South East confined aquifer modelling investigations – Kingston groundwater management area

DEWNR Technical report 2015/48

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

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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

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Summary

The South East Natural Resources Management Board (SENRMB) administers allocation of groundwater from the unconfined and confined aquifers in the Lower South East of South Australia through the Lower Limestone Coast Water Allocation Plan (LLCWAP). The current LLCWAP (2013) includes an allocation limit of 40 GL/y for the Kingston confined aquifer management area. However groundwater extraction in the Kingston area (based on metered data) is only 8–15 GL/y.

Natural Resources South East have commissioned the Department of Environment, Water and Natural Resources (DEWNR) to assess what impact extraction of 40 GL/y from the Tertiary confined sand aquifer (TCSA) in the Kingston area management area would have on groundwater resource condition. This has been done using a numerical groundwater flow model originally developed by Brown (2000). The SENRMB has also requested that DEWNR provide advice on alternative management targets for the TCSA, to replace the current approach of assessing groundwater resource condition against trigger-level rates of groundwater level decline.

The results show that extraction of 40 GL/y in the Kingston confined aquifer management area is likely to have a negative impact on the condition of the groundwater resource in this area. This is expressed in groundwater-level declines that exceed the current trigger-level rate of decline (declines of >0.1 m/y). More importantly though, extraction of 40 GL/y in Kingston leads to a reduction in artesian pressure in the TCSA, which is a key characteristic of the TCSA in this area, and what makes it a valuable resource.

A further model scenario where extraction was set at 25 GL/y in Kingston did not show declines that exceeded the trigger level. However the modelling showed that extraction of 25 GL/y was likely to have some impact on the extent of artesian pressure in the TCSA in Kingston during the irrigation season. This discrepancy between trigger level impact and resource condition impact opens a discussion about the suitability of current groundwater management principles in this area.

It is recommended that groundwater resource condition limits are determined for the TCSA in this area. This process should involve consultation with key stakeholders and groundwater users (primarily irrigators in the region). It is likely that acceptable resource conditions will be based around maintaining artesian pressures in the TCSA in Kingston so that current irrigation practices can continue. However further work and community consultation will be required to determine:

- what level of impact on the TCSA is acceptable
- where impact should be measured (eg. which observation wells are critical to monitor)
- how management arrangements can be developed around maintaining acceptable resource condition.

1 Introduction

1.1 Policy background

The South East Natural Resources Management Board (SENRMB) administers allocation of groundwater from the unconfined and confined aquifers in the Lower South East of South Australia through the Lower Limestone Coast Water Allocation Plan (LLCWAP). The current LLCWAP was adopted in November 2013.

The current LLCWAP (2013) included a conversion of the amount of groundwater allocated from area-based estimates (hectare irrigation equivalents (haIE) allocations) to volumetric allocations. Through the volumetric conversion process, target management level (TML) allocations from the confined aquifer in the Kingston management area were set at 40 GL/y, much higher than the previously used permissible annual volume (PAV) of 25 GL/y. The previously set PAV was based on scenario modelling using a numerical groundwater-flow model of the confined aquifer in the South East (Brown, 2000; Harrington and Brown, 2005).

Metered groundwater extraction data started to become available in the South East around 2007. Data suggested groundwater use from the confined aquifer in the Kingston management area was only 8–15 GL/y. Hence it is not known if extraction of 40 GL/y from the confined aquifer in the Kingston management area would have an adverse effect on groundwater resource condition.

Owing to this discrepancy between metered use (up to 12 GL/y) and the TML of more than 40 GL/y, the LLCWAP (2013, Section 4.6) stated that it would "*run the numerical confined aquifer underground water flow model within two years of adoption date of the Plan, with varying scenarios of extraction, to determine an appropriate TML for the Kingston management area. If required, the Board will recommend that the Minister amend the Plan in order to incorporate the new TML.*"

In addition to assessing the potential impact of 40 GL/y extraction from the TCSA in Kingston, the SENRMB wishes to explore alternative arrangements for managing groundwater resources in the TCSA. Under current arrangements, condition of the groundwater resource is assessed by hydrograph trend analysis. The trigger for assessing resource condition in the TCSA is where hydrographs show declining trends of >0.1 m/y over a five year period. If groundwater levels are declining at a rate >0.1 m/y in a particular management area, no further allocations are granted in that management area, and further monitoring of the resource is required. However hydrograph trend analysis on its own does not necessarily reflect groundwater resource condition.

An alternative approach is water level response management. In this approach – key values or conditions of the groundwater resource are determined in consultation with the users of the resource. Target levels (groundwater levels) that the resource needs to be kept at to maintain the resource condition are then specified (McIntyre and Wood, 2011). Groundwater modelling can then be used to assist making decisions as to what level of groundwater extraction can be supported while maintaining resource condition. An example resource condition target for the Kingston confined aquifer management area may be maintaining artesian pressure in the confined aquifer, so that current irrigation practices can continue.

1.2 Objectives

The aim of this project is to perform the groundwater modelling exercise stipulated in Section 4.6 of the LLCWAP (2013). An additional aim is to discuss the implications of this work for possible alternative management approaches for the confined aquifer (e.g. water level response management). Specifically this report aims to:

1. Evaluate the suitability of different models for the confined aquifer in the LLCPWA (ie. the previously used groundwater model for the confined aquifer in the LLC PWA (Brown, 2000) or the new groundwater model of the LLCPWA (Morgan et al., 2015)).
2. Incorporate new metered groundwater extraction data into the model and check calibration to measured groundwater levels.
3. Run scenarios for groundwater extraction of 15, 25 and 40 GL/y in the Kingston confined aquifer management area.
4. Asses the simulated impact of these extraction volumes on the confined aquifer, including the simulated impact upon (1) groundwater levels in confined aquifer observation wells (trigger level trends); (2) extent of the artesian zone in the confined aquifer.
5. Discuss the implications of these model scenarios in terms of alternative management approaches (water level response management).

2 Hydrogeological background

2.1 Location

The LLCPWA occupies 14 500 km^2 in the south east of South Australia. However the domain of the groundwater models used in this study occupy a larger area, encompassing both the Murray and Otway Basins, and extending into western Victoria where these Basins are bounded by the Dundas Plateau (Figure 2.1). The Kingston confined aquifer management area occupies 2188 km^2 in the LLCPWA, and includes the coastal townships of Kingston SE and Robe (Figure 2.1).

2.2 Climate

The climate in the study area is Mediterranean with hot dry summers and cool wet winters. Average annual rainfall varies from 835 mm/y in the elevated Mount Burr Ranges (east of Millicent) to 450 mm/y in Bordertown. Average annual rainfall in Kingston SE is 587 mm/y – however contemporary rainfall in Kingston does not have a direct influence upon the groundwater resources in the Kingston confined aquifer management area, as will be discussed further below.

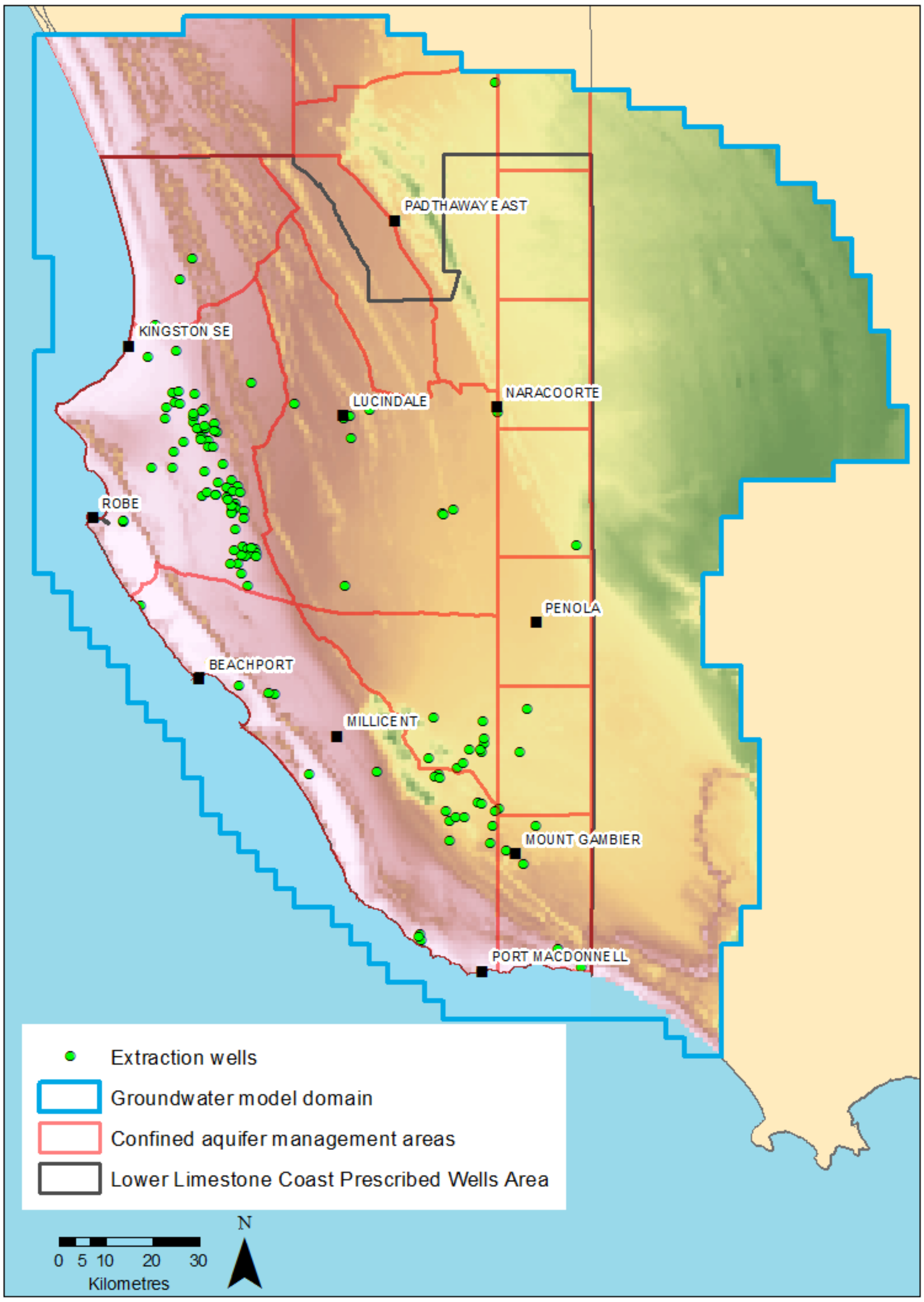


Figure 2.1 The Lower Limestone Coast Prescribed Wells Area in the Lower South East of South Australia.
Also shown is the domain of the groundwater model used in this study.

2.3 Regional hydrogeology

The hydrogeology of the South East, in particular the Lower Limestone Coast PWA, has been documented in great detail (Harrington and Lamontagne, 2013). Two regionally extensive aquifer units occupy the area: an upper unconfined Tertiary limestone aquifer (TLA), and a lower Tertiary confined sand aquifer (TCSA). The two units are separated regionally by a clay aquitard. Groundwater flow in both aquifer units is generally from the east to the west – towards the sea. South of Mount Gambier groundwater flows to the south to south-west, towards the Southern Ocean (Figure 2.2).

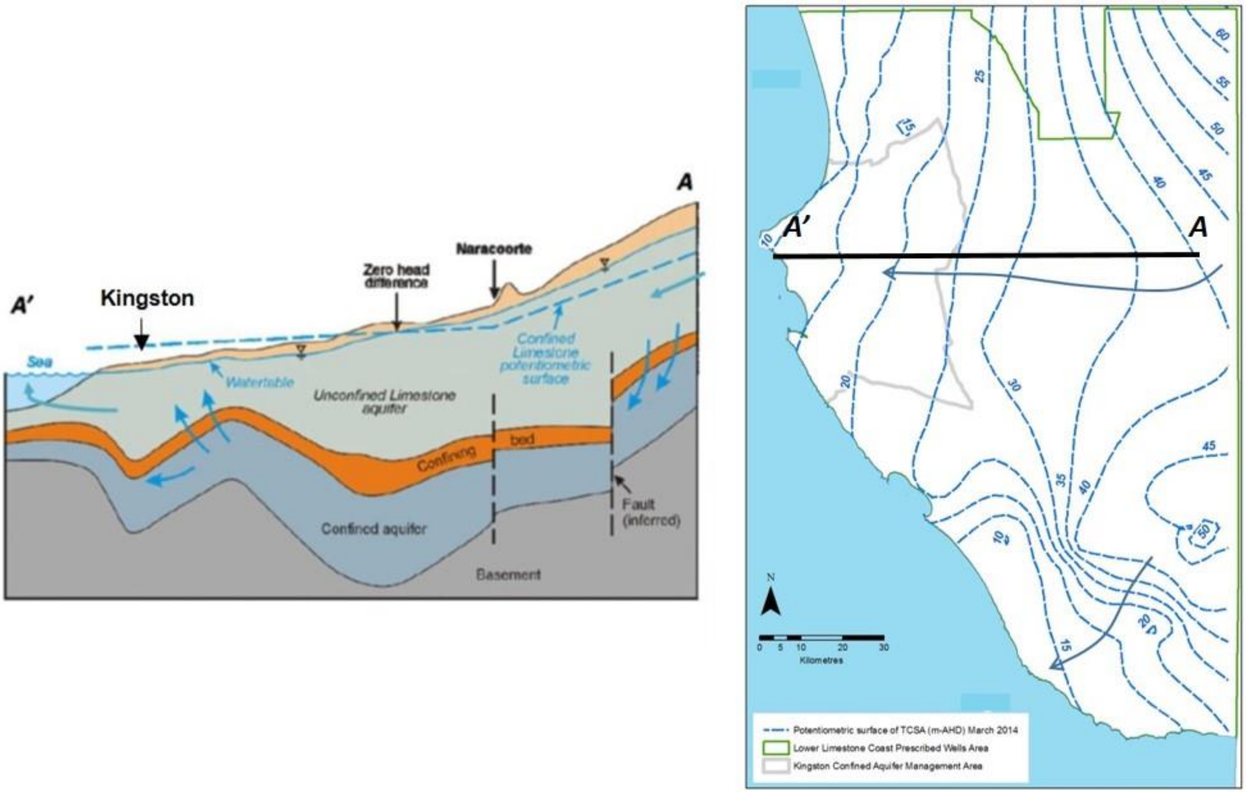


Figure 2.2 Regional hydrogeology and groundwater flow towards the Kingston confined aquifer management area
– where the potentiometric surface of the confined aquifer becomes artesian (cross section adapted from Love et al., 1994). The map on the right shows potentiometric contours for the TCSA measured at March 2014.

