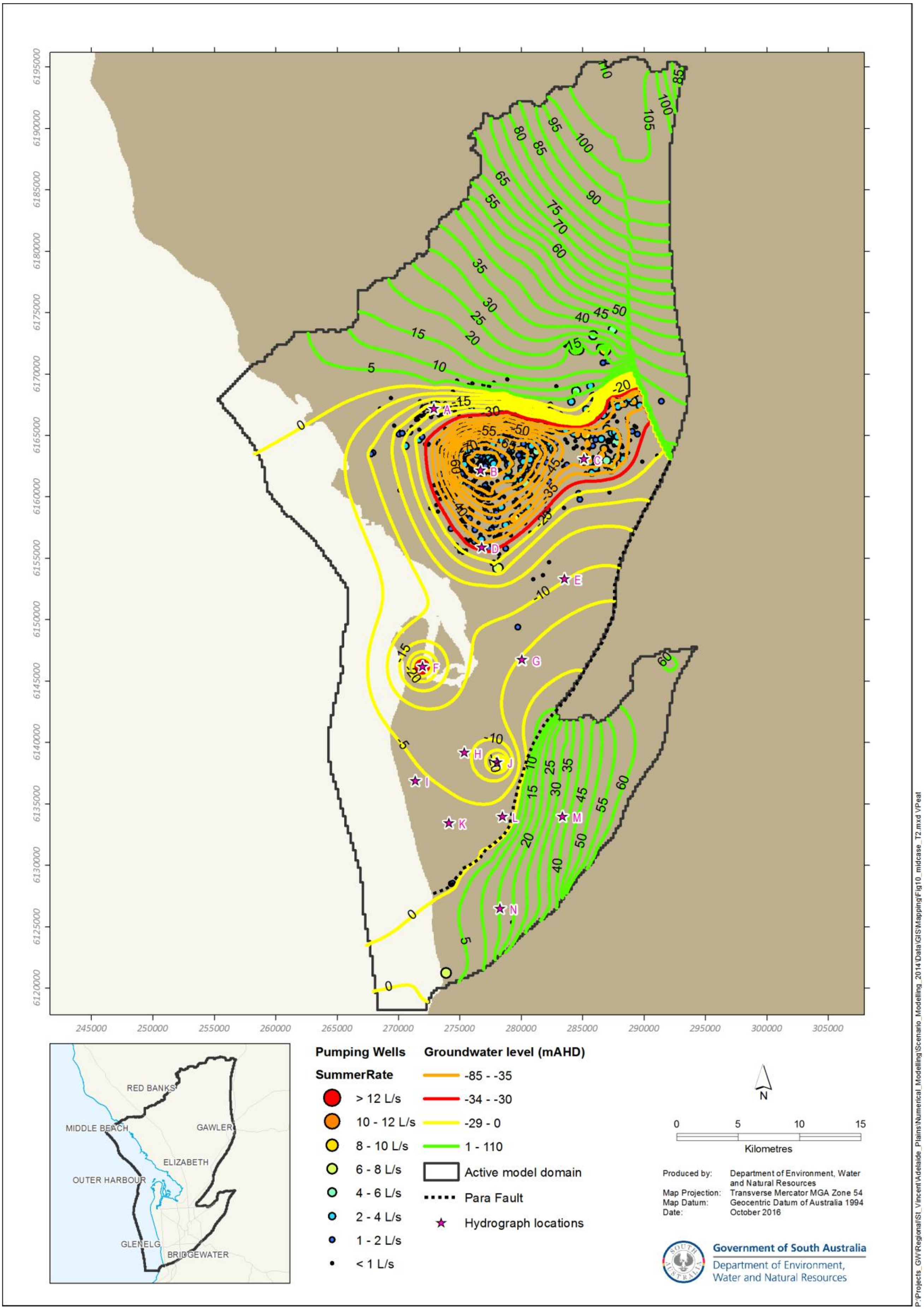

Figure 7.9 Scenario 3 – Maximum groundwater pressure levels after 30 years – T2 aquifer

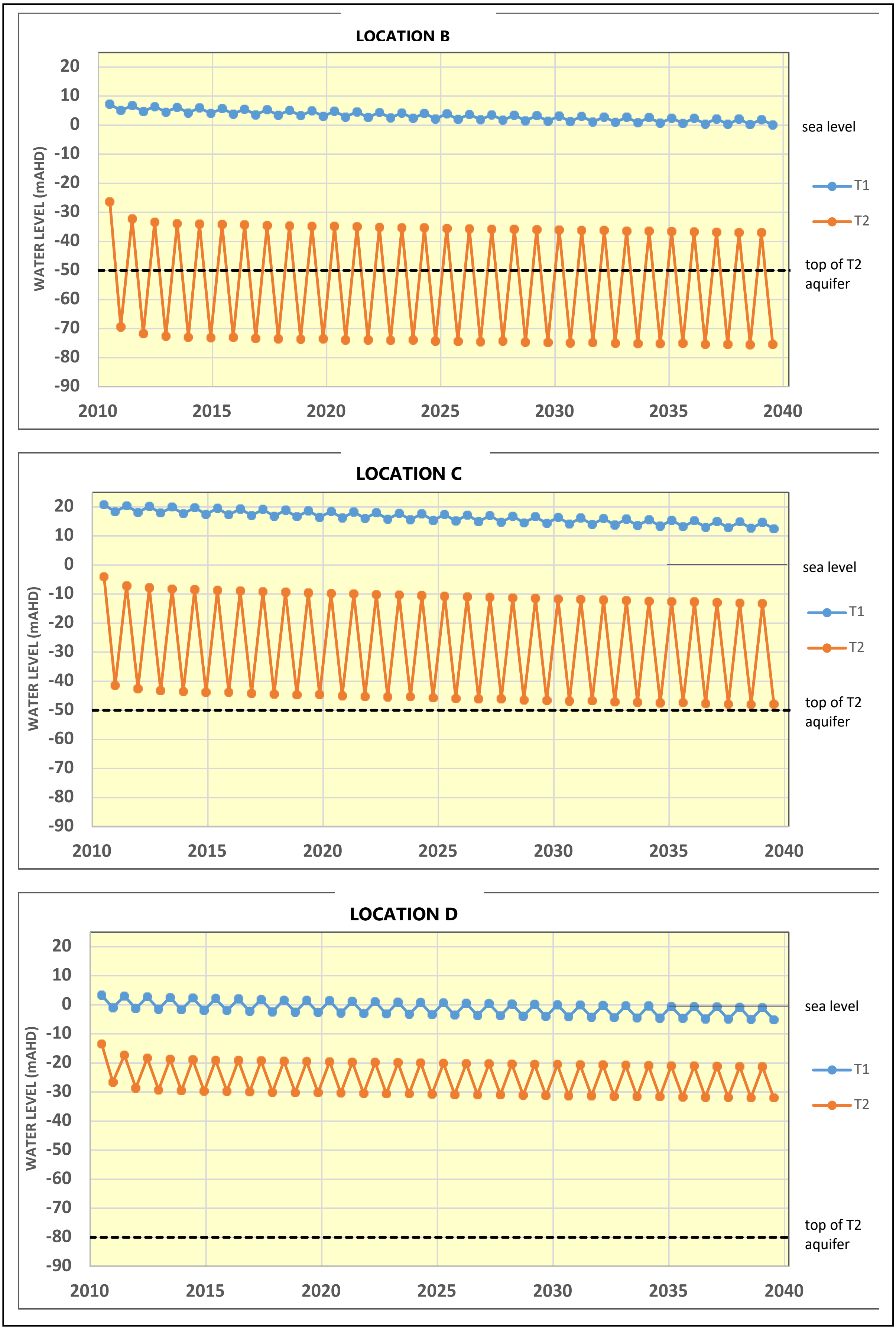

Figure 7.10 Scenario 3 – Selected hydrographs for the NAP PWA

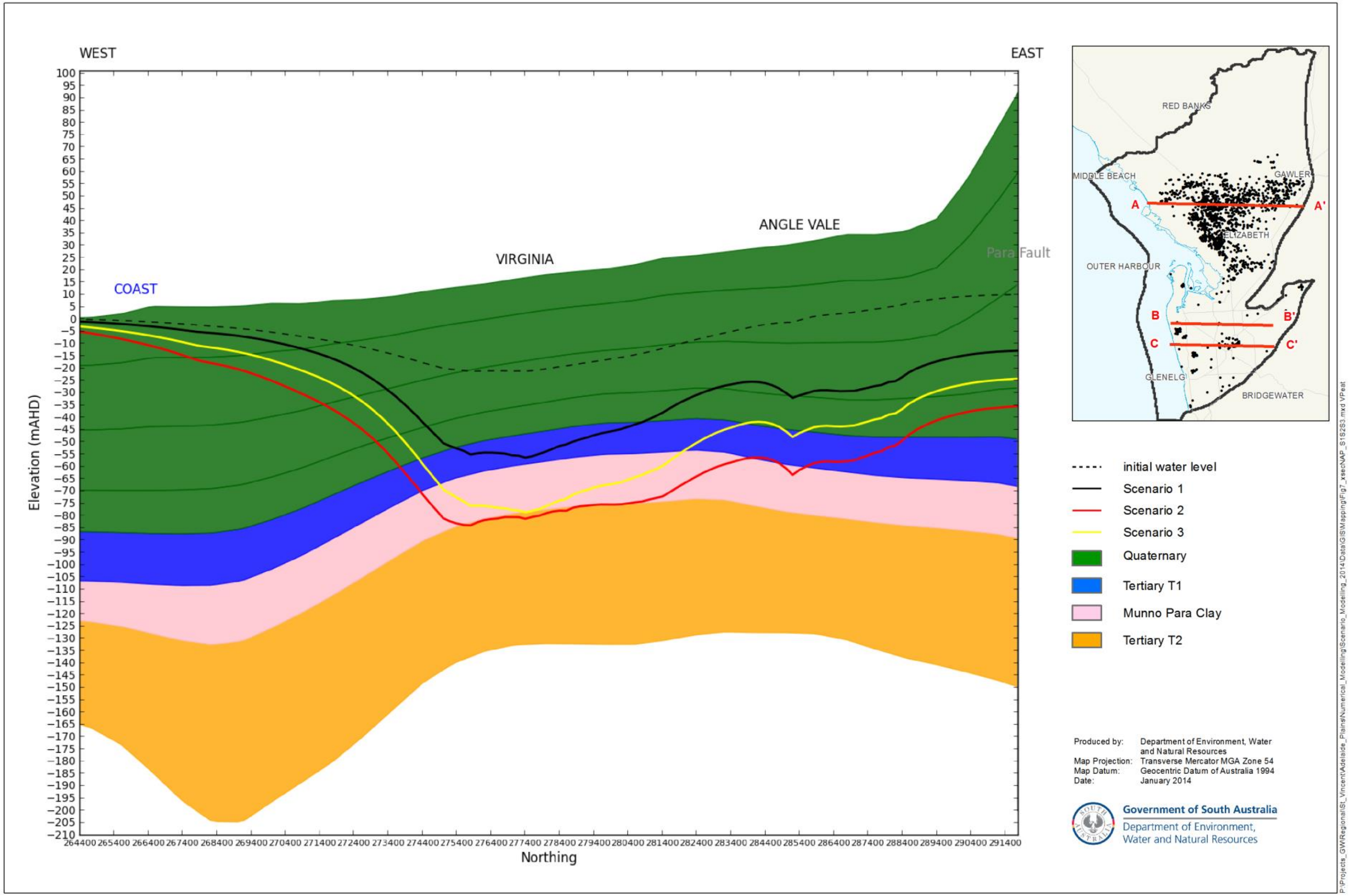

Figure 7.11 Predicted T2 groundwater levels for Scenarios 1, 2 and 3 (summer 2040), cross-section A–A′

Scenario 4 – Base case with an additional 10%

This scenario assumes that extraction in NAP over the next 30 years is 10% greater than the average condition over the last eight years. Extraction in Central Adelaide (CA) west of Para Fault (including Thebarton, Grange and North Haven) is also assumed to have increased by 10% beyond the estimated 2010 existing user demand. These increases correspond to an additional 1500 ML/y extraction in NAP PWA and 1000 ML/y in CA PWA. As with the previous scenarios, it is assumed that in the NAP, 80% of the annual volume is extracted in summer and 20% is extracted in winter.

Groundwater level contours at the end of summer after 30 years for the T1 aquifer and T2 aquifer are presented in Figures 7.12 and 7.13 respectively. Hydrographs at three locations in the NAP are given in Figure 7.14 and three for CA given in Figure 7.15.

<u>T1 aquifer</u> – In the Waterloo Corner area of the NAP, the predicted water level response is virtually identical to Scenario 1. In the CA PWA, the small cones of depression expanded slightly and deepened by a meter or so by 2040.

<u>T2 aquifer</u> – A long-term groundwater level decline of about 5 m below current levels in the T2 aquifer is predicted for the Virginia and Angle Vale areas. Unconfined and depressurized conditions would be expected for the T2 aquifer during summer, with some water level recovery expected during winter when confined conditions would temporarily resume.

Groundwater level is less than -30 m AHD in most areas of Virginia and Angle Vale at the end of summer after 30 years. The volume of groundwater pumped from the T2 aquifer in this area of 80 km^2 is over 7000 ML/y.

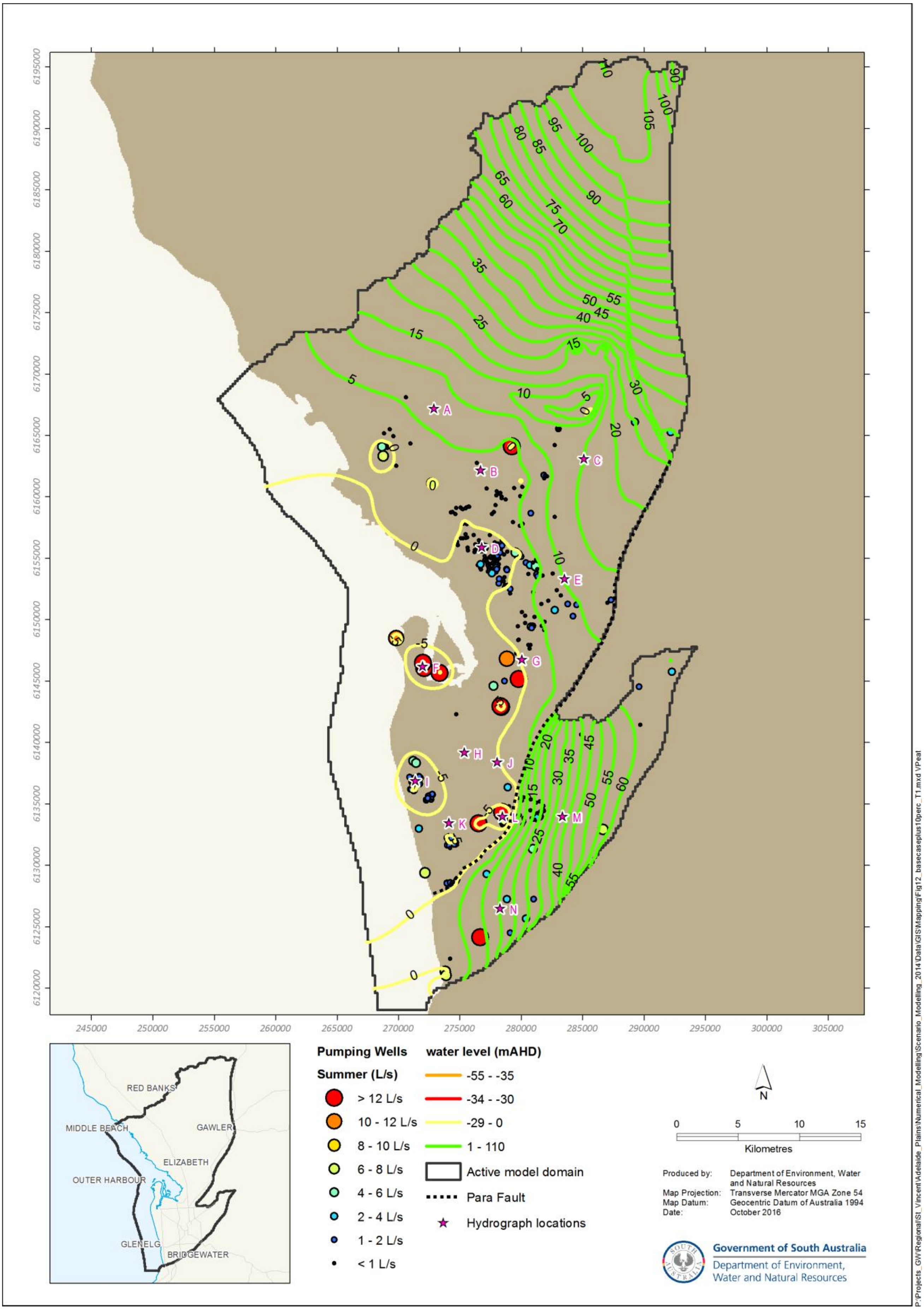

Figure 7.12 Scenario 4 – Maximum groundwater pressure levels after 30 years – T1 aquifer