Recharge to the TLA occurs across the region, primarily via diffuse rainfall infiltration. Recharge to the TCSA is thought to occur in western Victoria in the Dundas Plateau, and also via leakage from the unconfined aquifer, in areas where the potentiometric surface in the confined aquifer is lower than the unconfined aquifer (Love et al., 1994; Harington et al., 1999). This area is east of the zero-head difference (ZHD), an interpolated line which marks a change in the hydraulic gradient between the two aquifers (Figure 2.3). Much of the recharge to the confined aquifer (from the unconfined aquifer) is thought to occur preferentially via faults and fractures (Brown et al., 2001).

Figure 2.3 Location of the zero head difference (ZHD)
as shown by Love et al., (1994) and more recently Morgan et al., (2015). Also shown are TCSA observation wells used in model calibration.

2.4 Project region hydrogeology

The primary area of interest in this study is the Kingston confined aquifer management area. This area is west of the ZHD where the potentiometric surface in the TCSA is higher than the TLA. For much of area (excluding the topographic highs of remnant dune ranges) the potentiometric surface in the TCSA is artesian (greater in elevation than the ground surface). This means groundwater wells in the TCSA do not require pumps to extract groundwater. The extent of artesian conditions based on measured groundwater levels is shown in Figure 2.4. Here measured TCSA pressures are subtracted from the surveyed elevation at the observation point – if the result is positive then the TCSA is artesian (ie. TCSA pressure > ground surface elevation). The contoured extent of artesian conditions is based on the data available for 2014 (the observation wells shown). Figure 2.4 also shows the extent of artesian conditions at 2014 derived from both groundwater models assessed in this study (discrepancies will be discussed later in the report under Section 3 – Groundwater Model Selection).

Artesian conditions and generally good groundwater quality (salinity ~ 500–1000 mg/L) have made the confined aquifer a reliable source of irrigation water in this area (with groundwater extraction (based on metered data) of around 8–15 GL/y (Harrington and Li, 2013; LLCWAP, 2013).

Love et al., (1994) measured carbon-14 in the confined aquifer along the transect shown in Figure 2.2. The results showed carbon-14 activities decreasing monotonically west of the ZHD, reaching estimated ages of 12 000–20 000 years in the Kingston confined aquifer management area. The interpretation is that no recharge to the TCSA occurs west of the ZHD (with the decrease in carbon-14 being due to radioactive decay as groundwater flows west).

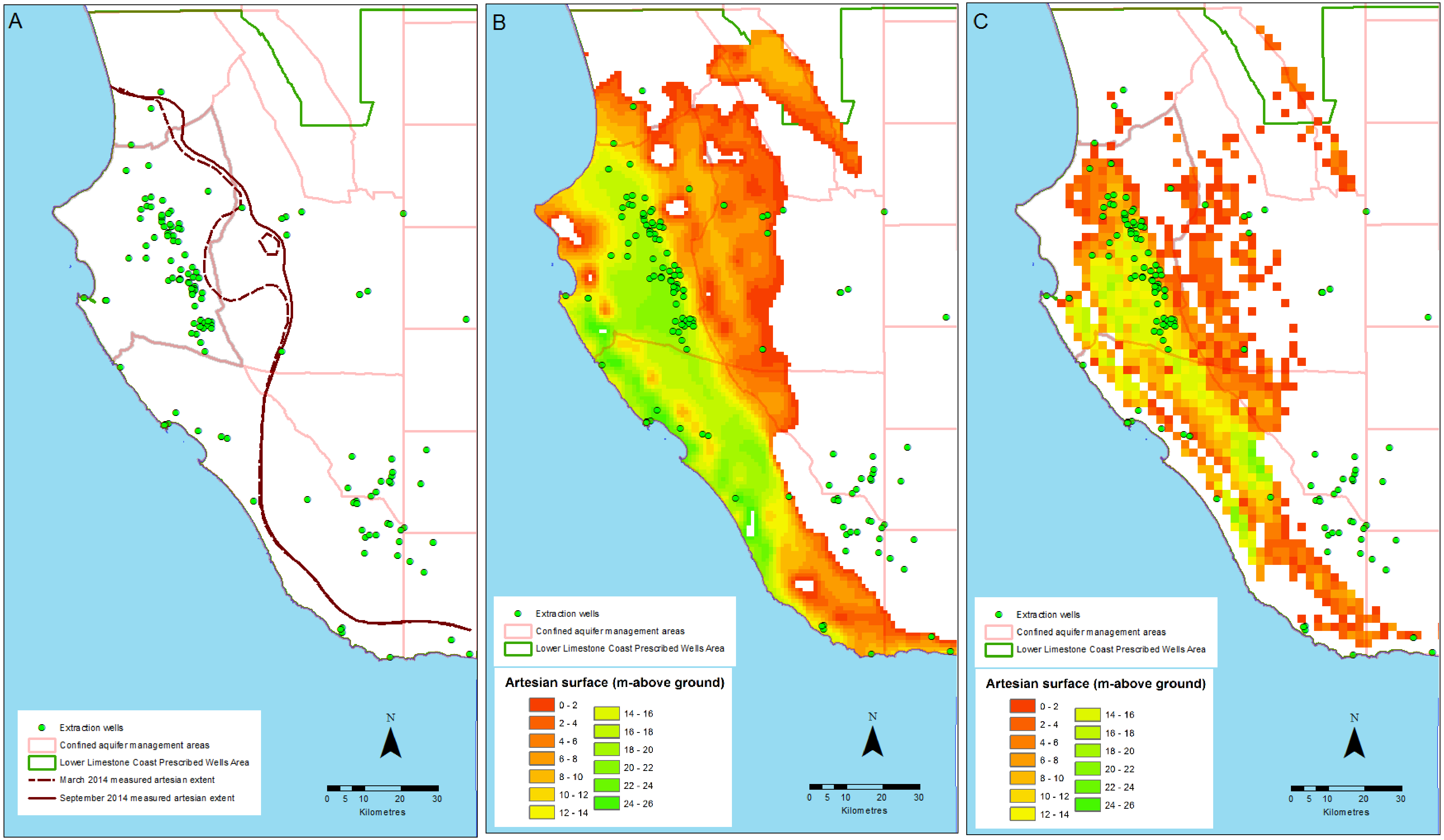


Figure 2.4 Extent of artesian conditions in the TCSA
Based on:
(A) measured groundwater pressure at March and September 2014,
(B) modelled groundwater pressure from the Brown (2000) model at March 2014
(C) modelled groundwater pressure from the Morgan et al. (2015)

2.5 Groundwater level trends in the TCSA

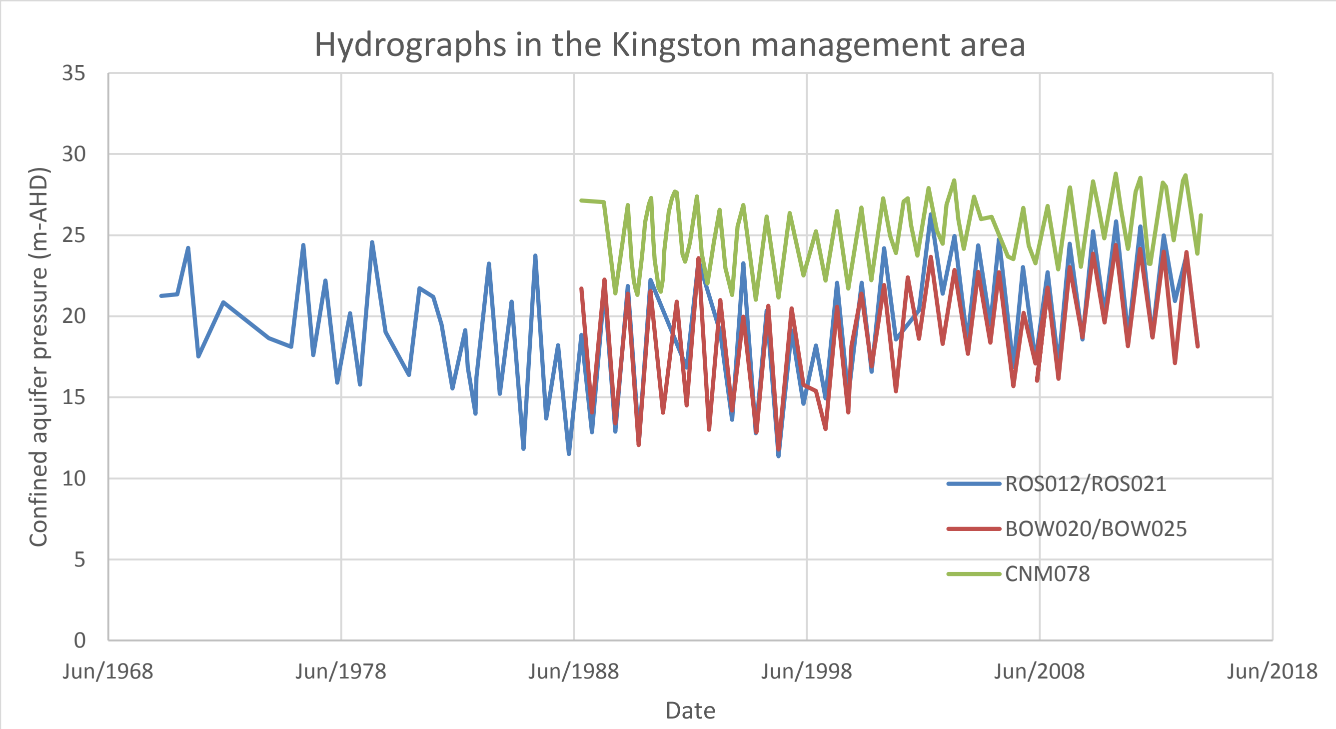


Figure 2.5 Confined aquifer trends in the Kingston management area

Hydrographs in the Kingston management areas are generally influenced by seasonal groundwater extraction (Figure 2.5). Seasonal fluctuations of between 5 to 10 m are frequently observed, owing to the large volumes of water extracted over the irrigation season, generally over summer. Also the results of pumping test analysis generally yield low aquifer storage coefficient values (~ 10^{-7}, Osei-Bonsu and Dennis, 2004) thereby contributing to the magnitude of seasonal fluctuations.

Longer term trends are observed in hydrographs in the TCSA in the Kingston area as well. For example the hydrographs in Figure 2.5 all show a rising trend, and reduction in the amount of seasonal fluctuation from the late 1990s onwards. These trends can be attributed to rehabilitation of leaking artesian bores during this period, and subsequent recoveries in artesian pressure. Hydrographs in the past five years have been consistent with seasonal fluctuations and no overall declining or rising trend. Seasonal fluctuation will vary from year to year in response to annual variations in extraction, which is now apparent with metered groundwater extraction data becoming available.

Elsewhere in the LLCPWA hydrograph trends for the TCSA are either static or showing some declines (DEWNR, 2013). In some cases these declines may be influenced by hydrostatic unloading - pressure changes in response to watertable fluctuations in the overlying TLA. This is discussed further in Appendix A.

In summary pressure trends in the TCSA are influenced by different factors across the LLCPWA. Where extraction is high (eg. Kingston), seasonal fluctuations are large, however recoveries in pressure have been observed in response to rehabilitation of leaky bores, generally from the late 1990s onwards. The large seasonal fluctuations mask any hydraulic loading/unloading that may be occurring in response to overlying TLA trends. Elsewhere it's possible that trends in the unconfined aquifer, driven by reduced rainfall, recharge interception and direct extraction by forestry, have influenced trends in the confined aquifer via hydrostatic unloading. However these effects are likely to be localised (see Appendix A).

3 Groundwater model selection and updates

3.1 Model selection

An important component of this project was selecting an appropriate groundwater model to perform the scenario analysis. There are two models which simulate regional groundwater flow in the TCSA: a model developed by Brown (2000) to assist in determining permissible annual volumes (PAVs) of groundwater extraction from the confined aquifer; and a model developed by Morgan et al., (2015) to assist in constraining the regional water balance in the LLCPWA.

The model developed by Brown (2000) was a three-layer model (Layer 1 – TLA; 2 – aquitard; layer 3 – TCSA) which used a 4 km x 4 km grid. The model was calibrated to groundwater levels within the confined aquifer only. The calibration was adequate and the model replicated groundwater behaviour (large seasonal fluctuations in areas of extraction, Figure 3.1) in the confined aquifer reasonably well. Considering the computational limits at the time the model was developed, it was a fit for purpose approach to determining the impact of extraction scenarios and recommending PAVs.

The Brown (2000) model was not calibrated to groundwater levels in the TLA. Rather this layer of the model was parameterised such that modelled groundwater levels were kept relatively constant (at an arbitrary level) during calibration, so that variation in modelled TLA heads would not interfere with the TCSA pressures when they were subjected to extraction. Again, while it was a fit for purpose model for examining the influence of extraction on TCSA pressures, the lack of calibration to TLA pressures makes it unsuitable for investigating the influence of extraction on the location of ZHD.