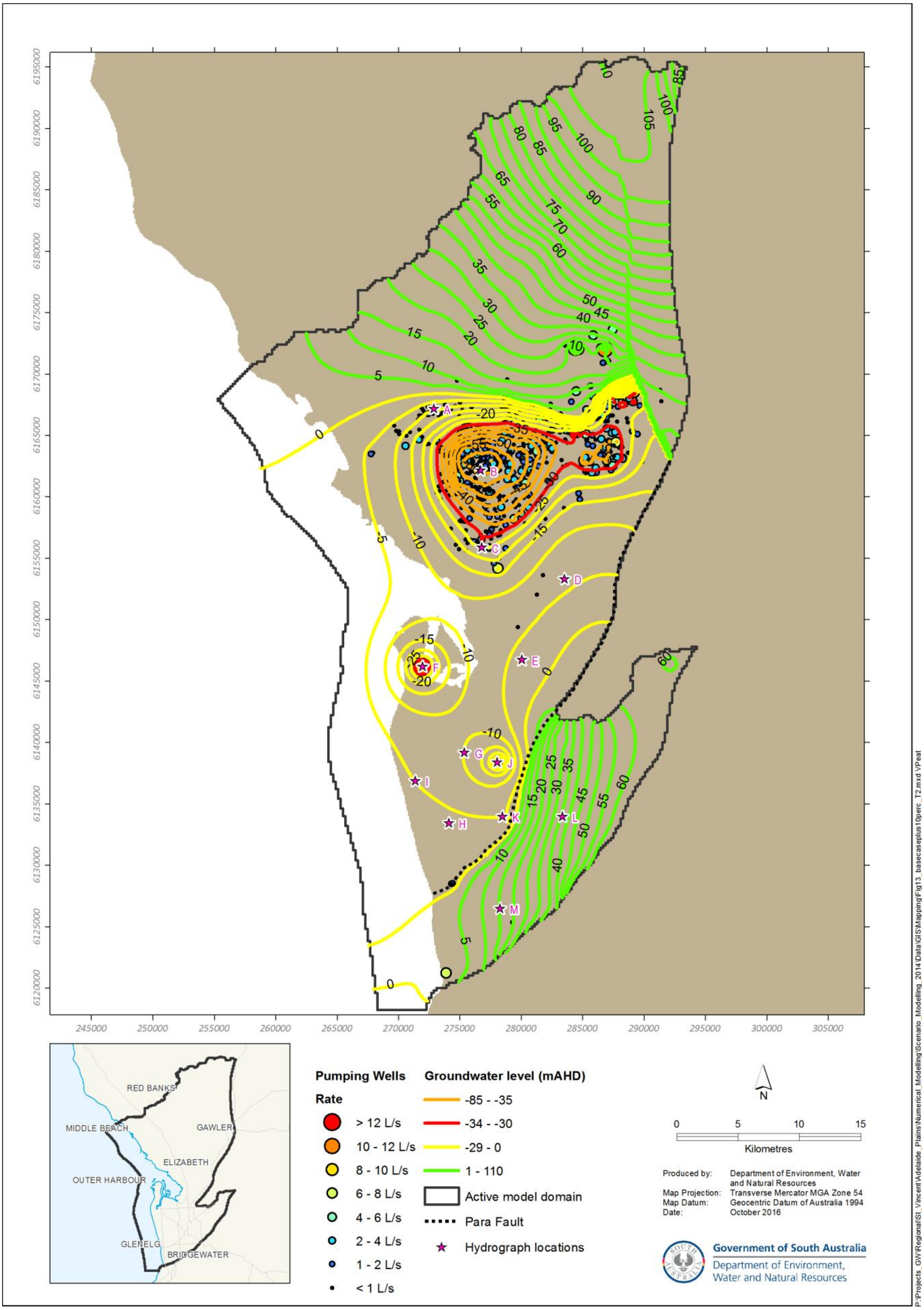

Figure 7.13 Scenario 4 – Maximum groundwater pressure levels after 30 years – T2 aquifer

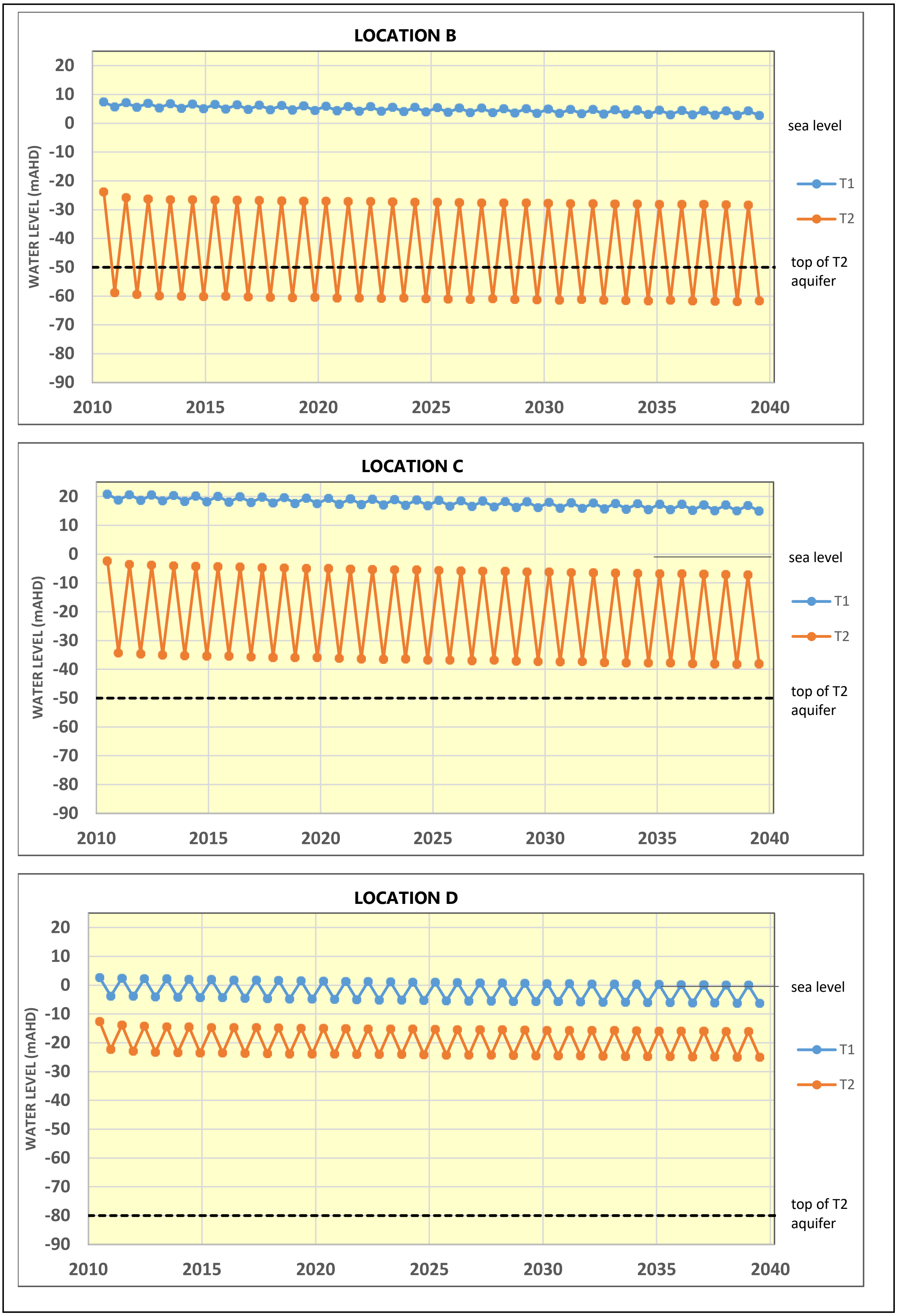

Figure 7.14 Scenario 4 – Selected hydrographs for the NAP PWA

Figure 7.15 Scenario 4 – Selected hydrographs for the CA PWA

Scenario 5 – Base case with an additional 20%

This scenario assumes that groundwater extraction in NAP over the next 30 years is 20% greater than the average condition over the last eight years. Extraction in Central Adelaide (CA) west of Para Fault (including Thebarton, Grange and North Haven) is assumed to have increased by 20% beyond the estimated 2010 existing user demand. These increases correspond to almost 2800 ML/y additional extraction in NAP and over 2000 ML/y in CA. As with the previous scenarios, it is assumed that in NAP 80% of the annual volume is extracted in summer and 20% is extracted in winter.

Groundwater level contours at the end of summer after 30 years for the T1 and T2 aquifers are presented in Figures 7.16 and 7.17 respectively. Hydrographs at three locations in the NAP are given in Figure 7.18 and three for CA given in Figure 7.19. A cross-section from the coast to the hills through the T2 cone of depression in the NAP shows the water levels after 30 years for both Scenarios 4 and 5 in summer (Fig. 7.20). A cross-section from the coast to the hills through Thebarton in CA presents the T1 water level after 30 years for both scenarios due to increase in industrial use (Fig. 7.21).

<u>T1 aquifer</u> – In the Waterloo Corner area of the NAP, the predicted water level response is only 1 m lower than Scenario 1. In the CA PWA, the small cones of depression have expanded and deepened by several metres. Although the cones of depression at Thebarton and Grange have merged, the T1 aquifer will remain pressurised in the CA PWA west of the Para Fault due the greater depth to the Tertiary aquifers than occurs in the NAP.

<u>T2 aquifer</u> – In the NAP, water levels in the T2 aquifer are expected to decline by about 7 m after 30 years compared to Scenario 1, with the impact as significant in Angle Vale as it is in Virginia. Unconfined and depressurized conditions would be expected for the T2 aquifer during summer, with some water level recovery expected during winter when confined conditions would temporarily resume. Groundwater levels less than −30 m AHD cover an area of just over 100 km^2 around Virginia and Angle Vale at the end of summer after 30 years. The total volume of groundwater pumped from the T2 aquifer in this area is more than 11 000 ML/y.

The cones of depression at Osborne and Regency Park have merged with intervening water level below −10 m AHD, which is a decline of approximately 5 m over 30 years. The T2 aquifer will also remain pressurised in the CA PWA west of the Para Fault as the Tertiary aquifers are deeper. Similarly at Dry Creek, groundwater level decline is less than 5 m over 30 years.

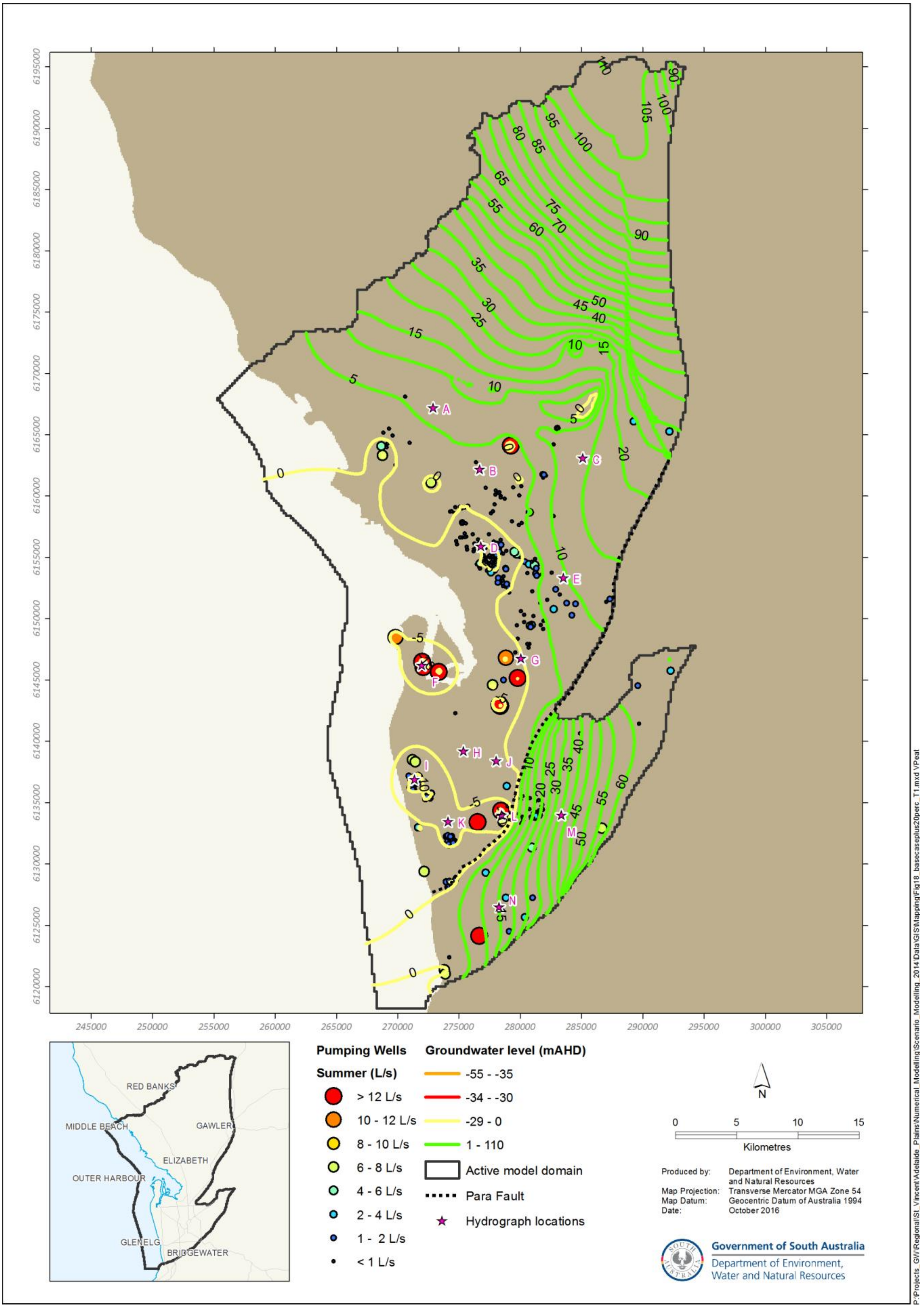

Figure 7.16 Scenario 5 – Maximum groundwater pressure levels after 30 years – T1 aquifer

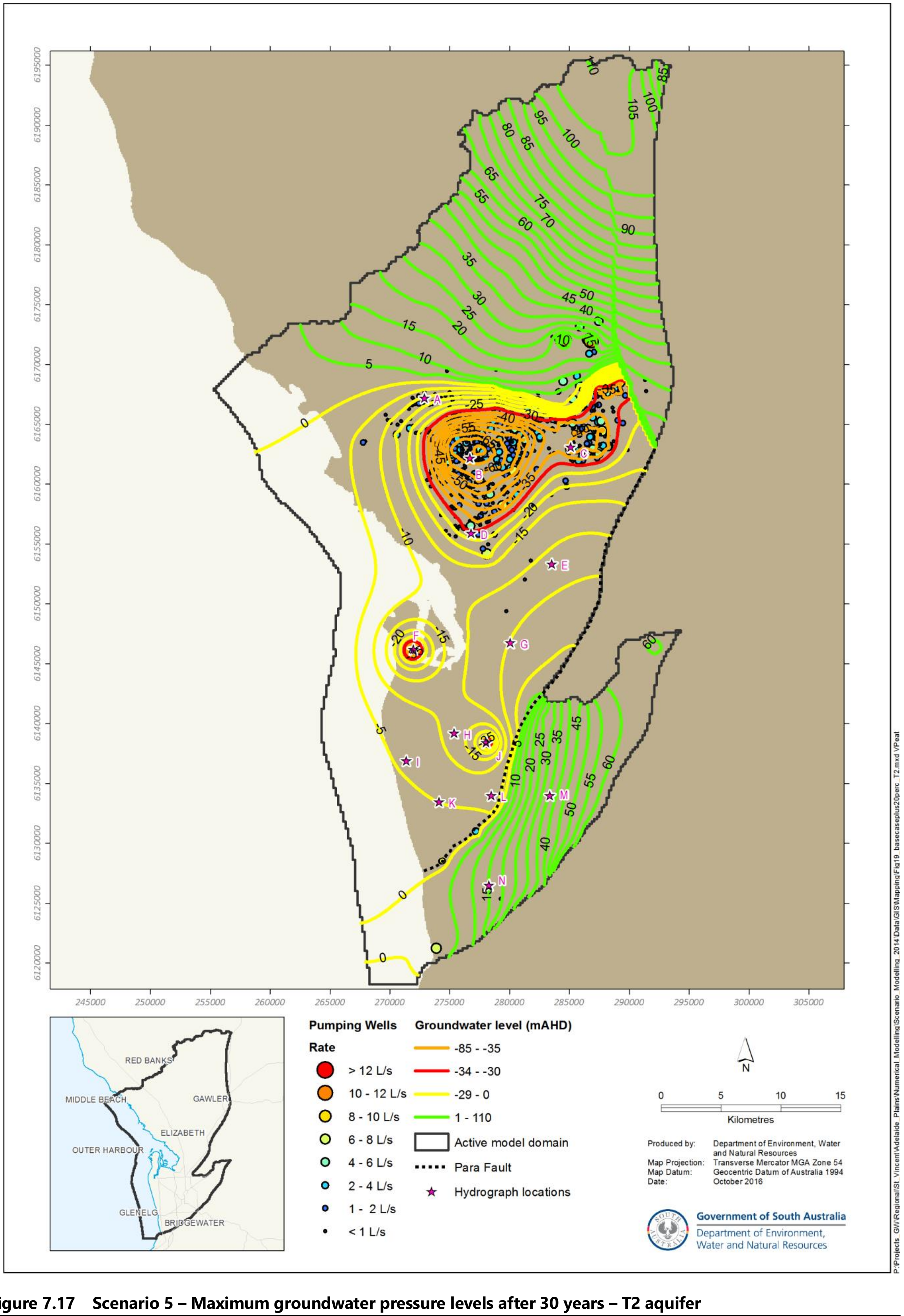

Figure 7.17 Scenario 5 – Maximum groundwater pressure levels after 30 years – T2 aquifer