As part of the Goyder Institute for Water Research program, a new regional groundwater model for the LLCPWA was developed by Morgan et al., (2015). This model used a 1km x 1 km grid, and both the TLA and the TCSA are explicitly modelled. Consequently it is able to simulate the location of ZHD with more accuracy. However while the model developed by Morgan et al., (2015) represents an important step forward in modelling groundwater processes, unconfined/confined aquifer interactions and the regional scale groundwater balance, it was not fully calibrated to either groundwater fluctuations (seasonal fluctuations) or trends in the confined aquifer, particularly in the Kingston confined aquifer management area (Figure 3.2). Both models capture the approximate extent of the artesian limit in the TCSA (Figure 2.4).

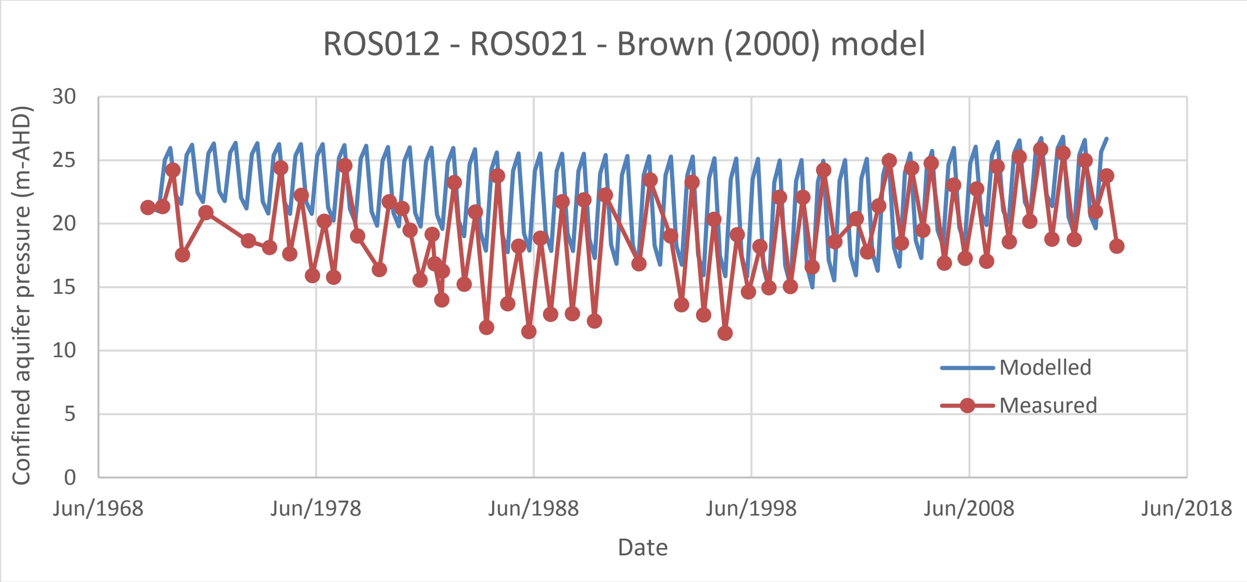


Figure 3.1 Measured and modelled trends in ROS021/ROS021 (TCSA in Kingston MA) from the Brown (2000) model, showing reasonable match to seasonal extraction. Note observation well ROS012 was replaced by ROS021 (located 15m away) in 2003.

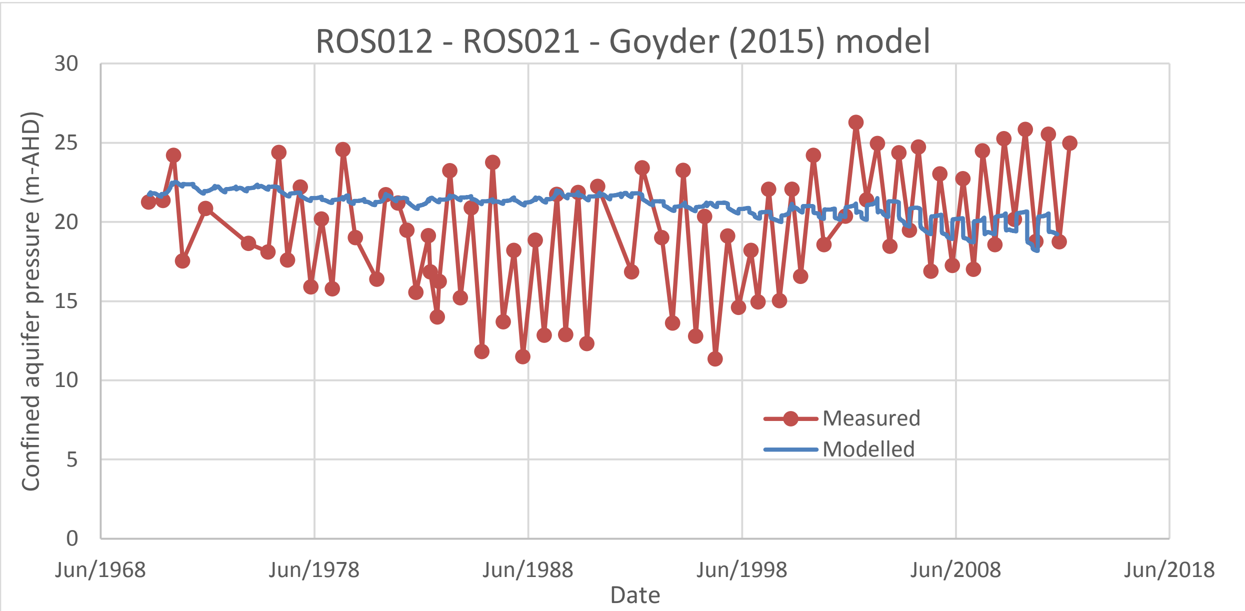


Figure 3.2 Measured and modelled trends in ROS021 (TCSA in Kingston) from the Morgan et al., (2015) model, showing poor match to seasonal extraction.

Given that the purpose of this project is to assess the impact of increased groundwater extraction on the TCSA, a model which better matches the dynamic behaviour of the TCSA and its response to extraction historically is more suitable. For this reason, the model developed by Brown (2000) was chosen for use in this project.

3.2 Model refinement and updates

The model used in this project was calibrated by Brown (2000), and revisited by Harrington and Brown (2005) with additional calibration (including optimisation of hydraulic conductivity values using PEST (Doherty 2010)). Calibration statistics are considered good in line with Australian Groundwater Model Guidelines (Barnett et al., 2012; root mean squared error (RMSE) ~ 2.9 m, normalised RMSE of 6.7% at the time step representing March 2005 reported by Harrington and Brown (2005).

As part of this project the model grid was refined from 4 km x 4 km to 1 km x 1 km. The newly refined model was re-run and had an RMSE of 3.5 m at March 2005 (compared to 2.9 m reported by Harrington and Brown (2005), Figure 3.3). Overall (for all observation times) the model RMSE was 4.25m (RMS 7.8%).

The model was then extended to run to 2014 with a revised extraction schedule. The revised extraction schedule incorporated metered groundwater extraction data from 2009–10 to 2012–13 (extraction for 2013–14 was based on an average of these years). Historical extraction rates were generally based on rates previously used by Harrington and Brown (2005), the reasons for this are further discussed in Appendix B. The model of Harrington and Brown (2005) included rehabilitation of leaking TCSA bores by assigning a constant discharge rate for these bores (to simulate leakage) from their date of construction to their date of rehabilitation. Simulation of bore rehabilitation after 2005 was based on the groundwater extraction data set generated by Morgan et al., (2015). Calibration statistics at March 2014 were similar to March 2005 (RMSE 3.45 m, Figure 3.4). Further calibration plots for individual hydrographs can be found in Appendix C.

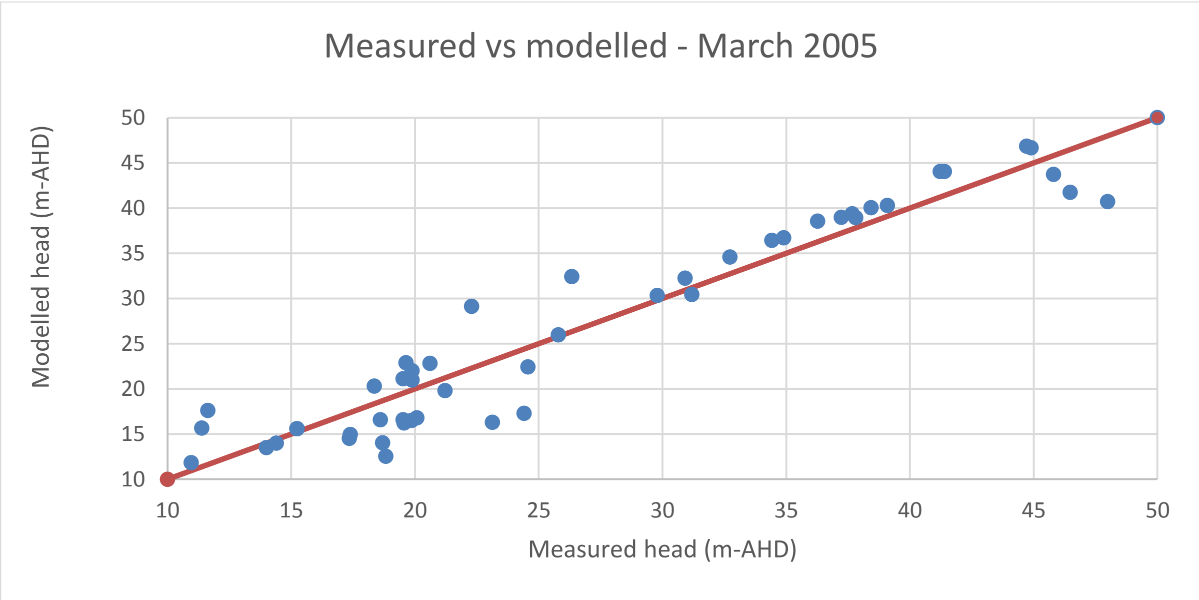


Figure 3.3 Measured vs. modelled TCSA pressure levels at March 2005 (RMSE 3.5 m)

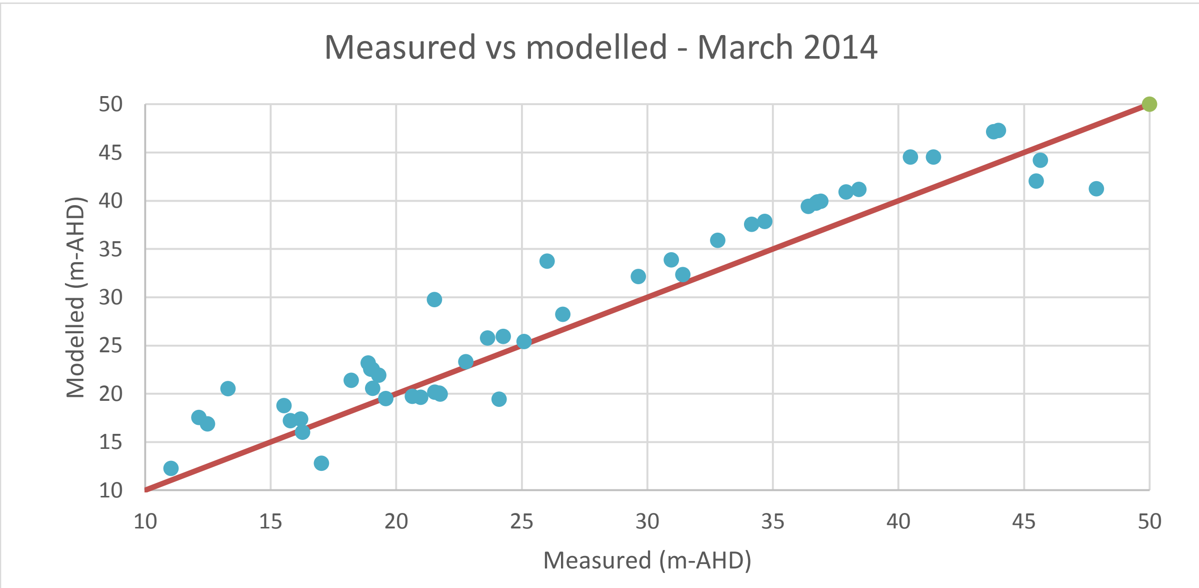


Figure 3.4 Measured vs. modelled TCSA pressure levels at March 2015 (RMSE 3.45 m)

Figure 3.4 (and individual hydrograph plots in Appendix C) show the groundwater model over-predicts levels somewhat consistently in some areas (where measured levels range from 30–40 m AHD). A key reason for this is that pressures in some parts of the TCSA have declined since 2005 in response to hydraulic unloading (groundwater level declines in the overlying TLA as described in Appendices). However the model of Brown (2000) does not explicitly simulate conditions in the TLA (no variation in recharge, extraction or changes in land use, and no calibration to TLA levels). Therefore it is not expected that the model accurately simulate levels influenced by hydrostatic unloading. The cause of some hydrograph trends outside of the Kingston management area is unclear and has not been investigated in this study (e.g. BEN013 and KEN019, see Appendix C). Re-calibration of the model was beyond the scope of this project, and the model is considered fit for purpose for assessing the impact of different extraction scenarios in the Kingston management area. Nevertheless further calibration of the model may help improve some of these issues.

As shown earlier in Figure 2.4 there are discrepancies between the extent of artesian pressures shown by the Brown (2000) model and the Morgan et al., (2015) model. This is mainly due to differences in the ground surface elevations in the two models. The model of Morgan et al., (2015) assigned elevations to each 1 km x 1 km cell based on mean values derived from a regional digital elevation model (DEM). When the Brown (2000) was refined in this study – these values were imported in order to assign a more accurate elevation (more accurate than that of the original 4 km x 4 km cell model). However the default option for importing elevation data in Visual MODFLOW is to perform an interpolation (e.g. kriging or nearest neighbour interpolation) of the data. Consequently the surface elevation in the refined Brown (2000) model has a 'smoother' ground surface elevation. The difference between the elevations in the two models is presented in Appendix D. The greatest areas of error are in the dune ranges (higher elevations assigned in the Morgan et al., 2015 model). Thus the artesian extents presented in the scenario results in this report (based on the model of Brown, 2000) should only be considered indicative, and not definite. Modelled changes in the extent of artesian pressure should be considered relative.