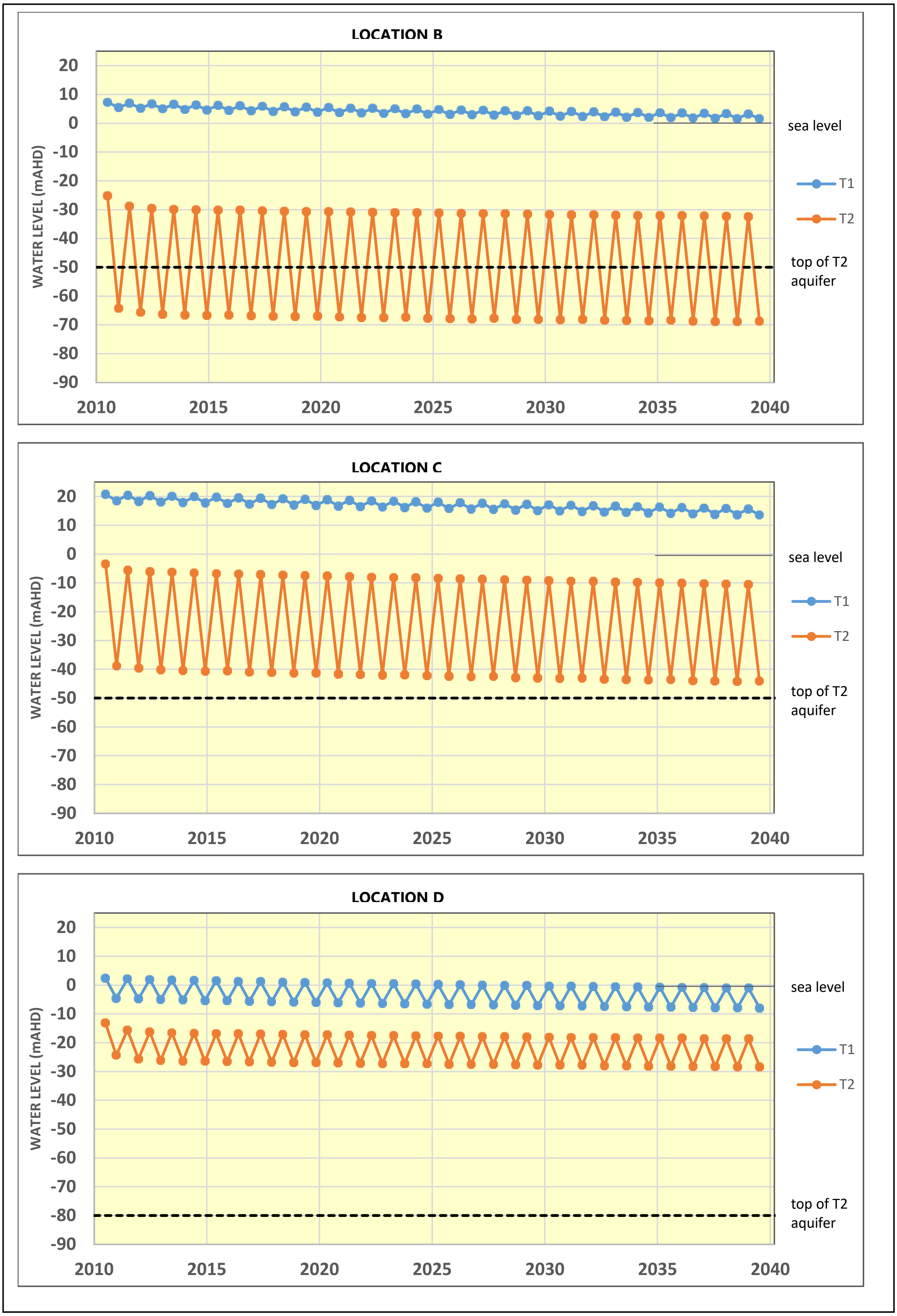

Figure 7.18 Scenario 5 – Selected hydrographs for the NAP PWA

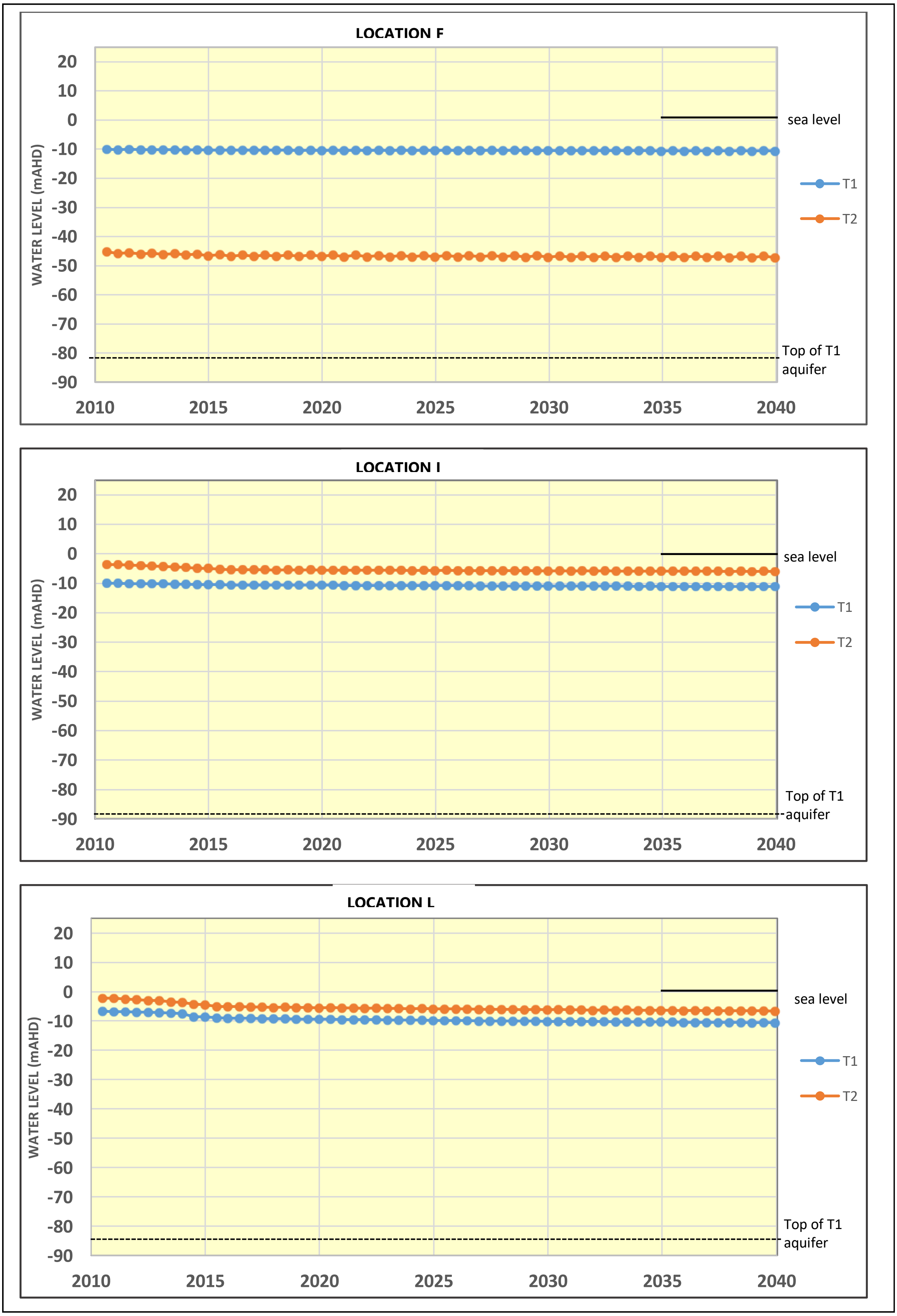

Figure 7.19 Scenario 5 – Selected hydrographs for the CA PWA

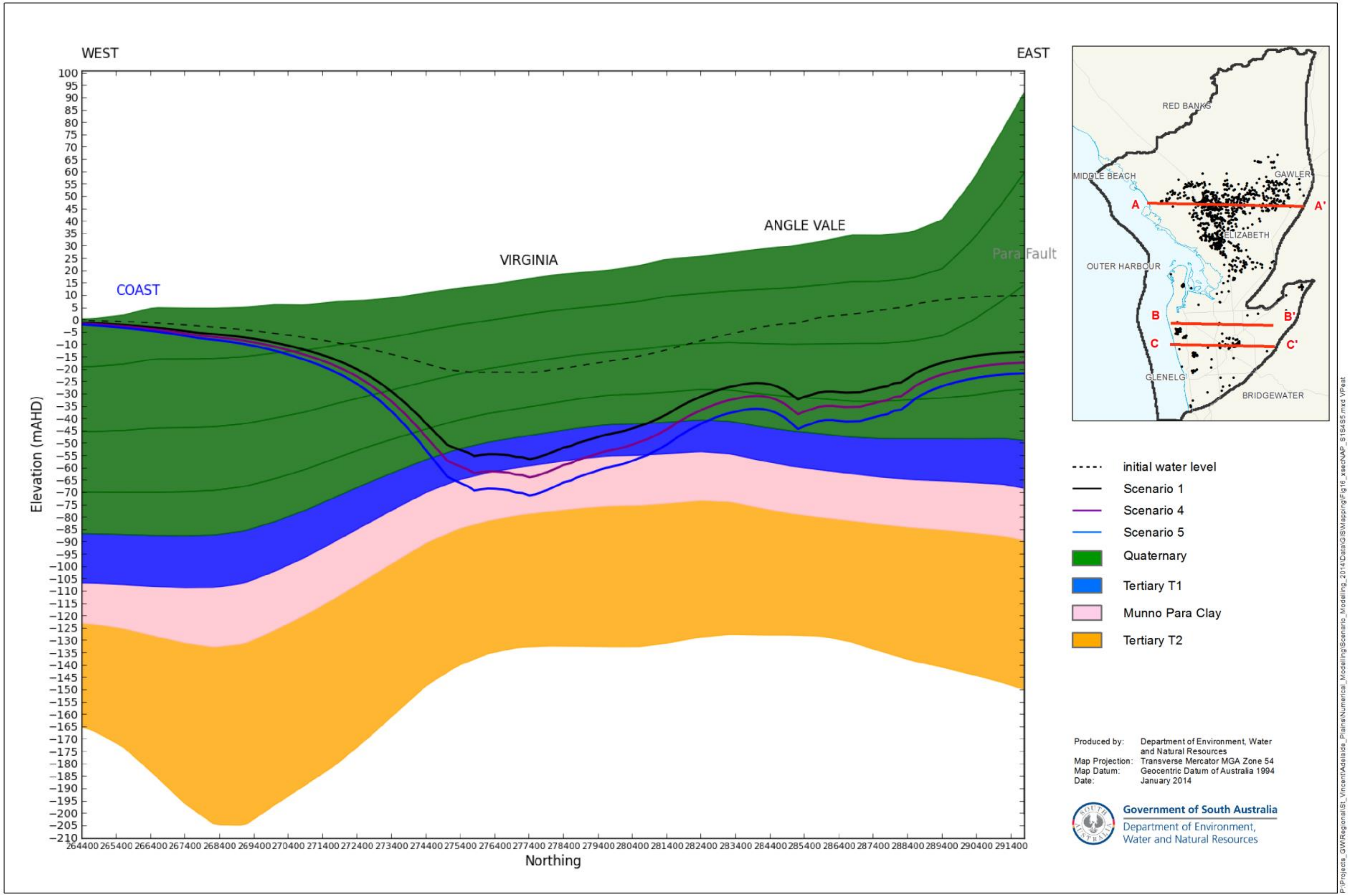

Figure 7.20 Predicted T2 groundwater levels for Scenarios 1, 4 and 5 (summer 2040), cross-section A–A′

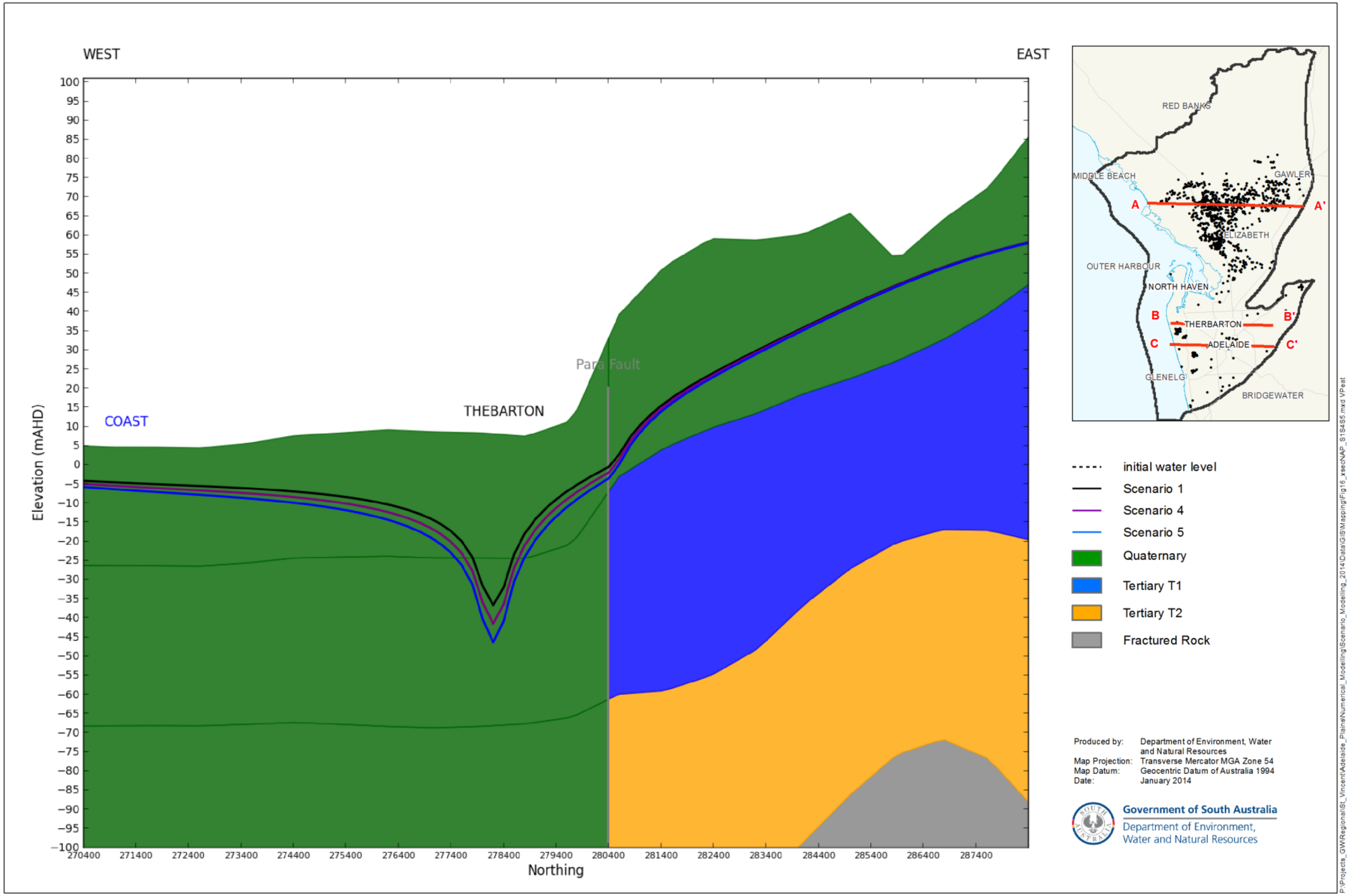

Figure 7.21 Predicted T1 groundwater levels for Scenarios 1, 4 and 5 (summer 2040), cross-section B–B′

Scenario 6 – Base case with double the existing user demand in the Golden Grove Embayment

Currently, about 1500 ML/y is assumed to be extracted from the T1 and T2 aquifers within the GGE. To determine the impacts of higher extractions, Scenario 6 assumes Scenario 1 (base case) extractions for the other GMZs, but models double the existing user demand in the T1 and T2 Golden Grove Embayment GMZ.

Figure 7.22 presents hydrographs from two locations – Stepney in the centre of the GMZ, and Edwardstown in the southwest. The grey lines represent the base case water levels.

The modelled water level response from both aquifers is very similar, suggesting a high degree of connectivity between them. If double the volume was to be extracted, a maximum decline in groundwater pressure levels of about 5 m, but predominantly one metre or less, is predicted to occur, with water levels in the T1 and T2 aquifers approaching equilibrium after 30 years. This indicates that this rate of extraction is sustainable in the long term.

The pattern of lowered groundwater pressure levels in the T1 and T2 aquifers at the end of 30 years is presented in Figures 7.23 and 7.24. The modelled decline is shown to extend into the Quaternary aquifers to the west of the Para Fault, but this response is likely to be the result of simplifications required for model construction and is unlikely to occur in reality. The Para Fault is a complex system and causes aquifer displacement. RPS Aquaterra (2011) implemented a "layered cake approach" whereby aquifers either side of the faults have been modelled using aquifer property changes and the faults are represented by general head boundaries. The base of the T1 and T2 aquifers in the GGE (Layers 2 and 3 in the model) align with the 2nd and 3rd Quaternary layers in the Adelaide Plains Sub-basin due to the Para Fault. In reality, drawdown caused by pumping in the Golden Grove Embayment is unlikely to travel across a complex fault system such as the Para Fault.

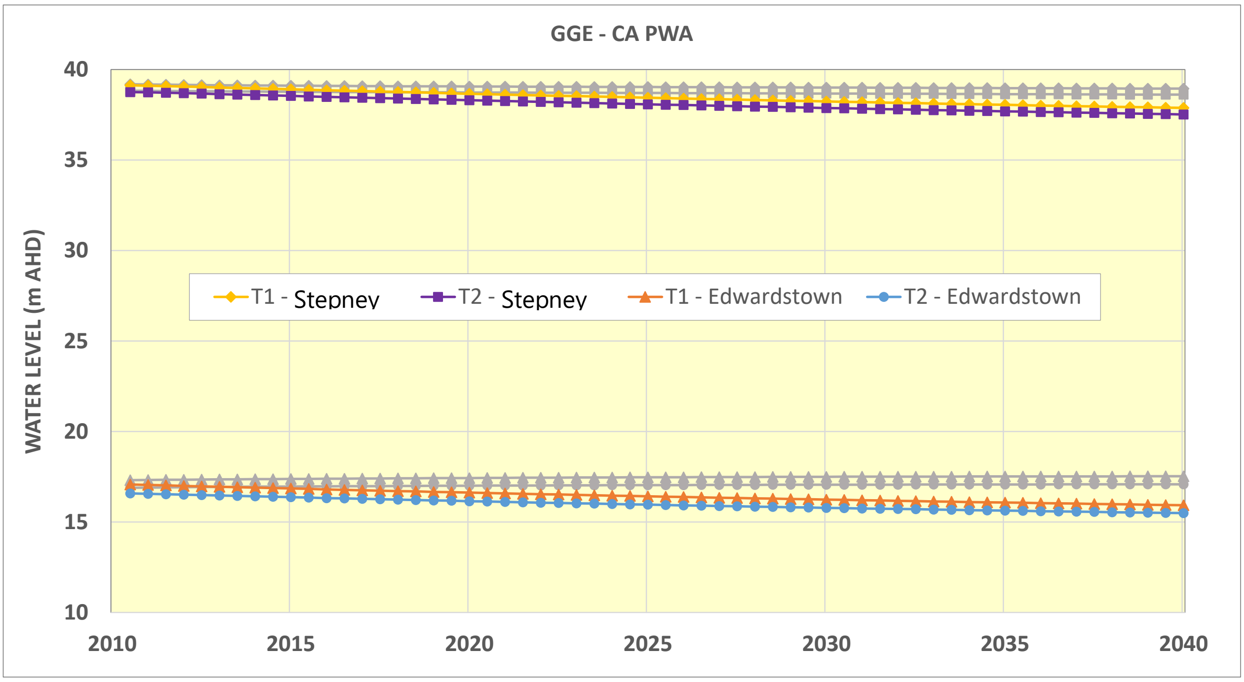

Figure 7.22 Predicted T1 and T2 groundwater level trends for Scenario 6 in the GGE

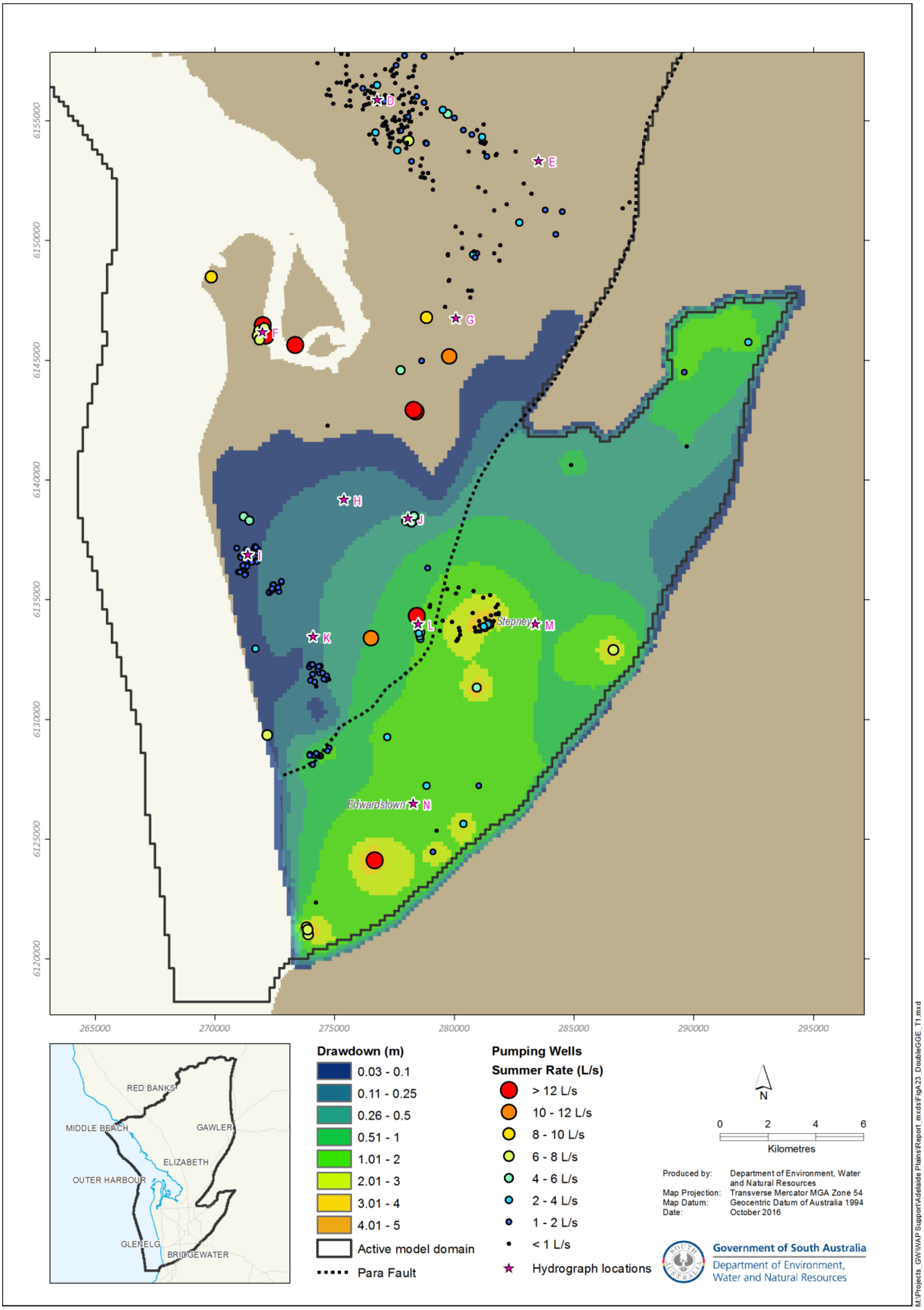

Figure 7.23 Scenario 6 – Maximum groundwater after 30 years – T1 aquifer

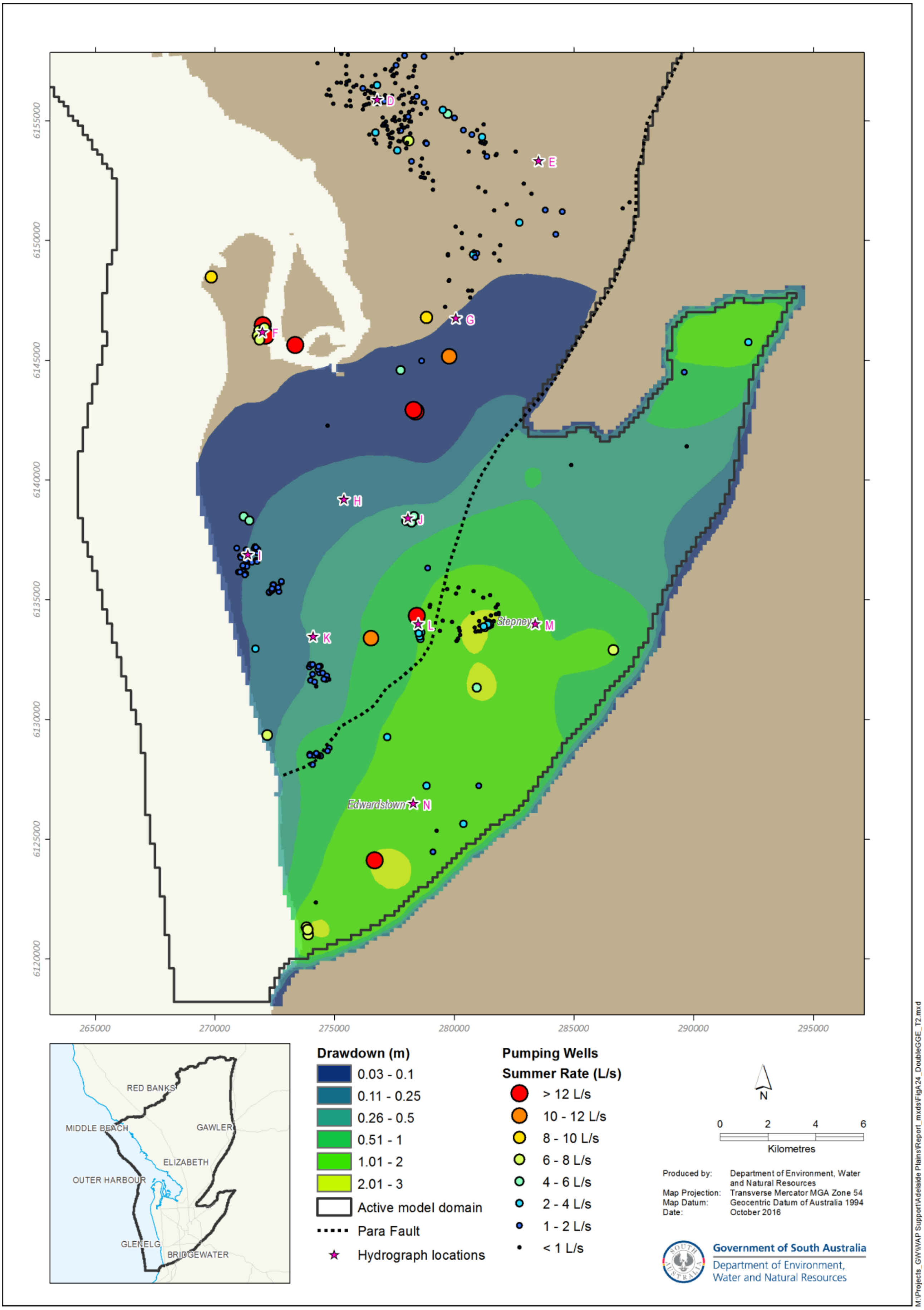

Figure 7.24 Scenario 6 – Maximum groundwater after 30 years – T2 aquifer

Scenario 7 – Scenario 6 with additional 2000 ML in the Golden Grove Embayment

To determine the impacts of higher extractions for industrial purposes and the degree of interference from multiple wells, a hypothetical scenario was run including an additional 24 wells targeting both the T1 and T2 aquifers at a minimum distance of 1.5 km from each other and from existing users. Scenario 7 assumes base case (Scenario 1) extractions for the remainder of the GMZs but models an additional 2000 ML/y in addition to double the existing user demand in the GGE (Scenario 6), with each additional well pumping at a constant rate of approximately 2.6 L/s for 30 years. Extraction occurs from both T1 and T2 aquifers in each well.

Figure 7.25 presents hydrographs from two locations – Stepney in the centre of the modelled extraction, and Edwardstown at the southwestern margin of the extraction. The grey lines represent the base case water levels.

The modelled water level response from both aquifers is very similar, suggesting a high degree of connectivity between them. If an extra 2000 ML/y in addition to double the existing user demand were to be extracted, a maximum drop in groundwater pressure levels of around 7 m is predicted to occur in the centre of the pumping area, with water levels in the T1 and T2 aquifers still declining after 30 years. This suggests that the aquifers do not reach a new equilibrium resulting in the continued long-term decline of the resource. This indicates that this rate and density of extraction is not sustainable in the long term. To the southwest, levels declined by around 3.5 m and also showed no sign of an equilibrium being reached.

The pattern of water level changes in the T1 and T2 aquifers at the end of 30 years is presented in Figures 7.26 and 7.27. The modelled decline in groundwater pressure levels is shown to extend to the west of the Para Fault, but this response is likely to be the result of simplifications required for model construction is unlikely to occur in reality. Potential impact on the fractured rock aquifer east of the Eden–Burnside Fault is evident.

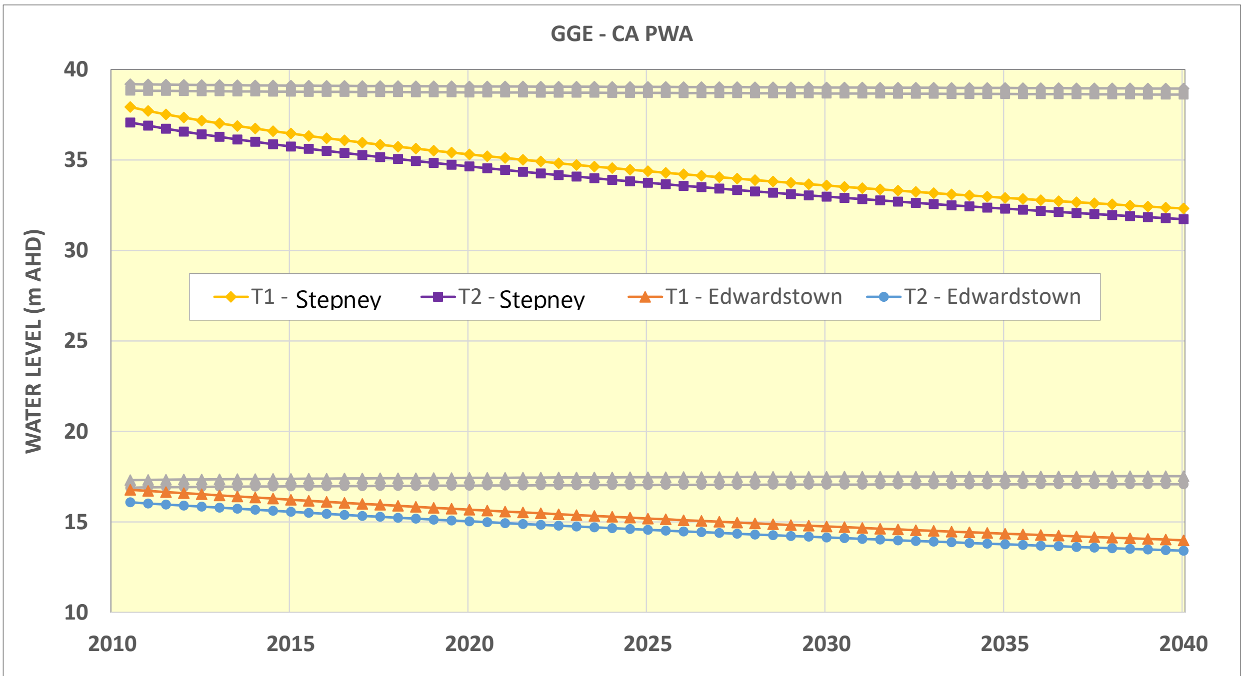

Figure 7.25 Predicted T1 and T2 groundwater level trends for Scenario 6 in the GGE

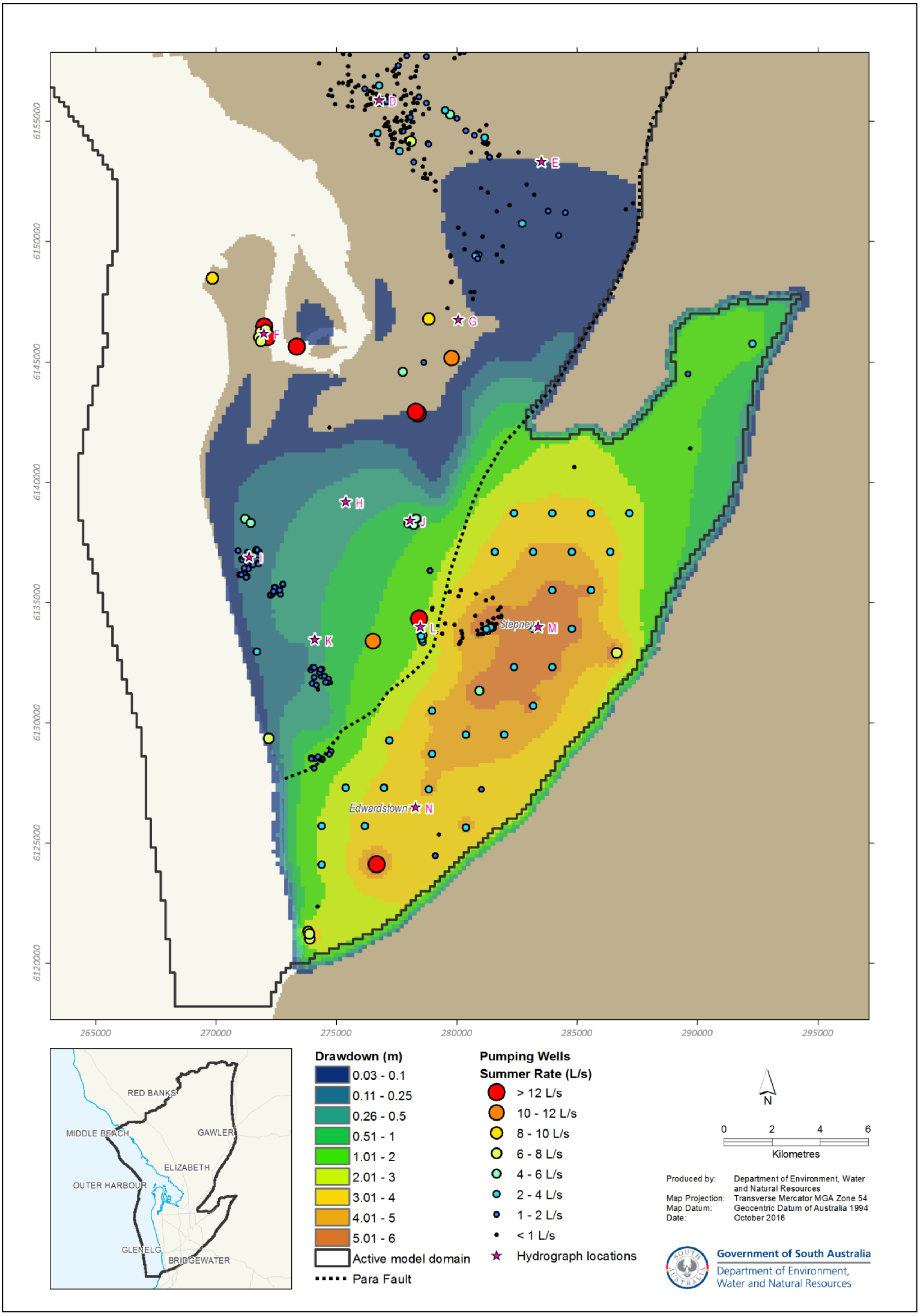

Figure 7.26 Scenario 7 – Maximum groundwater after 30 years – T1 aquifer

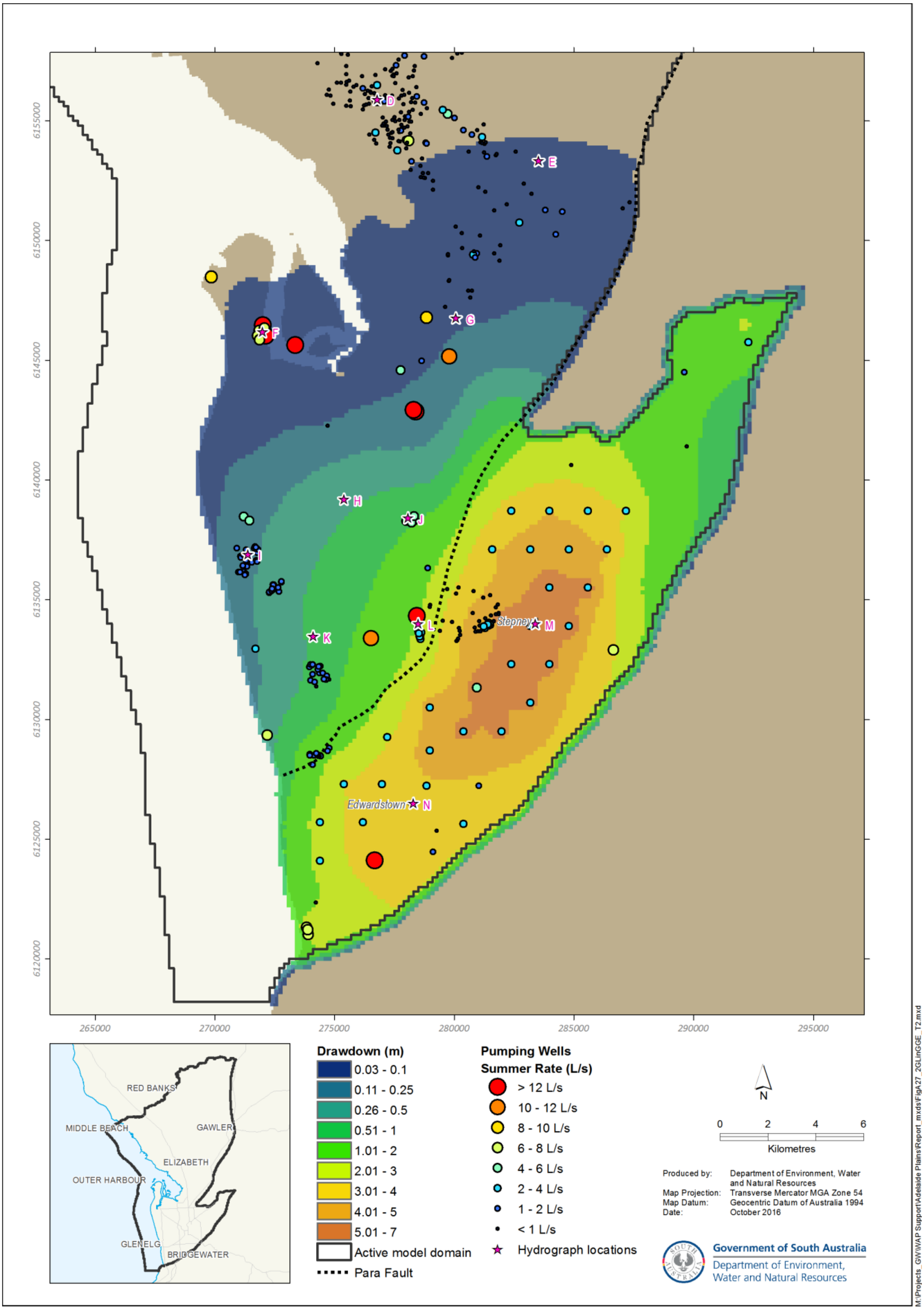

Figure 7.27 Scenario 7 – Maximum groundwater after 30 years – T2 aquifer

Scenario 8 – Scenario 6 with additional 1000 ML in the Golden Grove Embayment

Another hypothetical scenario was run with a reduced increase in industrial extractions of 1000 ML/y. This was achieved by reducing the number of wells by 50% to 12 wells targeting both the T1 and T2 aquifers at a minimum distance of 1.5 km from each other and from existing users. Scenario 8 assumes base case (Scenario 1) extractions for the remainder of the GMZs but models an additional 1000 ML/y in addition to the doubled existing user demand in the GGE (Scenario 6), with each of the 12 wells pumping at a constant rate of approximately 2.6 L/s for 30 years from both aquifers.