4 Predictive modelling scenarios

4.1 Methods

Four scenarios have been run to investigate the impact of levels of groundwater extraction in the Kingston management area on the condition of the groundwater resources in the confined aquifer. The scenarios are each run from 2014 to 2050, and differ only in their groundwater extraction data, where:

- Scenario 1 sets groundwater extraction rates from each of the wells at the average value from the last four years of metered data. This is considered a base case run, that is current conditions continue until 2050. Total groundwater extraction from the Kingston management area in this scenario is 10.7 GL/y.
- Scenario 2 increases total extraction in the Kingston management area to 15 GL/y. This is achieved by multiplying the extraction rate from each well by a constant factor (1.4) from 2014 onwards.
- Scenario 3 increases total extraction in the Kingston management area to 25 GL/y. This is achieved by multiplying the extraction rate from each well by a constant factor (2.34) from 2014 onwards.
- Scenario 4 increases total extraction in the Kingston management area to 40 GL/y. This is achieved by multiplying the extraction rate from each well by a constant factor (3.73) from 2014 onwards.

Multiplying extraction rates from each individual well by a constant factor is not necessarily the most realistic scenario for future groundwater extraction. However for assessing the impact of increases in groundwater extraction in this study it is considered suitable.

4.2 Results

The results of each scenario (presented on the following pages) are expressed in the following ways:

1. A map showing the extent of artesian conditions (areas where the confined aquifer is artesian) at the end of the irrigation season at the end of the scenario (i.e. at March 2049). As maintenance of artesian pressures for groundwater extraction is considered a key value of the confined aquifer in Kingston, a suitable Target Management Level would ideally maintain this condition (ie. artesian wells remain artesian throughout the irrigation season).
2. Seasonal drawdown at the end of the scenario (ie. drawdown from September 2048 to March 2049). This reflects why there is a change in artesian conditions shown, by demonstrating the amount of seasonal drawdown induced by increased extraction in each scenario.
3. Leakage from the overlying aquitard into the Kingston management area, as calculated by the Zone Budget (Harbaugh, 1990) tool in each scenario. As the model is not calibrated to unconfined aquifer levels, it is not possible to accurately calculate a change in the zero head difference for each scenario. However, induced downward leakage from the aquitard in the Kingston management area indicates that seasonal drawdown is sufficient to change the modelled hydraulic gradient – which indicates that a significant change in the location of the zero head difference is likely to occur. This could potentially have a negative impact upon the quality of the groundwater resource if there is high salinity water in the aquitard (downward leakage of high salinity water). Love et al., (1996) measured chloride concentrations in the aquitard of up to 6000 mg/L, however these measurements were made east of the zero head difference, and no known measurements of aquitard pore water salinities have been made in the Kingston area.
4. Modelled hydrographs at representative observation wells in the Kingston management area. These demonstrate the seasonal drawdown and how it varies across the management area, and they are also

used to calculate the trend in each scenario, for comparison with current management triggers (ie. groundwater declines > 0.1 m/y).

Scenario 1 - Base case, current extraction continues to 2050

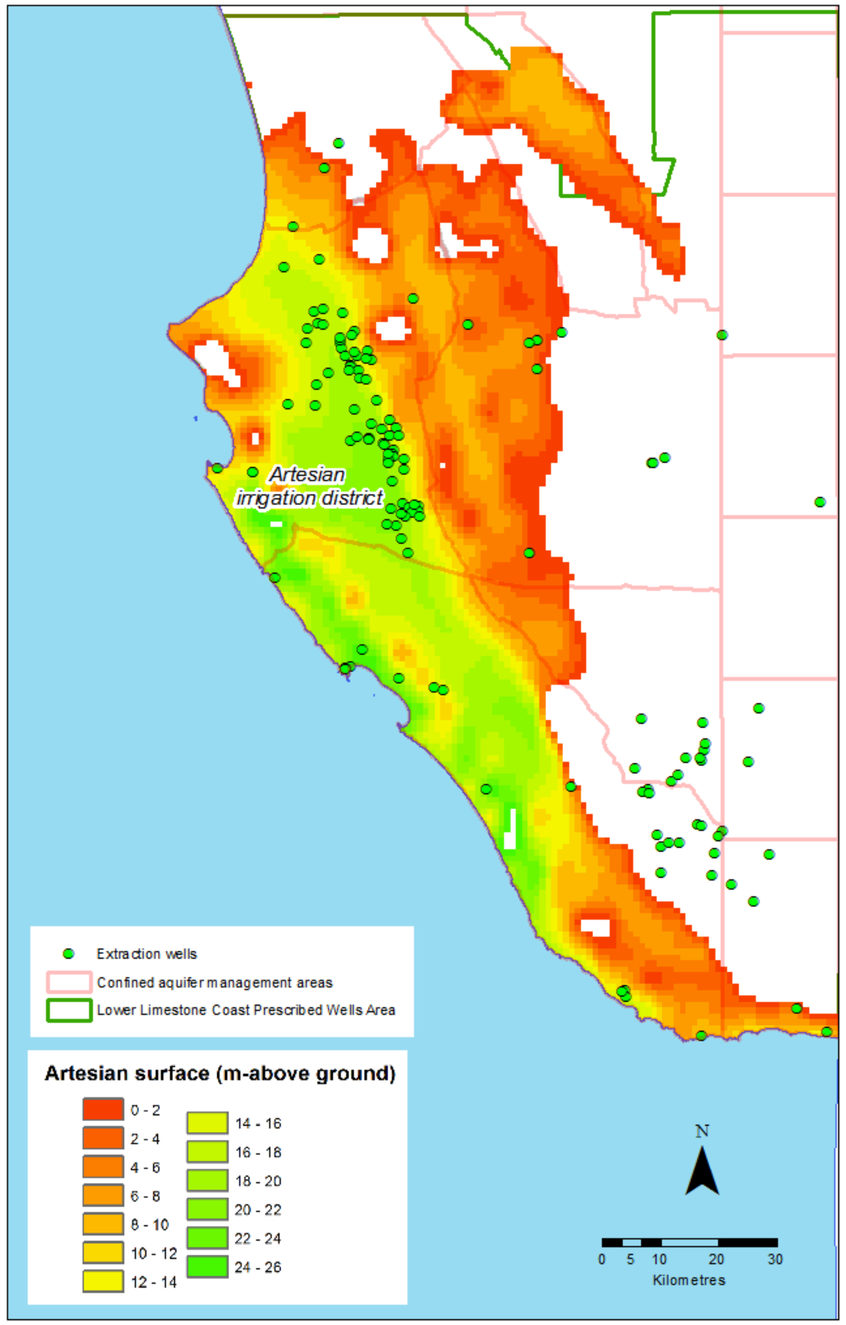


Figure 4.1 Extent of artesian conditions at March 2049 (end of irrigation season) for Scenario 1.

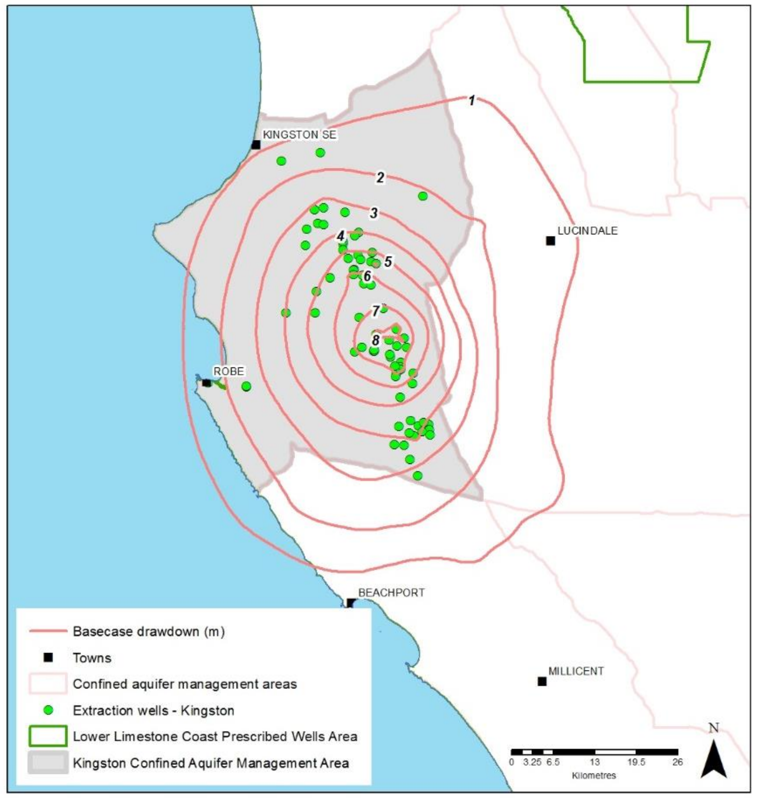


Figure 4.2 Seasonal drawdown in the TCSA in Scenario 1 (difference in groundwater pressure level between September and March)

Scenario 1 continues extraction at the average rate (from the last four years of metered extraction) until 2050 (35 years). Artesian extent remains unchanged at the end of the irrigation season – i.e. artesian wells would still flow through irrigation season. There is no change in the magnitude of seasonal drawdown, and hydrographs are stable or show recovery.

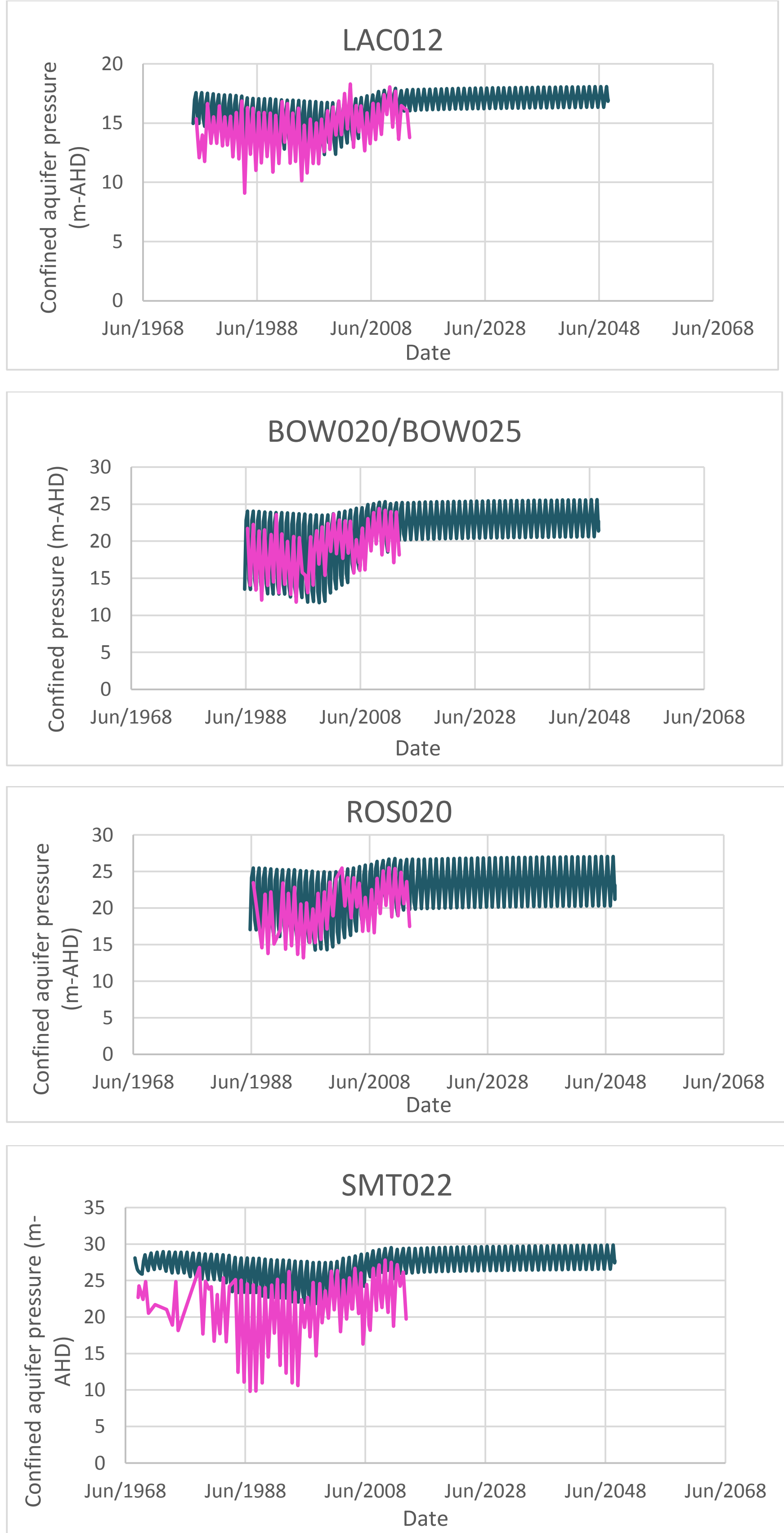


Figure 4.3 Groundwater trends at key observation bores in the Kingston management area in Scenario 1 (pink – measured, blue – modelled).