Figure 7.28 presents hydrographs from two locations – Stepney in the centre of the modelled extraction, and Edwardstown at the southwestern margin of the extraction. The pattern of decline in the groundwater pressure levels in the T1 and T2 aquifers at the end of 30 years is presented in Figures 7.29 and 7.30.

The reduction in extraction to 1000 ML/y produced much less drawdown than Scenario 7, with a maximum drop in levels of only around 4 m predicted to occur in the centre of the pumping area and water levels in the T1 and T2 aquifers approaching equilibrium after 30 years. This rate and density of extraction is considered more sustainable than Scenario 7. To the southwest, decreases in water levels were only about 2.5 m.

The modelled decline in groundwater pressure levels is also shown to extend to the west of the Para Fault, but this response is unlikely to occur in reality as discussed earlier. The potential impact on the fractured rock aquifer east of the Eden–Burnside Fault is reduced.

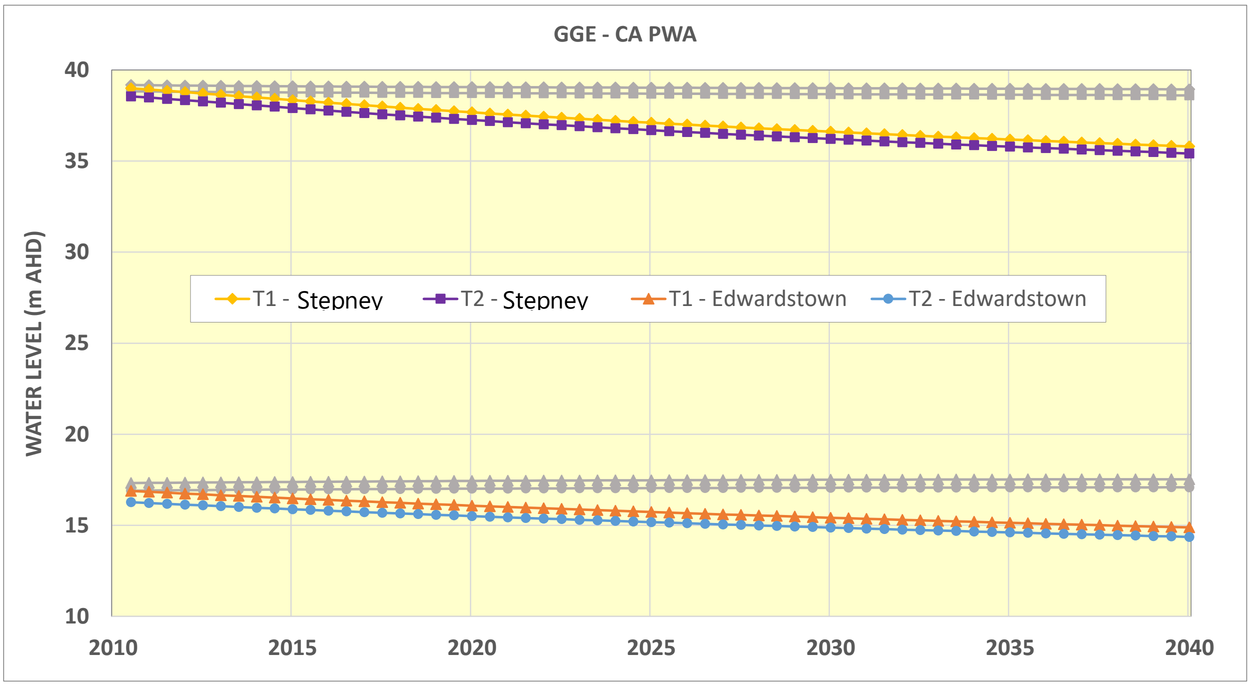

Figure 7.28 Predicted T1 and T2 groundwater level trends for Scenario 7 in the GGE

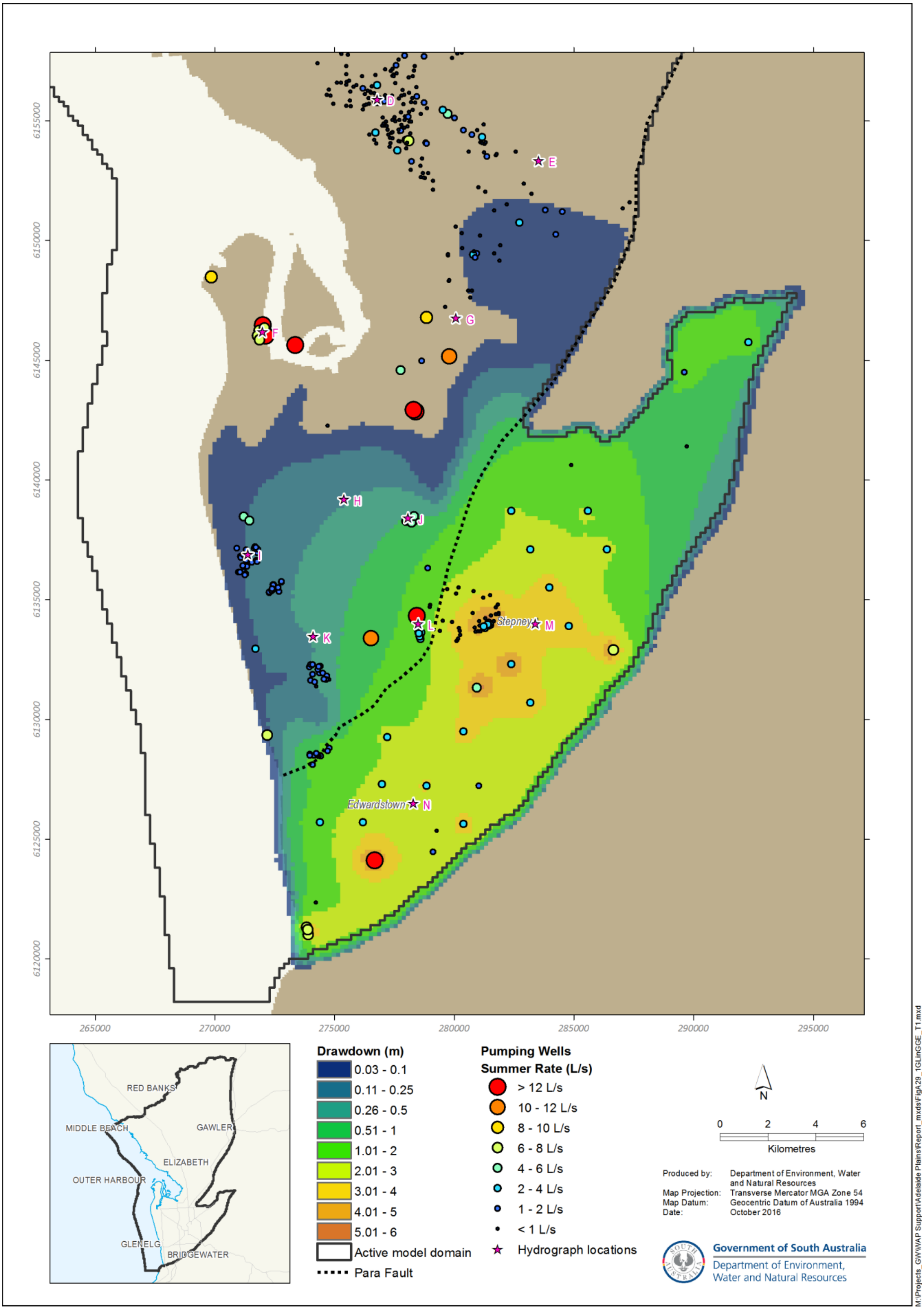

Figure 7.29 Scenario 8 – Maximum groundwater after 30 years – T1 aquifer

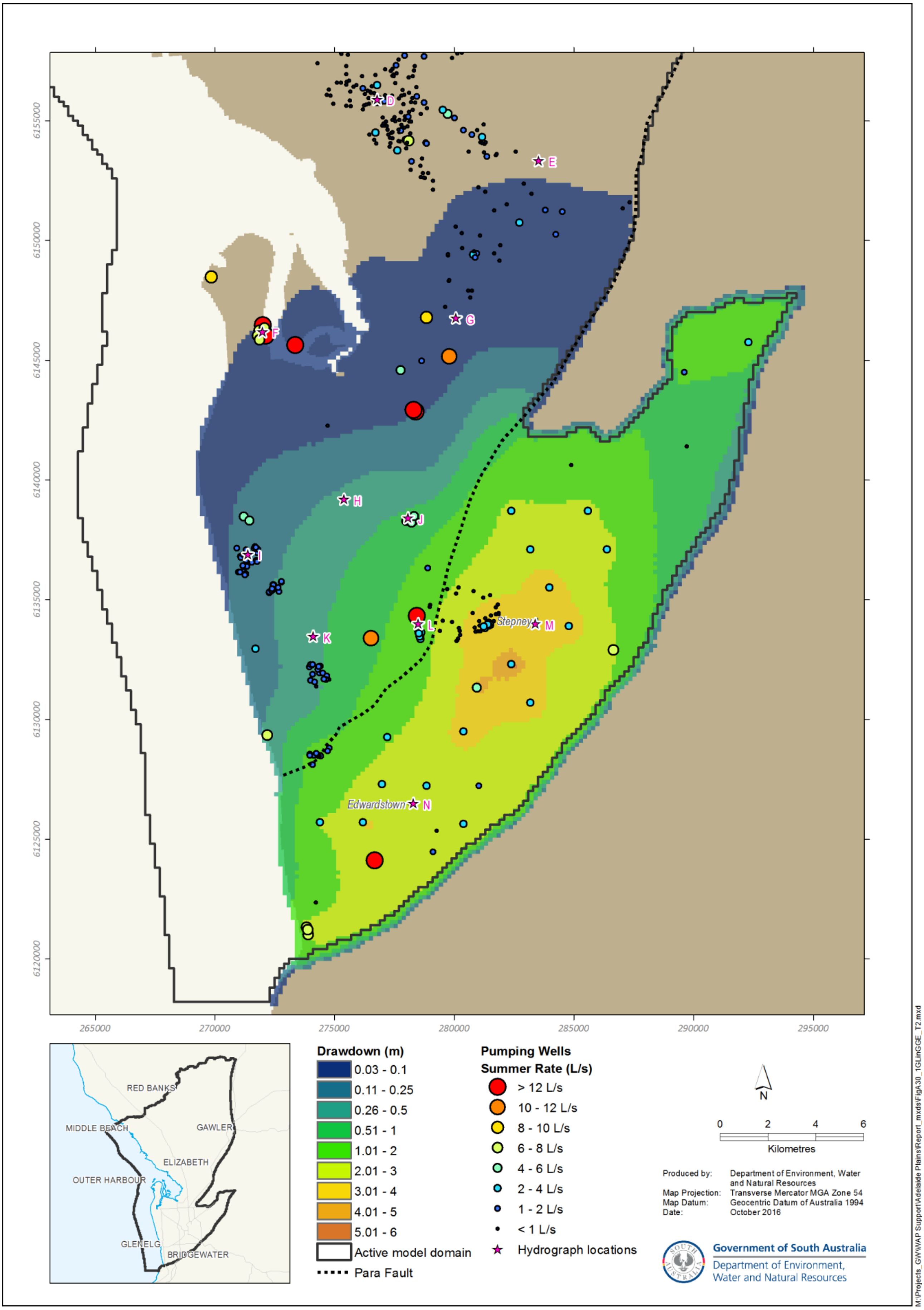

Figure 7.30 Scenario 8 – Maximum groundwater after 30 years – T2 aquifer

Scenario 9 – Base case all GMZs except Worst case in T2 NAP and T2 Regional GMZs + 2000 ML in T2 Regional GMZ

After considering the results of all of the scenarios, it was decided to run a scenario that is a mixture of some previous scenarios. The two GMZs where intensive irrigation extraction occurs, the T2 Virginia and T1 NAP GMZs, were modelled the same as Scenario 1, or base case, which is the average extraction over the eight years from 2006 to 2013. All other GMZs were modelled the same as Scenario 2, or worst case, which is the full allocation volume for the year 2011. As there are minimal existing users in the T2 Regional GMZ, a further 2000 ML in addition to the Scenario 2 volume was extracted to determine the impacts of higher extractions and the degree of interference from multiple wells. An additional 134 wells targeting the T2 aquifer at a minimum distance of 1.5 km from each other and from existing users were included. Each additional well pumps at a seasonal rate of approximately 1 L/s for 30 years.

Groundwater level contours at the end of summer after 30 years for the T1 and T2 aquifers are presented in Figures 7.31 and 7.32 respectively. Hydrographs at six locations in the NAP are given in Figures 7.33 and 7.34 and six for CA given in Figures 7.35 and 7.36.

The results for Scenario 9 typically fall somewhere between the results for Scenario 4 and 5. In the T2 Virginia GMZ, groundwater pressure levels in the T2 aquifer are expected to decline by about 6 m after 30 years, in both summer and winter, compared to Scenario 1 (Fig. 7.33, locations B and C). Unconfined and depressurised conditions would be expected for the T2 aquifer during summer, with some pressure level recovery expected during winter when confined conditions would temporarily resume. Groundwater pressure levels less than −30 m AHD cover an area of just over 100 km^2 around Virginia and Angle Vale at the end of summer after 30 years and are almost identical to those from Scenario 5.

In the T2 NAP GMZ that surrounds the T2 Virginia GMZ, the summer groundwater pressure levels after 30 years are 10–15 m lower than at the same time in Scenario 1, but 5–10 m higher than at the same time in Scenario 2 (Fig. 7.33, Location A). Compared to Scenarios 4 and 5, the summer levels are 0–10 m lower.

The winter groundwater pressure levels in the T2 Osborne GMZ decline by about 3 m after 30 years compared to Scenario 1, but is 1 m higher than Scenario 4 (Fig. 7.35, Location F). The -30 m AHD contour covers a larger area though, around 4 km^2, but this would be due to the surrounding wells added to extract the extra 2000 ML.

In the T2 Regency Park GMZ, the winter groundwater levels reach about -43 m AHD after 30 years, and the -30 m AHD contour covers an area of 0.5 km^2 (Fig. 7.36, Location J). This result is somewhere between the Scenario 4 and 5 results.

Four locations throughout the T2 Regional GMZ were chosen to observe the results of extracting an additional 2000 ML from this GMZ. Groundwater pressure levels in the Edinburgh area would be 13 m lower at the end of summer after 30 years and 6.5 m lower in winter than those in Scenario 1 (Fig. 7.34, Location E). In the Green Fields area, pressure levels are nearly 14 m lower in summer and nearly 5 m lower in winter after 30 years than in Scenario 1 (Fig. 7.34, Location G). Summer groundwater pressure levels are nearly 11 m lower after 30 years in Woodville North, but just 3 m lower in winter compared to Scenario 1 (Fig. 7.35, Location H). At Kidman Park, levels are about 6 and 2 m lower in summer and winter, respectively after 30 years compared to Scenario 1 (Fig. 7.36, Location K).

Scenario 9 extraction volumes from the T1 aquifer are the same as Scenario 1, however, a decline in groundwater pressure levels of around 3.5 m is predicted to occur in both winter and summer after 30 years in the Waterloo Corner area (Fig. 7.34, Location D). In the Osborne area, a lowering of levels of around 0.5–1 m is predicted to occur after 30 years and the area covered by the –5 m AHD contour reaches 18 km^2. A decline in groundwater pressure levels of around 0.5 m is predicted to occur after 30 years and the area covered by the –5 m AHD contour reaches 17 km^2 in the Grange area (Fig. 7.35, Location I). In the Thebarton area, a decline of around 0.5–2 m is predicted to occur after 30 years and the area covered by the –5 m AHD contour reaches 4 km^2 (Fig. 7.36, Location L). In the CA PWA, declines in the water levels are more similar to Scenarios 4 and 5 (Figs 7.36 and 7.36, Location H and K). This is likely due to the increased volume of extraction from the underlying T2 NAP GMZ under Scenario 9 causing downward leakage.