Scenario 2 – Extraction of 15 GL/y to 2050

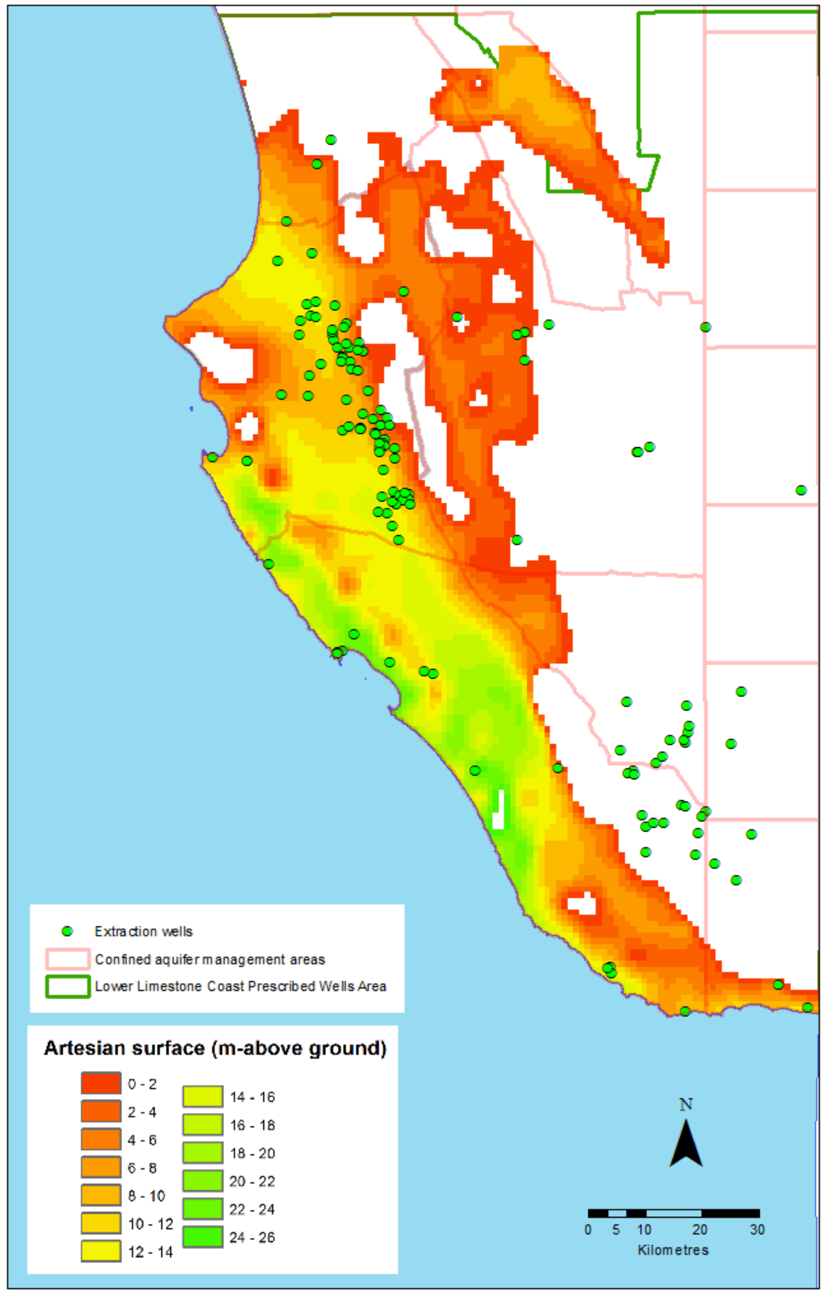


Figure 4.4 Extent of artesian conditions at March 2049 (end of irrigation season) for Scenario 2

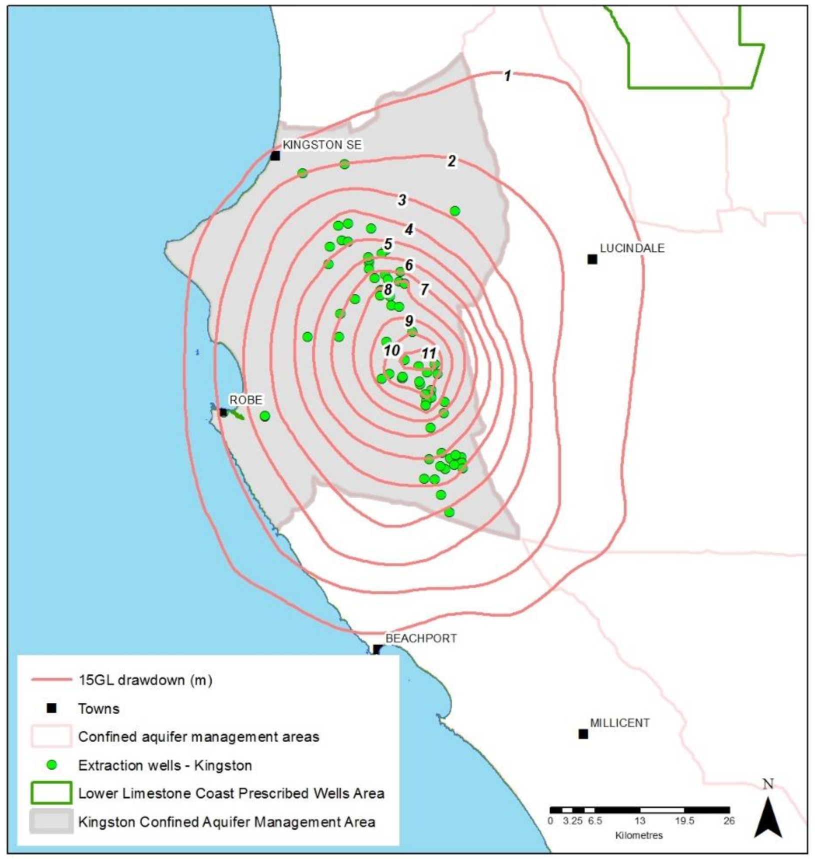


Figure 4.5 Seasonal drawdown in the TCSA in Scenario 2 (difference in groundwater pressure level between September and March)

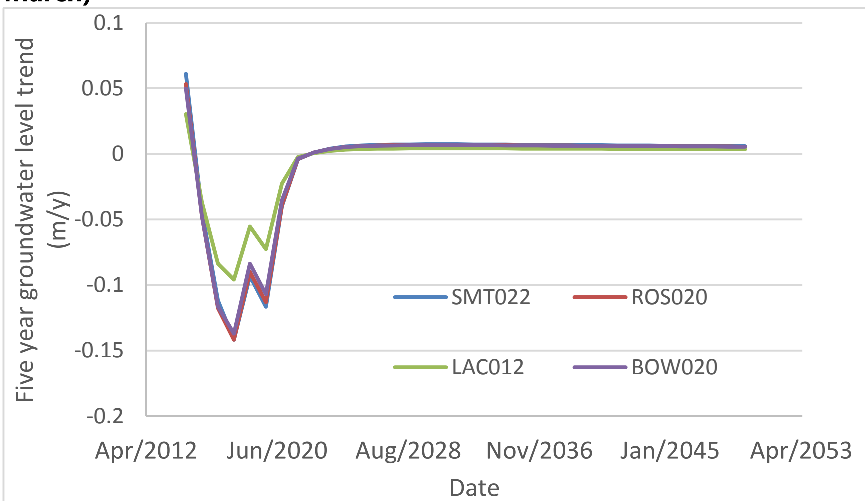


Figure 4.6 Five year groundwater level trends for Scenario 2, 2014 onwards

Scenario 2 increases extraction in Kingston to 15 GL/y until 2050 (35 years). Trigger levels are exceeded from 2016–19, and the artesian extent begins to shrink at end of irrigation season – however not into the zone where most extraction wells are located. Hence most artesian wells would likely still flow throughout irrigation season.

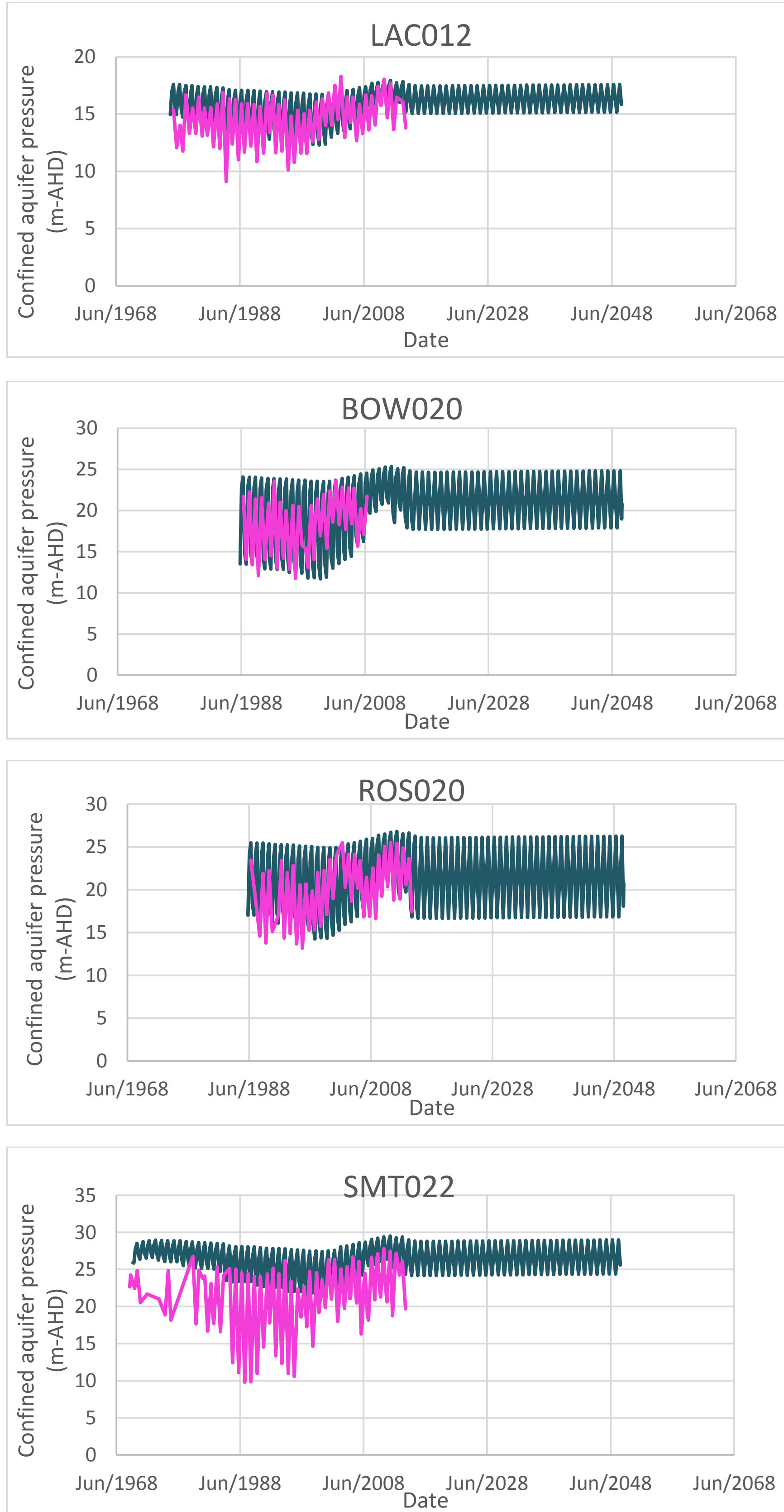


Figure 4.7 Groundwater trends at key observation bores in the Kingston management area in Scenario 2 (pink – measured, blue – modelled)

Scenario 3 – Extraction of 25 GL/y to 2050

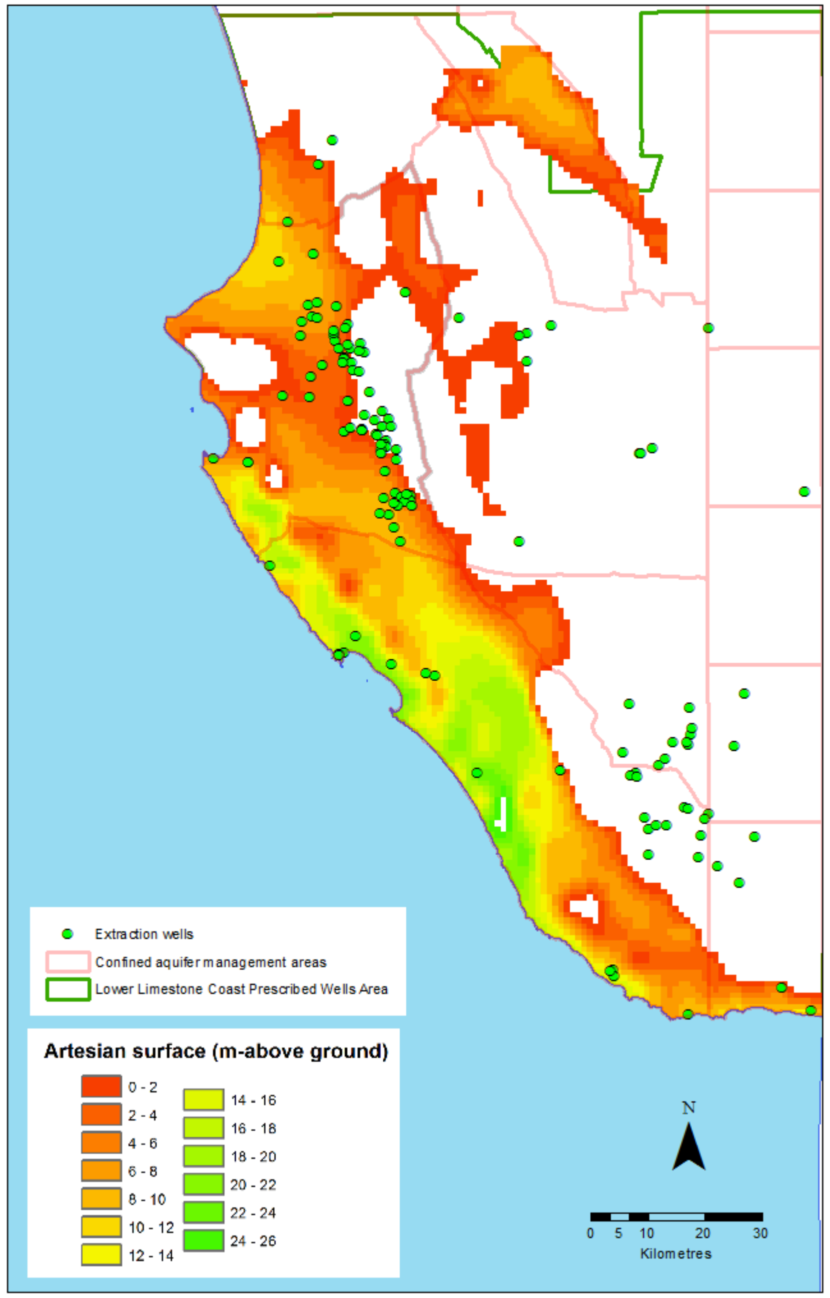


Figure 4.8 Extent of artesian conditions at March 2049 (end of irrigation season) for Scenario 3

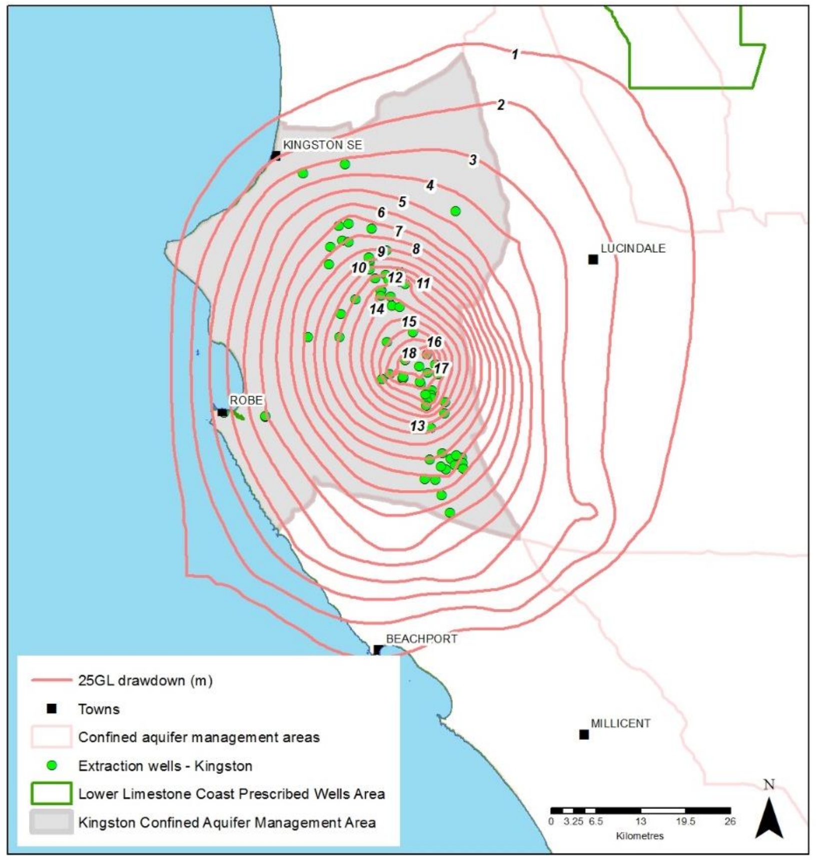


Figure 4.9 Seasonal drawdown in the TCSA in Scenario 3 (difference in groundwater pressure level between September and March)

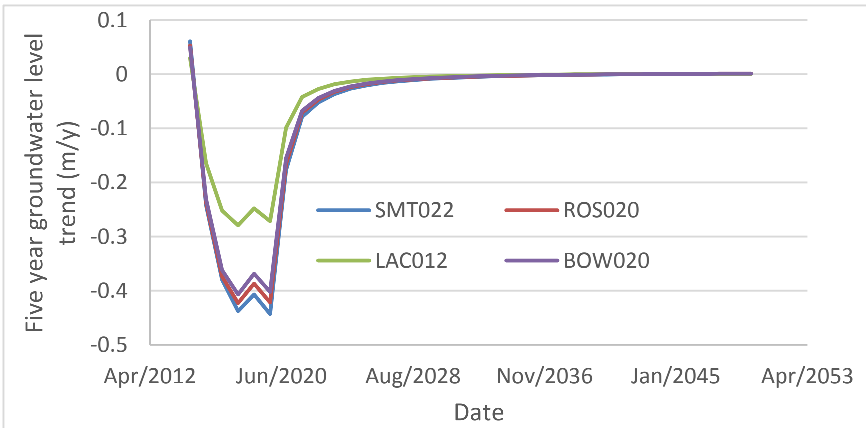


Figure 4.10 Five year groundwater level trend for Scenario 3, 2014 onwards

Scenario 3 increases extraction in Kingston to 25 GL/y until 2050 (35 years). Trigger levels are exceeded from 2015 until 2021. The artesian extent at the end of the irrigation season in March 2049 starts to show impact, and the seasonal cone of drawdown grows. This would likely have an impact upon flowing wells in some parts of the management zone. However after 2021, a new dynamic steady state is reached in terms of seasonal recoveries, and thus triggers are not exceeded from 2021–50. In other words a trigger is not reached in terms of water level decline, but there's likely to be an impact upon artesian conditions during the irrigation season, which would impact upon irrigation practices

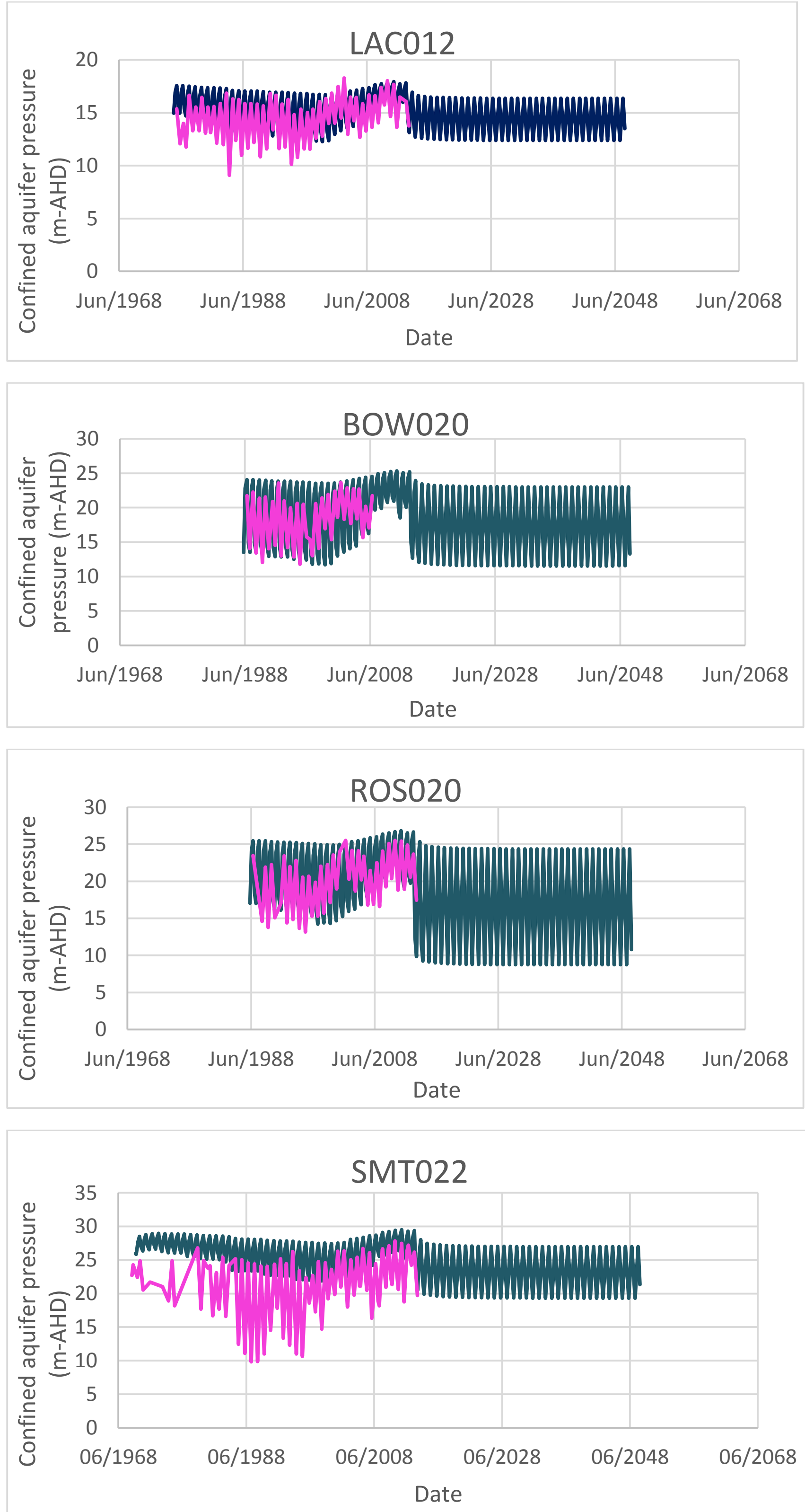


Figure 4.11 Groundwater trends at key observation bores in the Kingston management area in Scenario 3 (pink – measured, blue – modelled)

Scenario 4 – Extraction of 40 GL/y to 2050

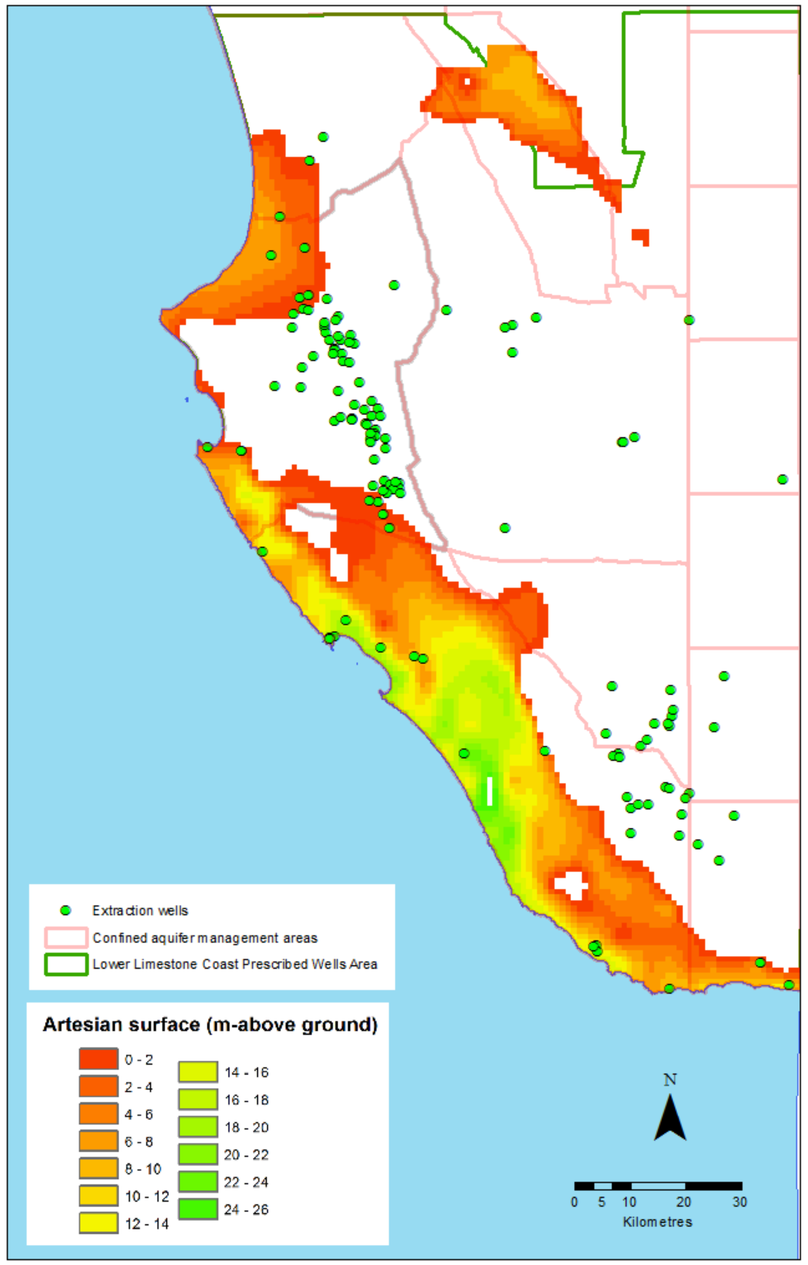


Figure 4.12 Extent of artesian conditions at March 2049 (end of irrigation season) for Scenario 4

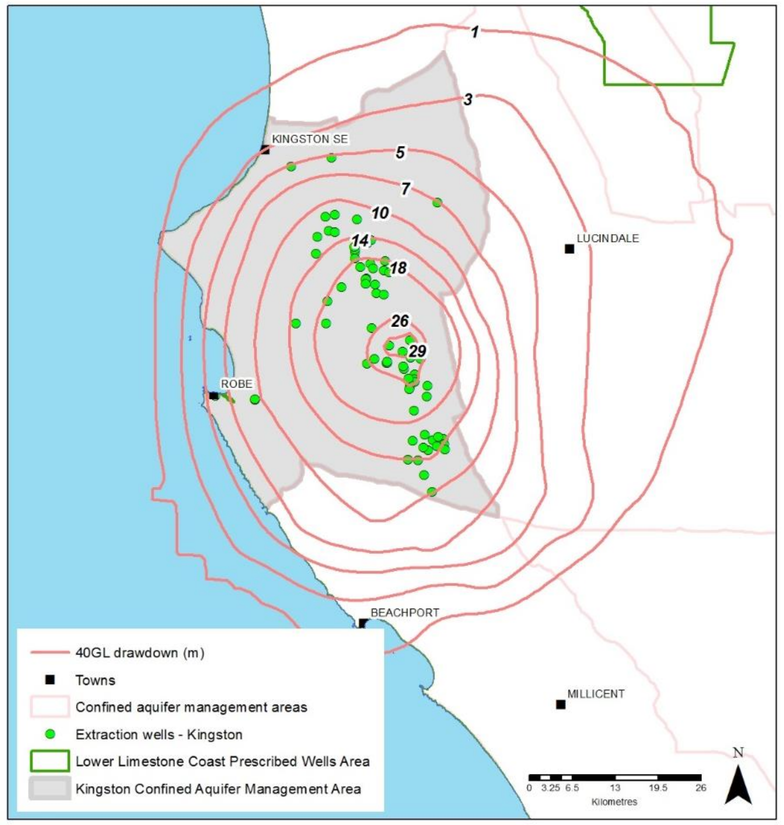


Figure 4.13 Seasonal drawdown in the TCSA in Scenario 4 (difference in groundwater pressure level between September and March)