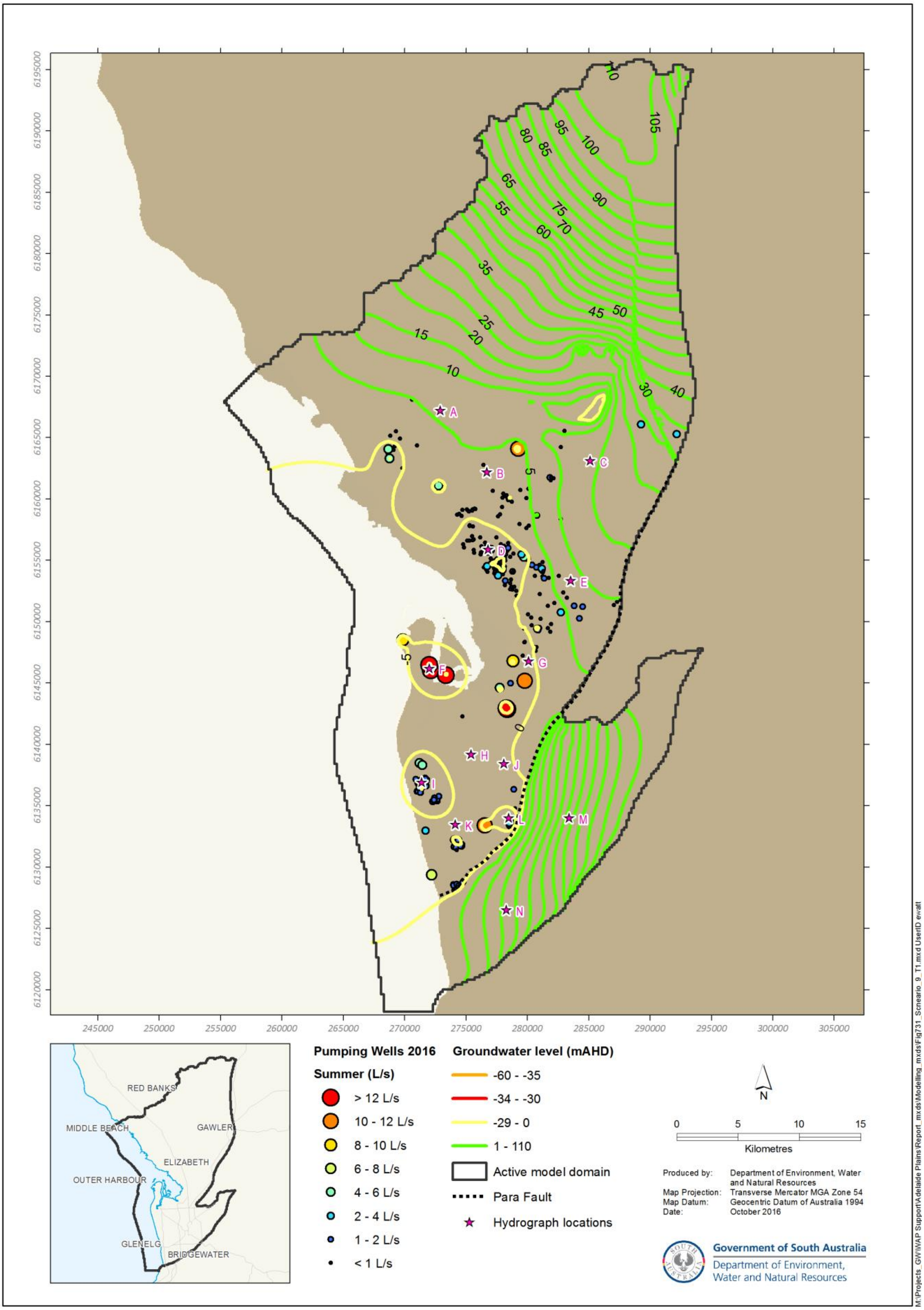

Figure 7.31 Scenario 9 – Maximum groundwater pressure levels after 30 years – T1 aquifer

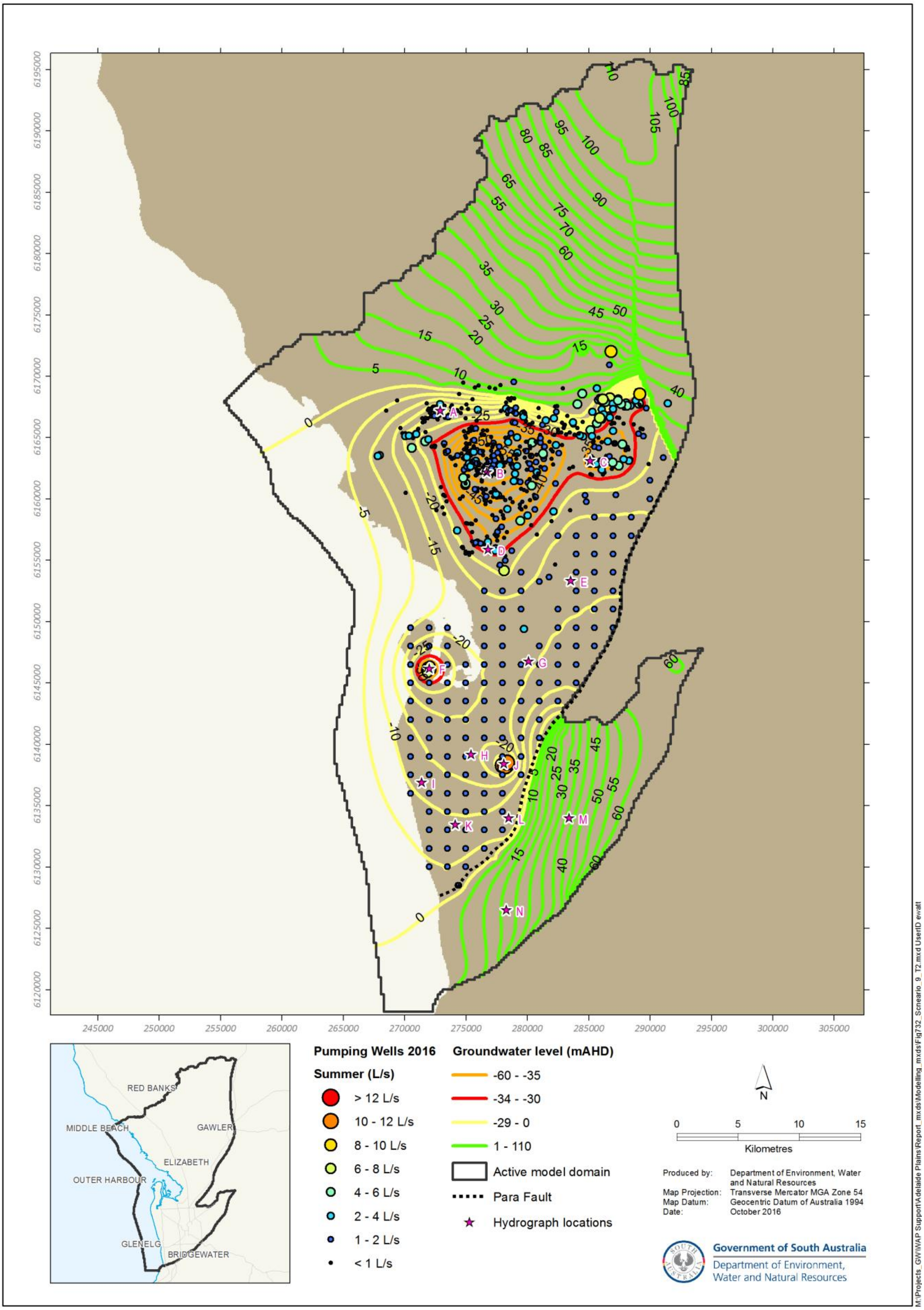

Figure 7.32 Scenario 9 – Maximum groundwater pressure levels after 30 years – T2 aquifer