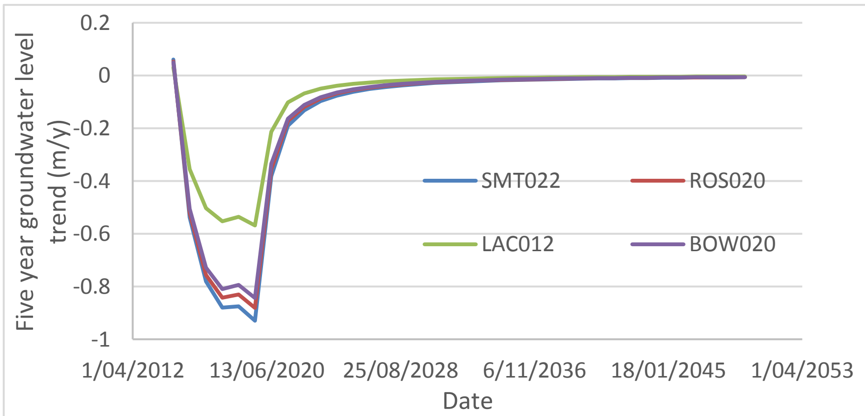


Figure 4.14 Five year groundwater level trends for Scenario 4, 2014 onwards

Scenario 4 increases extraction to 40 GL/y in the Kingston management area until 2050. Extent of artesian conditions is almost completely depleted from Kingston at end of the irrigation season, and seasonal drawdown grows even larger (drawdown of up to 29 m in the highest area of extraction). Trigger levels are exceeded from 2015–22, after which triggers are not exceeded. However given the simulated impact on artesian conditions during irrigation season, it can be concluded that trigger levels do not provide an accurate long term picture of resource condition.

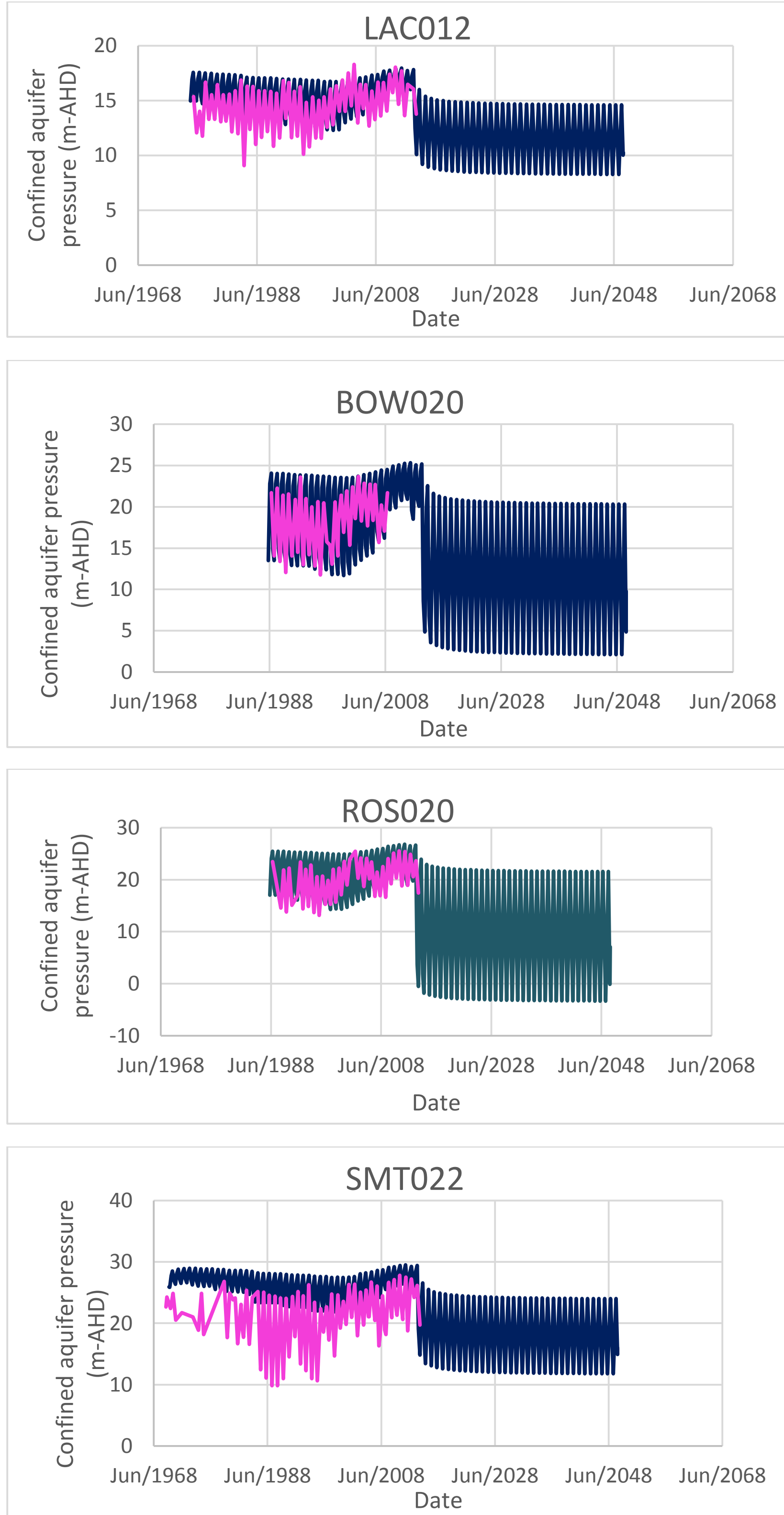


Figure 4.15 Groundwater trends at key observation bores in the Kingston management area in Scenario 4 (pink – measured, blue – modelled)

4.3 Summary of scenarios

4.3.1 Scenario 1

Scenario 1 simulates continued extraction in the Kingston at the current rate (the average extraction based on the last four years of metered extraction data) from 2015 to 2050. Hydrographs remain stable and seasonal drawdown remains the same (maximum drawdown of ~8 m in the eastern part of the Kingston management area). The extent of the artesian zone at the end of the irrigation season (March) each year remains the same as it is currently.

4.3.2 Scenario 2

Scenario 2 simulates extraction in Kingston increasing to 15 GL/y at 2015 through to 2050. Hydrographs show lower recovery levels, however drawdown levels are not as large as those observed historically. Maximum seasonal drawdown is ~11 m, which depletes artesian conditions in part of the Kingston management area, however most of the irrigation district remains artesian.

4.3.3 Scenario 3

Scenario 3 simulates extraction in Kingston increasing to 25 GL/y at 2015 through to 2050. Hydrographs start to show longer term declines that approach trigger levels (declines of 0.06 m/y) and maximum seasonal drawdown is greater than has been observed historically (seasonal drawdown of up to 18 m). This results in loss of artesian pressure in part of the irrigation district.

4.3.4 Scenario 4

Scenario 4 simulates extraction in Kingston increasing to 40 GL/y at 2015 through to 2050. Hydrographs show long declines that exceed the current trigger level (declines of up to 0.15 m/y), and maximum seasonal drawdown is much greater than observed historically (seasonal drawdown of up to 29 m). This seasonal drawdown results in loss of artesian pressure in almost the entire Kingston management area at the end of the irrigation season.

5 Performance of model scenarios against currently used targets and recommendations on new resource conditions targets

5.1 Currently adopted allocation and management targets

Allocations from the confined aquifer were originally based on estimates of lateral groundwater throughflow, determined by Sinclair Knight Merz in 1998 for the Department of Natural Resources and Environment in Victoria (Brown, 2000). Based on scenario analysis, Brown (2000) recommended allocations from the confined aquifer be set at 37.5% of the estimated lateral inflow to each management zone. For the Kingston management area this was calculated to be 9.5 GL/y, however it was recommended allocation be set at 25 GL/y.

The model used in this study (updated version of Brown (2000) model) estimates lateral groundwater inflow into the Kingston area to be ~ 35.3 GL/y, 37.5% of which is ~ 13.3 GL/y, close to the originally determined 9.5 GL/y. The LLCWAP (2013) updated the allocation for the Kingston management area to 40 GL/y following volumetric conversion, and states that the resource condition trigger for decline of the groundwater in the confined aquifer is an average potentiometric level decrease of >0.1 m/y over the preceding five years. This means that where hydrographs show a declining trend over five years of > 0.1 m/y, further allocation may not be approved in the management area, and the resource should be monitored further.

5.2 Model performance against current management targets

One of the key features of the groundwater resources in the TCSA in Kingston is artesian pressure. Combined with low salinity, it makes the aquifer highly valuable for irrigation, as groundwater supply is not reliant upon the cost of running and maintaining pumps for extraction. For Scenario 4 (40 GL/y extraction), the model shows that artesian conditions are generally lost during the irrigation season when extraction in Kingston is 40 GL/y. However five year groundwater trends show declines of > 0.1 m/y initially during this scenario (2015-2022), but as a new dynamic steady state is reached, trigger levels are not exceeded (2023 onwards) despite the ongoing impact on artesian pressure. These trends are based on measurements in September, when TCSA hydrographs typically rise/recover from the effects of irrigation.

For Scenario 3 (25 GL/y extraction), the model shows reduction in artesian pressure during the irrigation season, so that parts of the management zone (including areas where extraction wells are located) are no longer artesian. Again modelled groundwater levels exceed the trigger initially, before a new dynamic steady state is reached for seasonal recovery, and triggers are no longer exceeded. . Thus in both cases, while the trigger level is not being exceeded, the level of extraction is having a negative impact upon a likely key resource condition. (artesian pressures are not being maintained).

5.3 Alternative approaches to managing groundwater resource stress

The discrepancy (discussed above) between trigger levels and their expression of groundwater resource condition highlights the need to consider additional or alternative targets in managing the groundwater resource sustainably. One approach that has been trialled in the South East is defining groundwater resource values and framing management around them using Water Level Response Management (WLRM) (McIntyre and Wood, 2011). Rather than setting trigger levels based on rates of groundwater level decline (or rates of salinity increase), acceptable conditions of the resource are defined based around the resources values/attributes. Following on from this, the level or pressure at which the resource needs to be maintained to support these conditions is defined. Groundwater modelling can then help determine the level of extraction that can be sustained while maintaining these conditions. Ongoing monitoring of the resource is also key to track the response of the resource to the management arrangements and allocations determined.

Defining groundwater resource values and resource condition targets is a key step in this process. From a hydrogeological perspective, it is likely that resource condition targets in Kingston will relate to:

1. Maintaining artesian pressures in Kingston irrigation district (ie. maintain aquifer productivity) by setting target pressure levels in key observation bores that should not be exceeded (define these levels in consultation with community).
2. Maintaining the gradient between the TLA and TCSA (ie. not inducing a reversal in gradient and potential downward leakage into the TCSA in Kingston).

However defining resource condition targets should involve consultation with the users of the resource (eg. irrigators in Kingston). The consultation process would ideally seek feedback from users of the resource in response to questions such as:

- What groundwater resource conditions are acceptable?
- Have conditions been unacceptable at any point historically? If so when and what were the associated groundwater levels?
- For Kingston, is it pressure/flow/salinity?
- What is the community expectation from groundwater resource managers?
- What time scales of management are acceptable?
- Where and when should resource condition be measured?

In response to questions regarding whether the resource condition has ever been unacceptable historically, it may be possible to define a limit (a certain groundwater pressure level in the TCSA) that becomes a management target (ie. keep groundwater pressures above this level). This is difficult to determine without consulting the community, as an unacceptable condition may relate to a certain reduction in groundwater pressure that impacts on artesian bore flow in a specific area. Further work would also be required to determine where resource condition should be monitored. This means selecting appropriate observation wells, assessing their construction details and determining how representative they are.

6 Model uncertainty and limitations

The scenarios in this report were modelled using an updated version of the model of Brown (2000). A limitation identified in the original model was lack of groundwater extraction data. Four years of metered groundwater extraction data were incorporated into this model (2009–10 to 2012–13 irrigation seasons). However prior to this, groundwater extraction in the model is still based on estimated use. The way in which this was determined is discussed further in Appendix B. Given the significant influence that groundwater extraction has on hydrographs in the Kingston management area, estimated historical extraction is an obvious area of model uncertainty. The four years of metered data that are available demonstrate that extraction from a single bore may vary significantly between years. However historical groundwater extraction rates in the model are constant. Future collection of metered extraction data will improve our understanding of this variability, and help future model validation, but lack of historical extraction data will most likely remain an area of model uncertainty.

The actual impact of future groundwater extraction scenarios will depend upon spatial distribution of extraction. Our scenarios merely multiply all current extraction volumes from wells by a constant factor to obtain the desired scenario extraction volume across the Kingston management area. In reality, increases in extraction may be concentrated in particular locations, which may lead to spatially variable impacts on the extent of artesian pressure. Future measurement of metered groundwater extraction data will help build a better picture of the spatial variability of groundwater extraction in Kingston.

The TCSA is implemented in the model as one layer (of > 500 m thickness in some locations) with extraction wells that fully penetrate its thickness. In reality the TCSA is a multi-layered aquifer of inter-bedded sands and clays, and extraction wells are typically screened in sand units, which may be only 3–4 m thick (Osei-Bonsu and Dennis, 2004). This level of complexity is not captured in the model, and replicating aquifer heterogeneity at a suitable scale is a typical area of uncertainty for all groundwater models. However in spite of this, the model performs reasonably well in the Kingston area in terms of replicating the observed response in the TCSA to dynamic stresses (seasonal extraction).