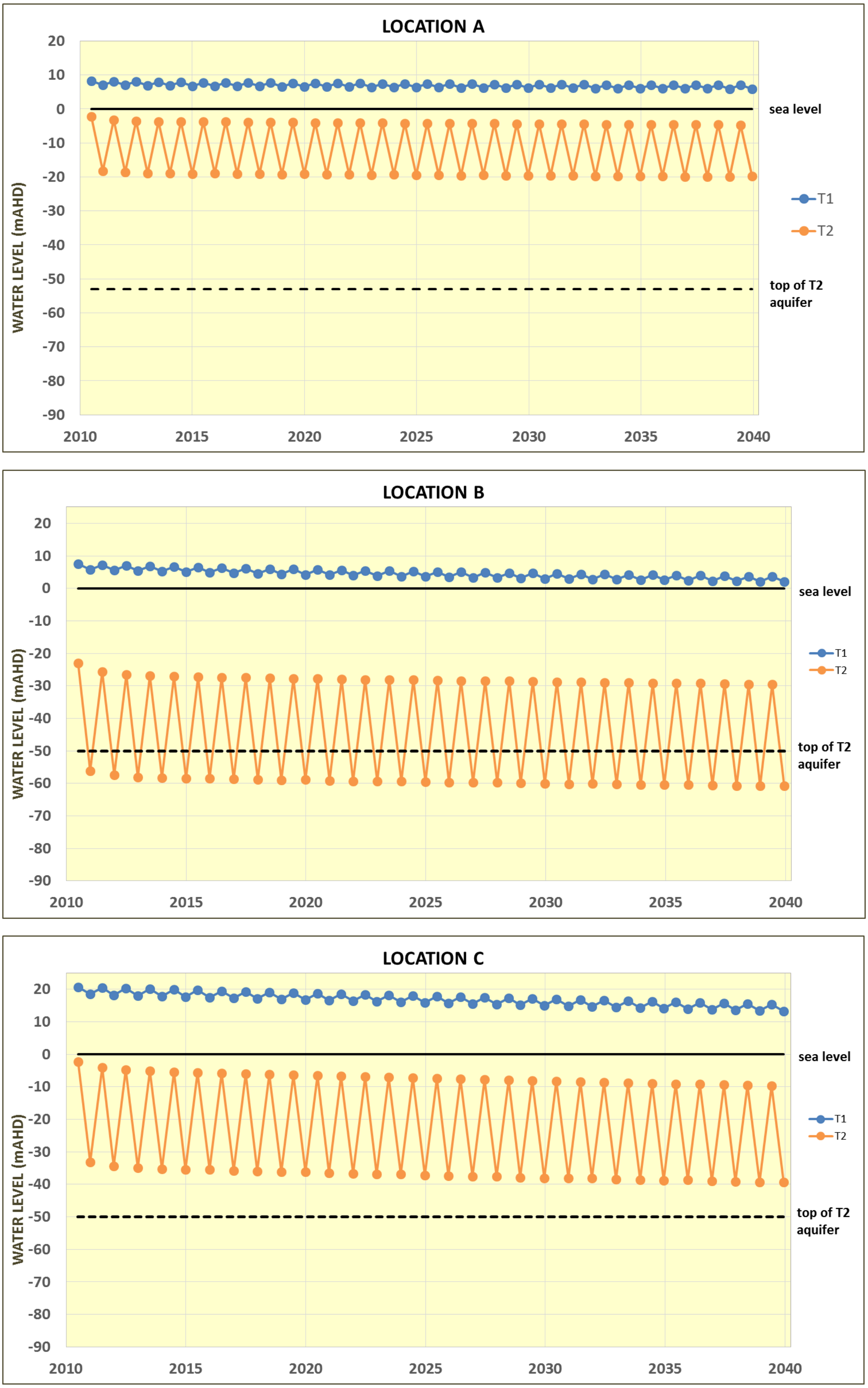

Figure 7.33 Scenario 9 – Selected hydrographs in the NAP PWA

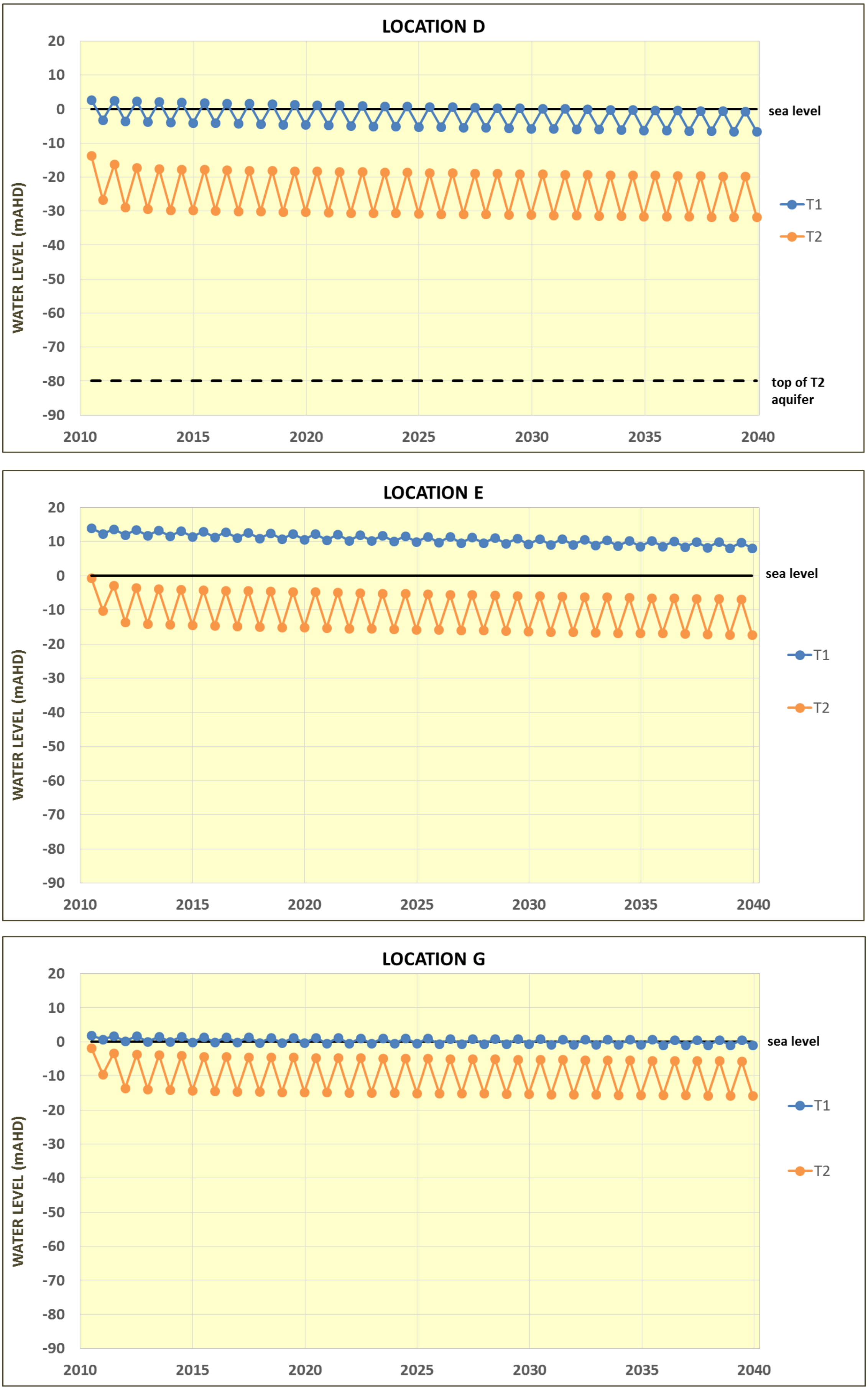

Figure 7.34 Scenario 9 – Selected hydrographs in the NAP PWA

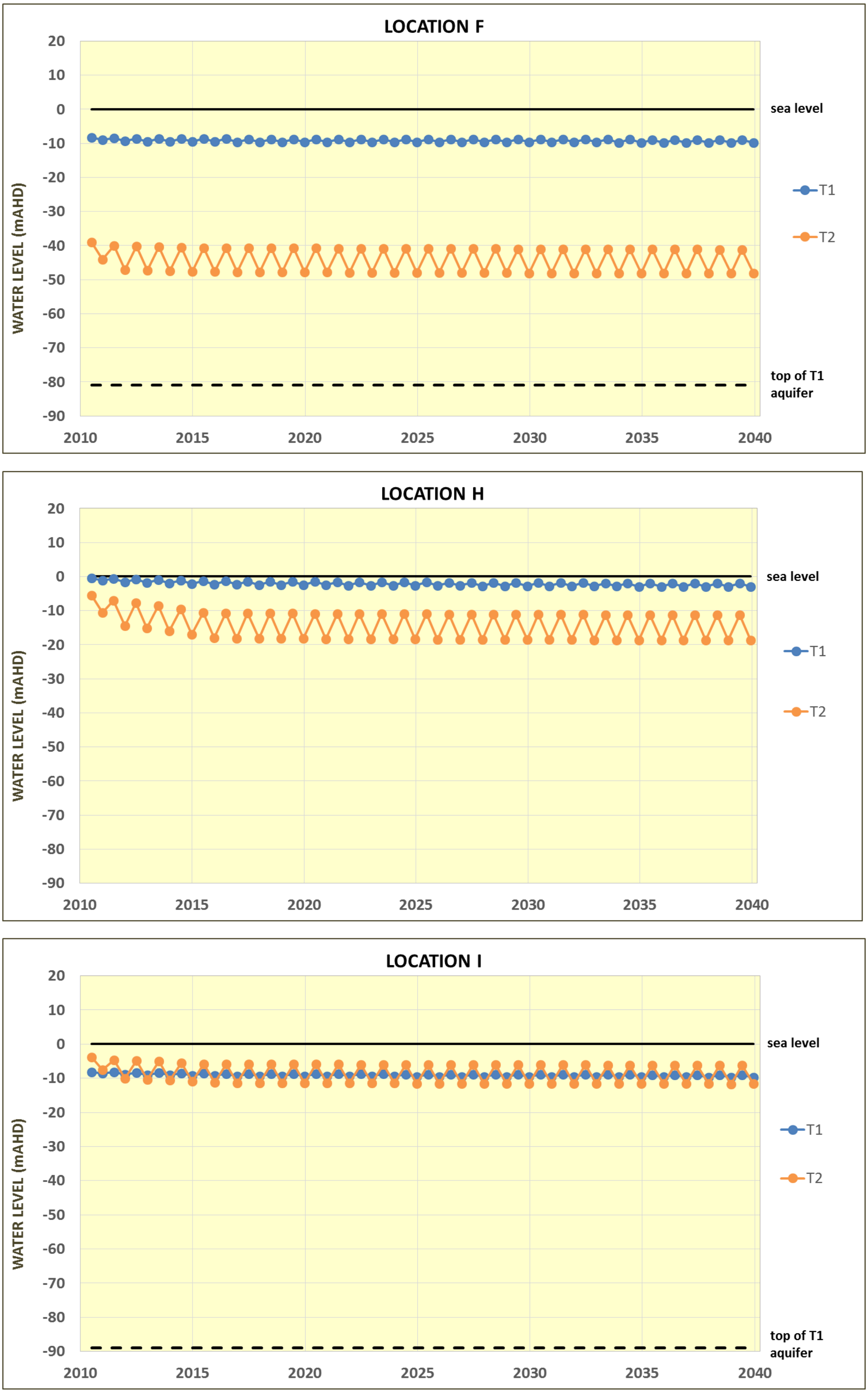

Figure 7.35 Scenario 9 – Selected hydrographs in the CA PWA

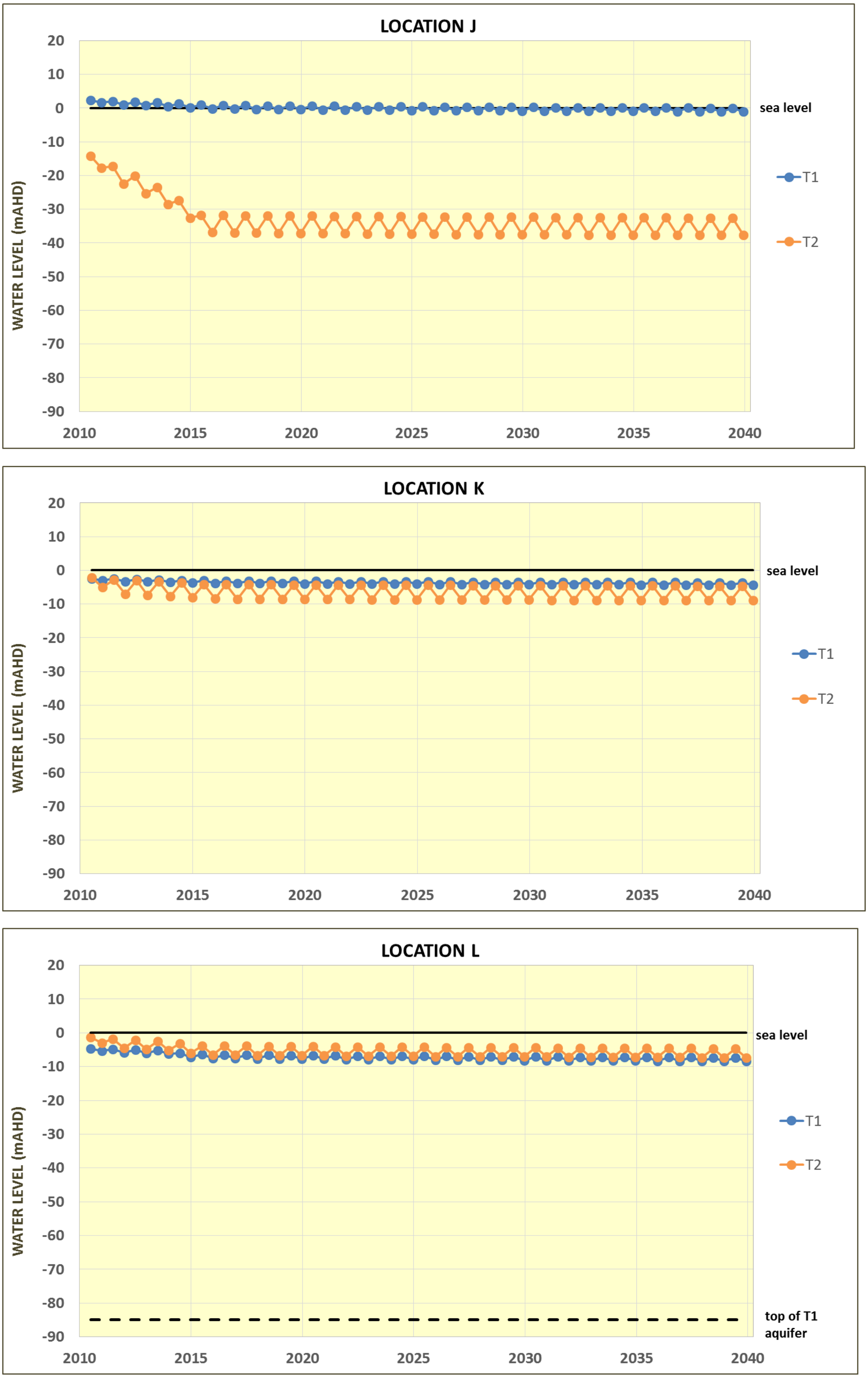

Figure 7.36 Scenario 9 – Selected hydrographs in the CA PWA

Scenario 10 – Scenario 1 in T2 Kangaroo Flat GMZ, Scenario 5 in T2 Virginia GMZ, Scenario 8 in T1 and T2 GGE GMZ, Scenario 9 in T2 Regional GMZ, and Scenario 1 with an additional 30% in all other GMZs

Scenario 10 also looked at the impacts of varying pumping levels in different management zones. In this scenario, pumping from the T2 Kangaroo Flat GMZ was kept at base case levels (Scenario 1); base case plus an extra 20% (Scenario 2) was pumped from T2 Virginia GMZ; double existing user demand plus an additional 1000 ML/y (Scenario 8) was pumped from the T1 and T2 GGE GMZ; full allocations plus an additional 2000 ML (Scenario 9) was pumped from the T2 Regional GMZ; and an additional 30% on top of base case volumes was pumped from all other GMZs. These increases correspond to almost 4800 ML/y additional extraction in NAP and 6700 ML/y in CA.

Groundwater level contours at the end of summer after 30 years for the T1 and T2 aquifers are presented in Figures 7.37 and 7.38 respectively. Hydrographs at six locations in the NAP are given in Figures 7.39 and 7.40 and six for CA given in Figures 7.41 and 7.42.

<u>T1 aquifer</u> – In the Waterloo Corner area of the NAP, the predicted water level response is nearly 3 m lower in winter and nearly 5 m lower in summer than Scenario 1, or about 1 m lower than those predicted from Scenario 5. In the CA PWA, the small cones of depression have expanded and deepened by several metres. Although the cones of depression at Thebarton, Grange and Osborne have merged, the T1 aquifer will remain pressurised in the CA PWA west of the Para Fault, due the greater depth to the Tertiary aquifers than occurs in the Adelaide Plains sub-basin.

<u>T2 aquifer</u> – In the NAP, water levels in the T2 aquifer are expected to decline by about 9 m after 30 years compared to Scenario 1, with the impact as significant in Angle Vale as it is in Virginia. Unconfined and depressurized conditions would be expected for the T2 aquifer during summer, with some water level recovery expected during winter when confined conditions would temporarily resume. Groundwater levels less than −30 m AHD cover an area of just over 100 km^2 around Virginia and Angle Vale at the end of summer after 30 years. The total volume of groundwater pumped from the T2 aquifer in this area is just over 11 000 ML/y.

The cones of depression at Osborne and Regency Park have merged with intervening water level below −20 m AHD, which is a decline of approximately 10 m over 30 years. The T2 aquifer will also remain pressurised in the CA PWA west of the Para Fault as the Tertiary aquifers are deeper.

Although the same volum e of groundwater was pumped from the T2 Regional GMZ as Scenario 9, results across the four observation locations were varied because of the increase in extractions from adjacent GMZs. At Edinburgh, the pressure levels are very similar to Scenario 9, with declines increasing by around 0.5 m. In the Green Fields area, pressure levels are about two metres lower than Scenario 9. Pressure levels are around 5 m lower than those of Scenario 9 in Woodville North and around 3 m lower in Kidman Park.

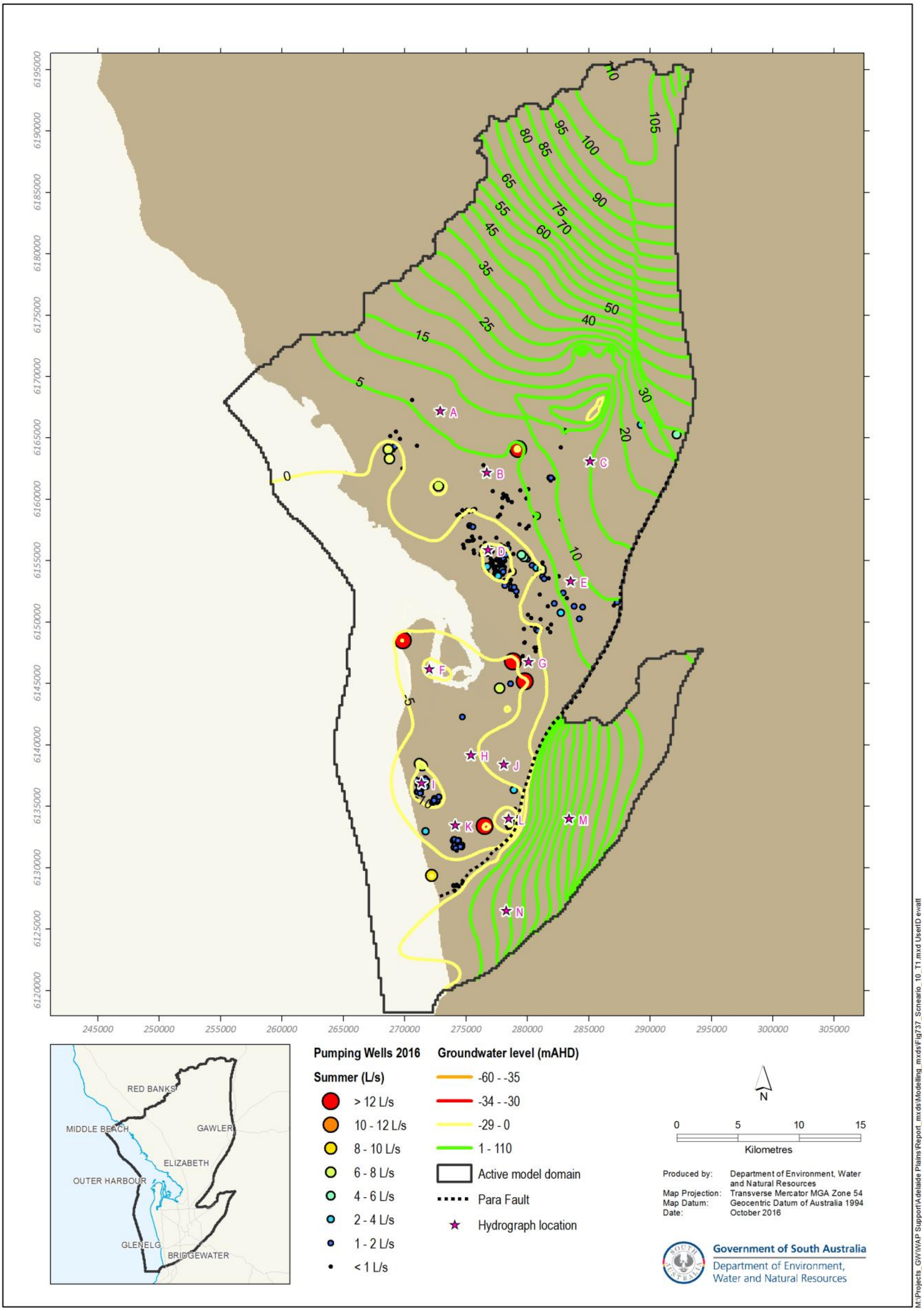

Figure 7.37 Scenario 10 – Maximum groundwater pressure levels after 30 years – T1 aquifer

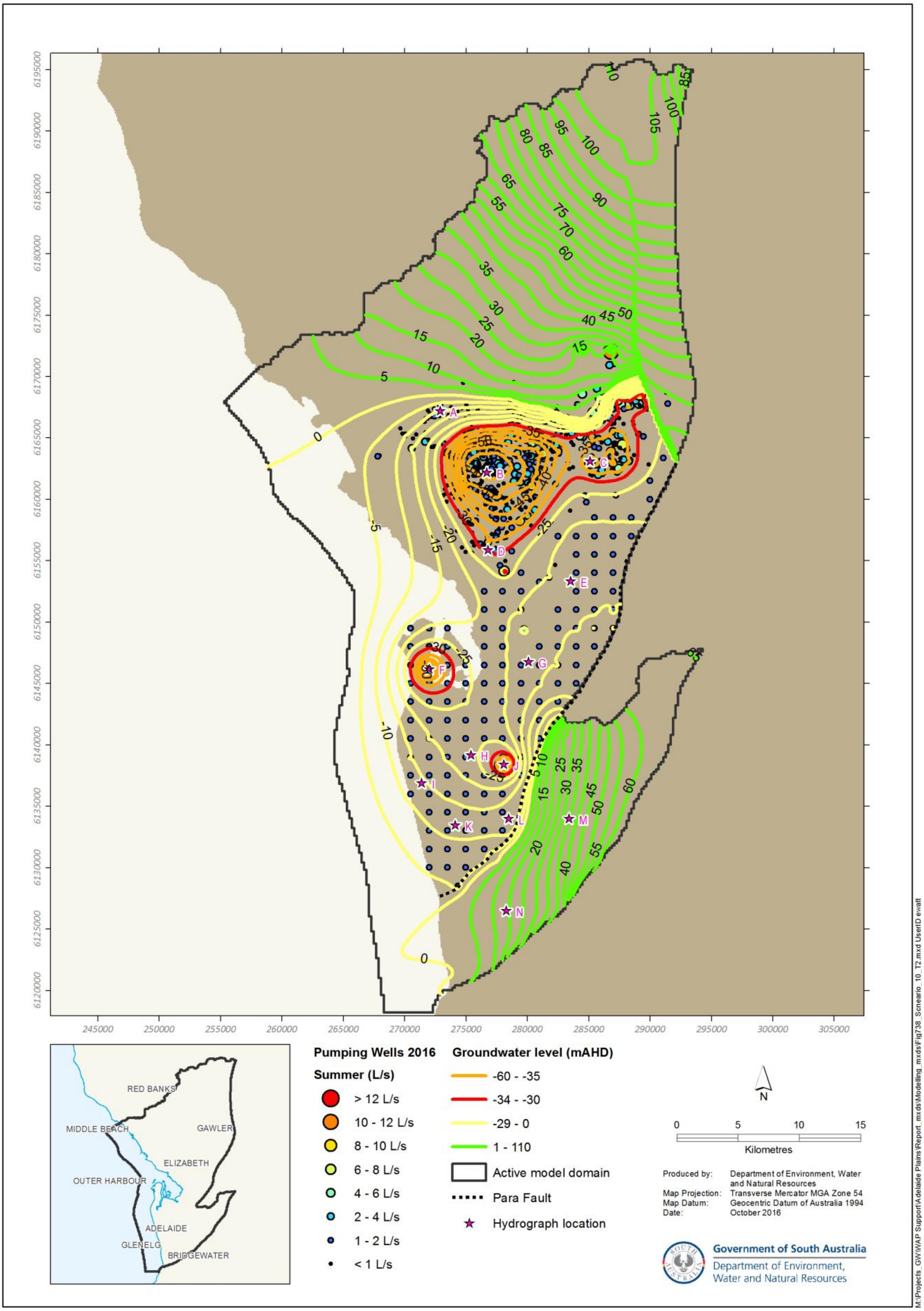

Figure 7.38 Scenario 10 – Maximum groundwater pressure levels after 30 years – T2 aquifer

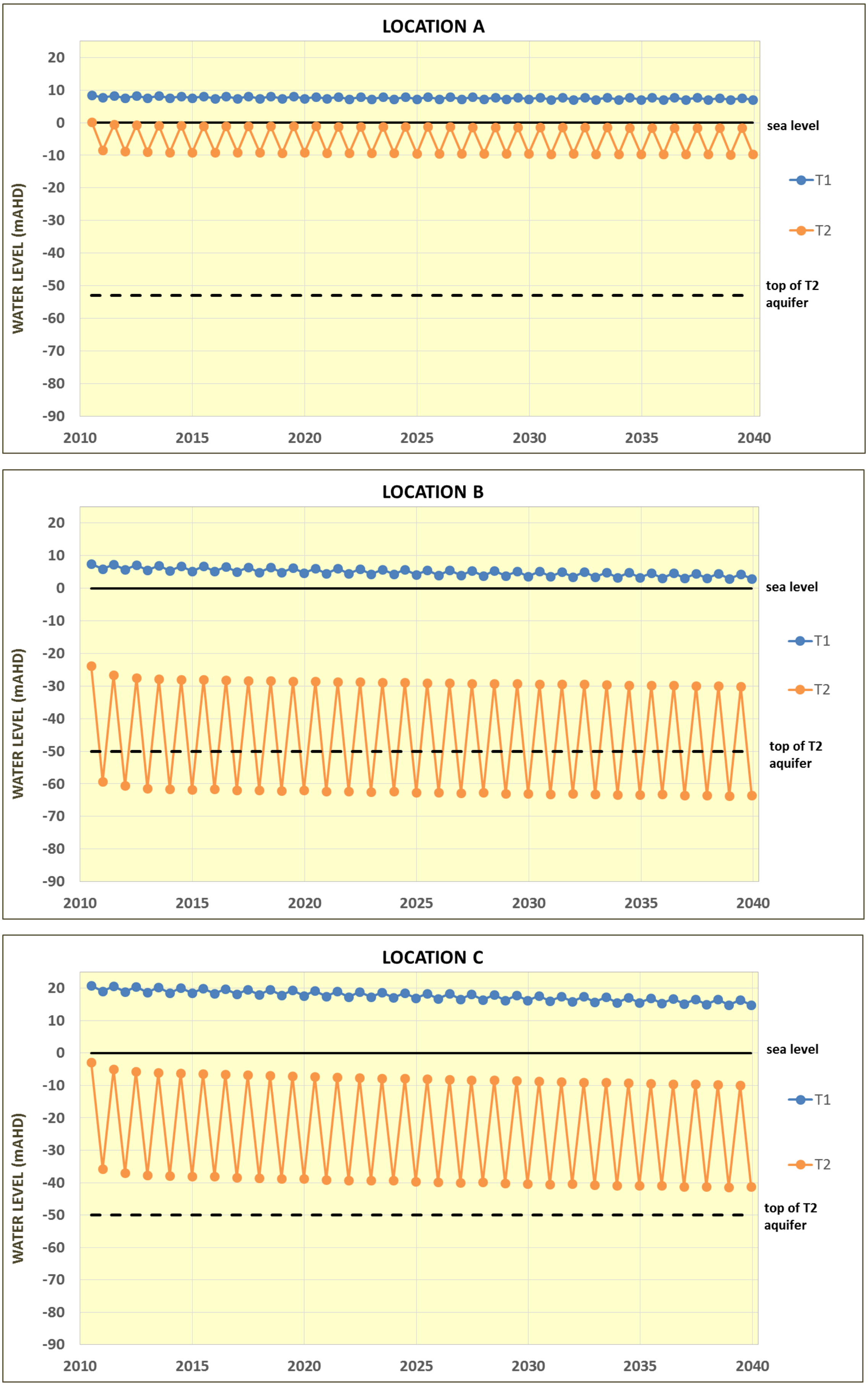

Figure 7.39 Scenario 9 – Selected hydrographs in the NAP PWA

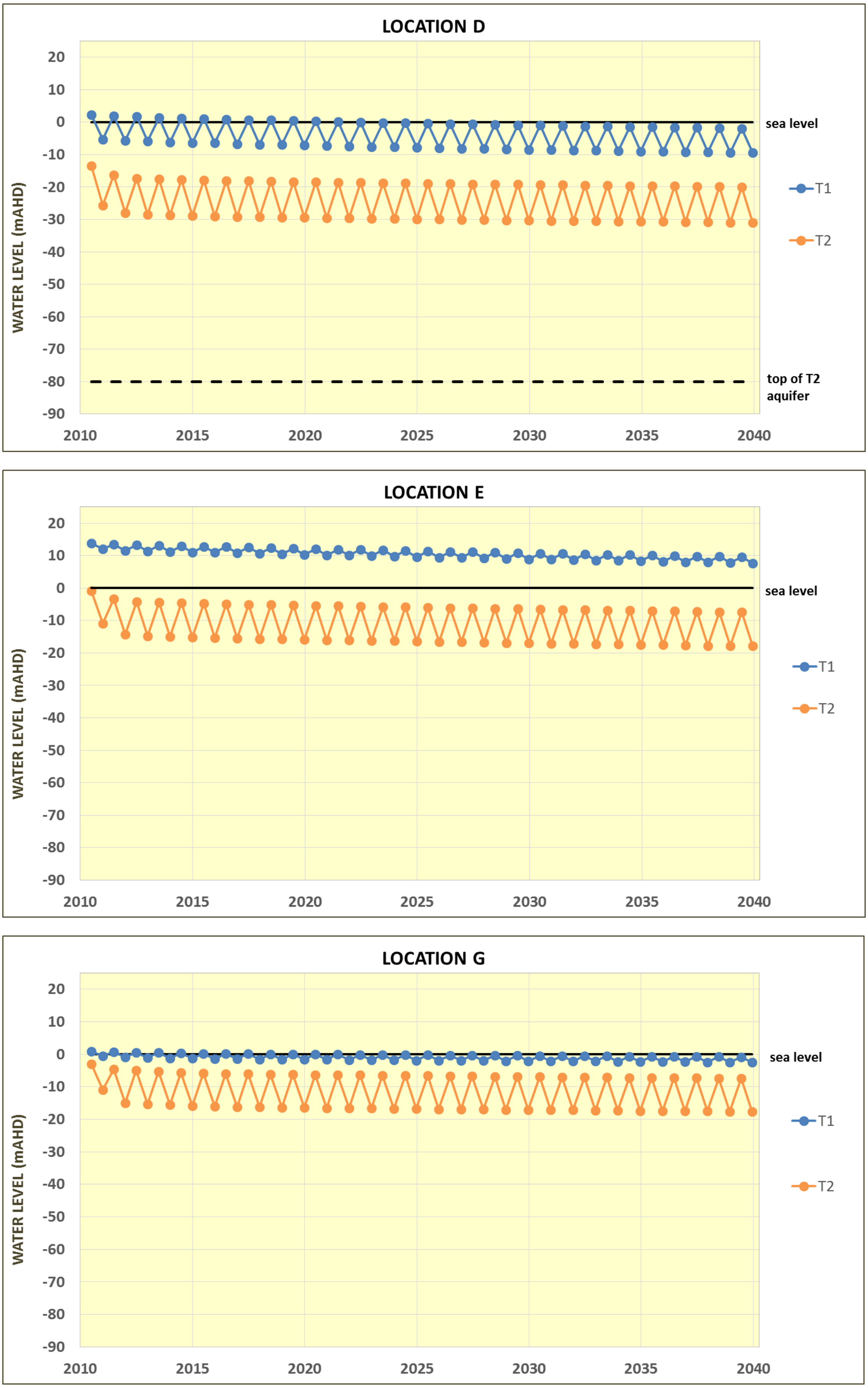

Figure 7.40 Scenario 9 – Selected hydrographs in the NAP PWA

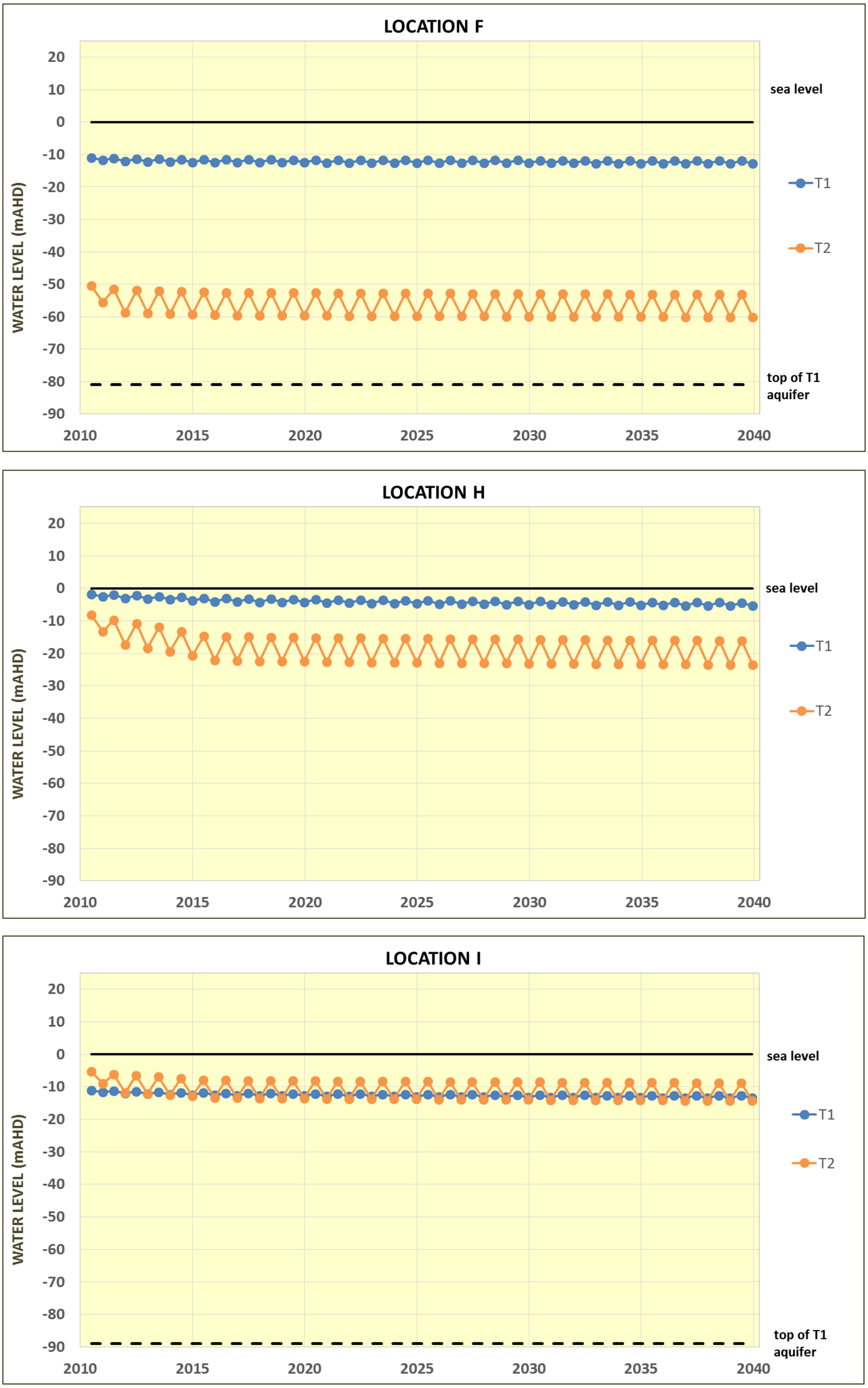

Figure 7.41 Scenario 9 – Selected hydrographs in the CA PWA

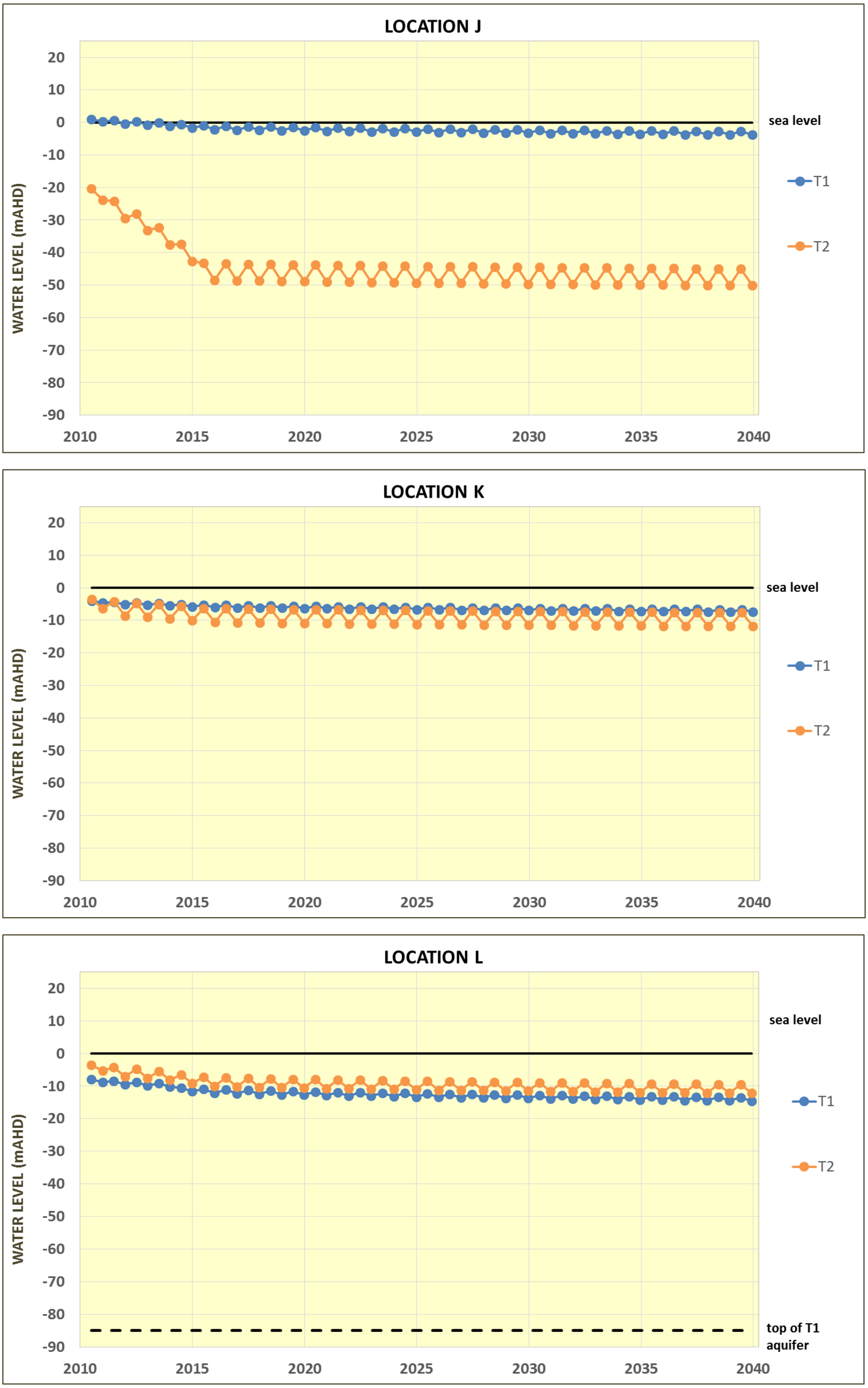

Figure 7.42 Scenario 9 – Selected hydrographs in the CA PWA

8 Units of measurement

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

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

9 Glossary

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

Aquifer — an underground layer of rock or sediment that holds water and allows water to percolate through

Aquifer, confined — aquifer in which the upper surface is impervious (see '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

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

Artesian — an aquifer in which the water surface is bounded by an impervious rock formation; the water surface is at greater than atmospheric pressure, and hence rises in any well which penetrates the overlying confining aquifer

Baseflow — the water in a stream that results from groundwater discharge to the stream; often maintains flows during seasonal dry periods and has important ecological functions

Basin — the area drained by a major river and its tributaries

Bore — see 'well'

Buffer zone — a neutral area that separates and minimises interactions between zones whose management objectives are significantly different or in conflict (e.g. a vegetated riparian zone can act as a buffer to protect the water quality and streams from adjacent land uses)

Catchment — that area of land determined by topographic features within which rainfall will contribute to run-off at a particular point

CMB — chloride mass balance

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

Confining layer — a rock unit impervious to water, which 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)

Domestic purpose — the taking of water for ordinary household purposes; includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares

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

Ecosystem services — all biological, physical or chemical processes that maintain ecosystems and biodiversity and provide inputs and waste treatment services that support human activities

Environmental water provisions — that part of environmental water requirements that can be met; what can be provided at a particular time after consideration of existing users' rights, and social and economic impacts

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

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

GDE — groundwater-dependent ecosystem

Geological features — include geological monuments, landscape amenity and the substrate of land systems and ecosystems

Geomorphic — related to the physical properties of the rock, soil and water in and around a stream

Geomorphology — the scientific study of the landforms on the Earth's surface and of the processes that have fashioned them

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

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

Habitat — the natural place or type of site in which an animal or plant, or communities of plants and animals, live

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

Intensive farming — a method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or mechanical means

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

Irrigation season — the period in which major irrigation diversions occur, usually starting in August–September and ending in April–May

Lake — a natural lake, pond, lagoon, wetland or spring (whether modified or not) that includes part of a lake and a body of water declared by regulation to be a lake. A reference to a lake is a reference to either the bed, banks or shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land — whether under water or not and includes an interest in land and any building or structure fixed to the land

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

Licensee — a person who holds a water licence

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

MAR — managed aquifer recharge (MAR) is a process where water is intentionally placed and stored in an aquifer for later human use, or to benefit the environment.

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 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

Monitoring well — a narrow well or piezometer whose sole function is to permit water level measurements

NAP — Northern Adelaide Plains

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

Natural resources — soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems

NRM — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

NWC — National Water Commission

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

Piezometer — a narrow tube, pipe or well; used for measuring moisture in soil, water levels in an aquifer, or pressure head in a tank, pipeline, etc.

Potable water — water suitable for human consumption such as drinking or cooking water

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

Production well — the pumped well in an aquifer test, as opposed to monitoring wells; a wide-hole well, fully developed and screened for water supply, drilled on the basis of previous exploration wells

PWA — Prescribed Wells Area

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

Recommended extraction limit — the volume of extraction for consumptive use that can be sustained over time to keep the system from exceeding resource condition limits

Resource condition indicator — bio-physical indicators that track the response of the groundwater system to various stresses such as extraction, land-use change or climate change (e.g. decreased recharge). Typically parameters that can be directly monitored, such as groundwater levels or salinity, but can also be derived from other field observations, such as estimates of groundwater discharge into watercourses (baseflow), or estimates of aquifer storage.

Resource condition limit — the acceptable levels of change to the condition of the system, with reference to resource condition indicators

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

Stock use — the taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act)

Stormwater — run-off in an urban area

Sub-catchment — the area of land determined by topographical features within which rainfall will contribute to run-off at a particular point

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Sustainability — the ability of an ecosystem to maintain ecological processes and functions, biological diversity and productivity over time

SWL — depth to groundwater below the natural ground surface

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

Tertiary aquifer — a term used to describe a water-bearing rock formation deposited in the Tertiary geological period (1–70 million years ago)

To take water — from a water resource includes (a) to take water by pumping or siphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir

Transfer — a transfer of a licence (including its water allocation) to another person, or the whole or part of the water allocation of a licence to another licensee or the Minister under Part 5, Division 3, s. 38 of the Act, the transfer may be absolute or for a limited period

Transmissivity (T) — a parameter indicating the ease of groundwater flow through a metre width of aquifer section (taken perpendicular to the direction of flow), measured in m^2/d

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

Volumetric allocation — an allocation of water expressed on a water licence as a volume (e.g. kilolitres) to be used over a specified period of time, usually per water use year (as distinct from any other sort of allocation)

Water affecting activities — activities referred to in Part 4, Division 1, s. 9 of the Act

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

Water allocation, area based — an allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water-use year

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

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-dependent ecosystems — those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems

Water licence — a licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area; this grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water; a water licence confers a property right on the holder of the licence and this right is separate from land title

Water plans — the State Water Plan, water allocation plans and local water management plans prepared under Part 7 of the Act

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

Water resource monitoring — an integrated activity for evaluating the physical, chemical, and biological character of water resources, including (1) surface waters, groundwaters, estuaries, and near-coastal waters; and (2) associated aquatic communities and physical habitats, which include wetlands

Water-use year — the period between 1 July in any given calendar year and 30 June the following calendar year; also called a licensing year

Well — (1) an opening in the ground excavated for the purpose of obtaining access to underground water; (2) an opening in the ground excavated for some other purpose but that gives access to underground water; or (3) a natural opening in the ground that gives access to underground water

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