The model performs poorly in some areas where hydrostatic loading/unconfined aquifer trends (particularly declines in 2000s in response to low rainfall recharge) appears to influence confined aquifer trends (this is discussed further in Appendices). As the model of Brown (2000) does not accurately simulate the TLA, it is not possible to reproduce the TCSA trends in these locations in a suitable way (i.e. without inducing drawdown via extraction – which is not thought to be the driver for these trends in the confined aquifer). The model developed Morgan et al., (2015) does model both the TLA and TCSA explicitly, therefore future refinement and calibration of this model may mean this type of model performance issue can be overcome in future.

The model used for scenario analysis here was that developed by Brown (2000). However this project also assessed the model developed by Morgan et al., (2015) for its potential use. It was found to be unsuitable without further calibration in this instance. While the reasons for this (poor calibration to seasonal fluctuations in the Kingston area) where not fully investigated and resolved, it is worth highlighting the limitation of the model here. The model of Morgan et al., (2015) represents a crucial improvement in understanding the regional scale water balance in the South East, and simulating regional scale processes and fluxes (eg. interaction between the TLA and TCSA). However future projects that aim to use it to investigate specific, sub-regional groundwater resource issues will need to understand its limitations. Further time will need to be spent in these projects refining and calibrating the model to make it fit-for-purpose in specific sub-regional investigations.

7 Conclusion and recommendations

The groundwater flow model of the TCSA in the LLCPWA originally developed by Brown (2000) has been revisited and updated. Four years of metered groundwater extraction data has been incorporated (2009–10 to 2012–13) and the model compared with the past 10 years of observation data. Four scenarios have been run to assess the impact of varying levels of groundwater extraction in the Kingston confined aquifer management area on groundwater resource condition.

Model results show that extraction of 40 GL/y from the TCSA in the Kingston confined aquifer management area (as allocated in the 2013 LLCWAP) will lead to deterioration of the resource. This is expressed through declines in groundwater level that exceed the trigger level specified in the LLCWAP for a relatively short time period (> 0.1 m/y from 2015–22). Perhaps more importantly, this level extraction leads to a depletion in artesian pressures in the TCSA in Kingston, which is one of the conditions that makes the resource highly valuable. This seasonal loss of artesian pressure continues after 2022 (i.e. resource condition is being negatively impacted upon while the trigger level is not being exceeded).

Model results show that extraction of 25 GL/y from the TCSA in Kingston also leads to declines that initially exceed trigger levels. At 25 GL/y extraction seasonal drawdown depletes artesian pressures in part of the irrigation district, meaning the resource may be negatively impacted (artesian bores may cease to flow).

The discrepancy between modelled impact on the resource (depletion of artesian pressure) and trigger level declines in the 25 GL/y scenario opens a discussion about potential alternative approaches to managing groundwater in the TCSA. Specifically, whether management targets based around maintaining resource values (eg. artesian pressure) should be considered instead of a trigger level based on rates of decline. This approach has been trialled elsewhere in the South East, and should involve community consultation to define key groundwater resource values, and define unacceptable conditions for the groundwater resource. Management targets based on groundwater pressure levels can then be determined once these key values and conditions have been defined, and further groundwater modelling can assess the impact of varying extraction on these resource condition targets.

The recently developed regional water balance model of the South East (Morgan et al., 2015) was assessed in this project for possible use. This numerical groundwater model simulates both the TLA and TCSA across the LLCPWA, and represents an important step forward in understanding regional scale processes and fluxes. However local scale calibration issues (it did not simulate the large scale seasonal fluctuations observed in the Kingston area) meant it was not suitable to use in this instance, as additional model refinement and calibration was beyond the scope of this project. Future projects that aim to use this model to investigate groundwater resource issues in the South East may need to plan for additional time to be spent on local-scale model refinement and calibration.

The model used in this study (based on the model of Brown (2000) and Brown and Harrington (2005) is considered fit for purpose in demonstrating the potential impact that extraction of 40 GL/y from the TCSA would have on the condition of the groundwater resource. However, as the model was not explicitly re-calibrated in this study (nor was a formal sensitivity analysis performed) it is not considered suitable for determining a new sustainable extraction limit. To do this, further work would be required to recalibrate the model and perform a formal sensitivity analysis. Also the scenarios modelled in this study consider a distribution of groundwater extraction wells based on their current location. Future modelling may need to consider different spatial distributions of extraction in the Kingston management area. Additionally, as outlined in section 5.3, further work may be required to refine resource condition limits before new management targets may be defined.

8 Appendices

A. Hydrograph summaries – hydrostatic unloading

In some cases, hydrographs in the TCSA that are not influenced by extraction show some influence of hydraulic loading/unloading. This occurs where watertable fluctuations in the overlying TLA are translated into pressure fluctuations in the underlying TCSA. Harrington and Cook (2011) investigated this process and demonstrated (using observation data from forestry areas in Nangwarry) that the maximum impact that hydraulic loading could have on a confined aquifer was only a fraction of the fluctuations in the unconfined aquifer, and that this fraction was equivalent to the specific yield.

Of considerable interest in the LLCPWA has been the trend in groundwater levels in the unconfined aquifer in response to recharge interception and groundwater use by plantation forestry. In particular TLA trends underneath blue gum forestry since the early 2000s, centred around the TLA management areas of Coles and Short (Figure 8.1).

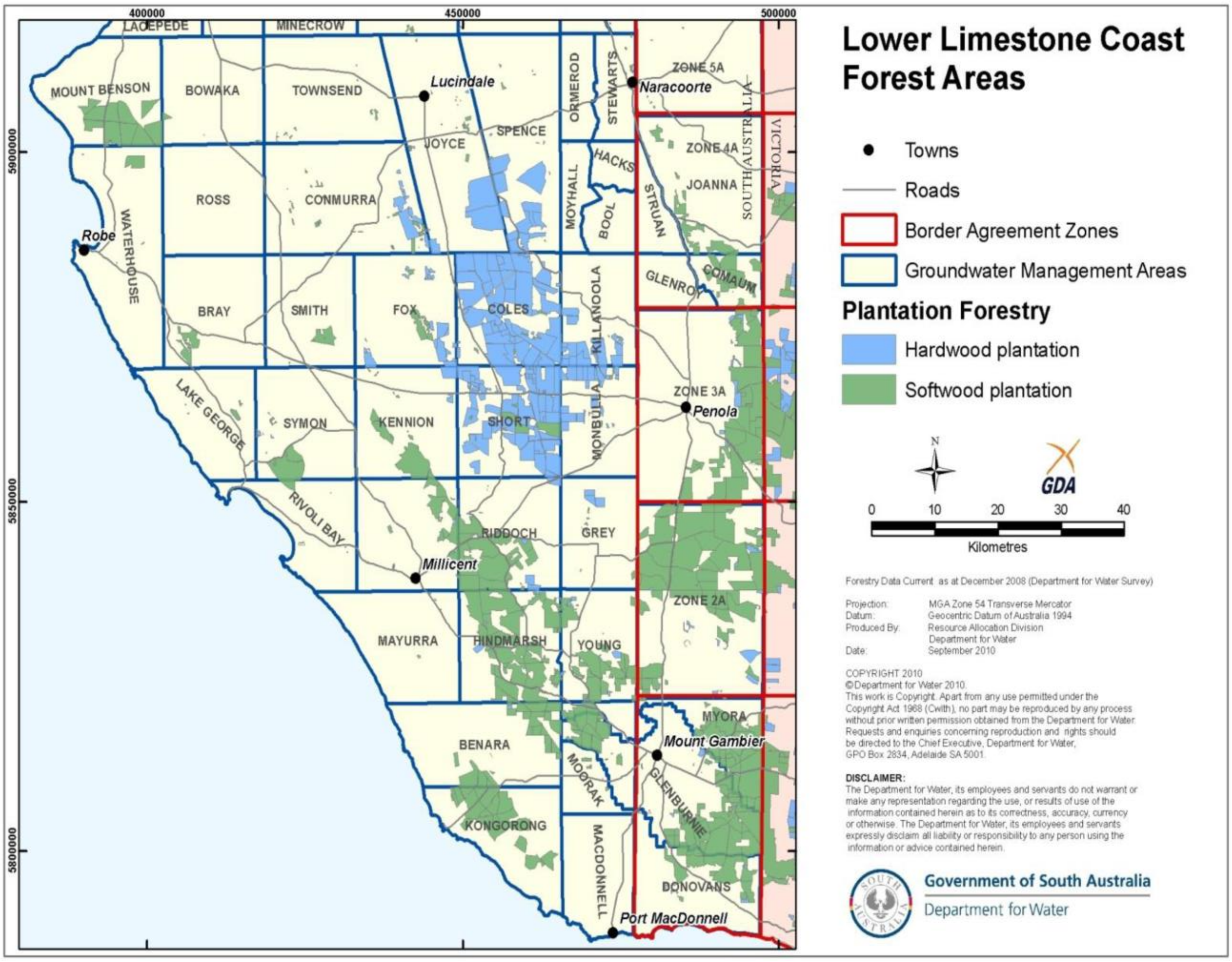


Figure 8.1 Extent of hardwood (blue gum) and softwood (pine) plantation forestry in the LLCPWA (from Harvey (2009))

There are only a few locations in the vicinity of blue gums plantations where both unconfined and confined aquifers are monitored at the same point. One example CLS013 (confined) and CLS009 (unconfined) (Figure 8.2). Here the TLA (CLS009) shows a typical hydrograph from this area – with reduction in seasonal fluctuation (from rainfall recharge) and decline in groundwater level from 2005–

10 attributable to recharge interception by blue gum forestry (Aquaterra, 2010). Seasonal fluctuations are again observed after 2010 (when winter rainfall is above average), however the response (and inferred recharge) is muted compared to recharge in years prior to blue gum plantations.

The TCSA here (CLS013) does not directly follow the same trend, showing some decline from up to 2006-07, but the magnitude of seasonal fluctuations does not change. Worth noting though is that CLS013 is closer to the edge of the plantation area that CLS009 is inside of, and closer to the Baker Drain. Therefore it’s possible that CLS013 could be displaying a hydraulic loading response from multiple influences. However determining the relative contribution of these different factors is beyond the scope of this project. Therefore it’s difficult to say anything conclusive at this location regarding the influence of recharge interception from forestry on TCSA pressure via hydraulic unloading.

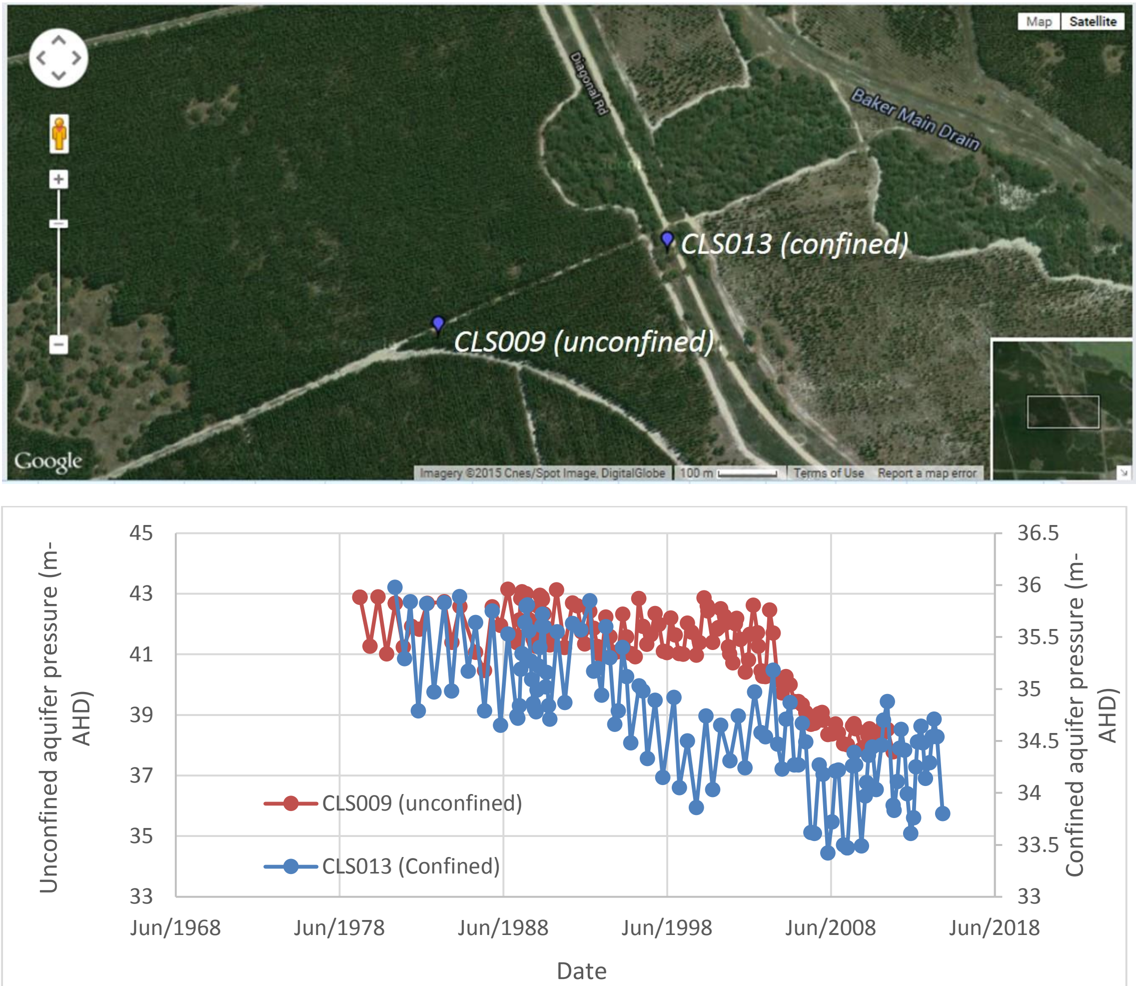


Figure 8.2 Hydrographs in the TLA and TCSA in the Coles management area

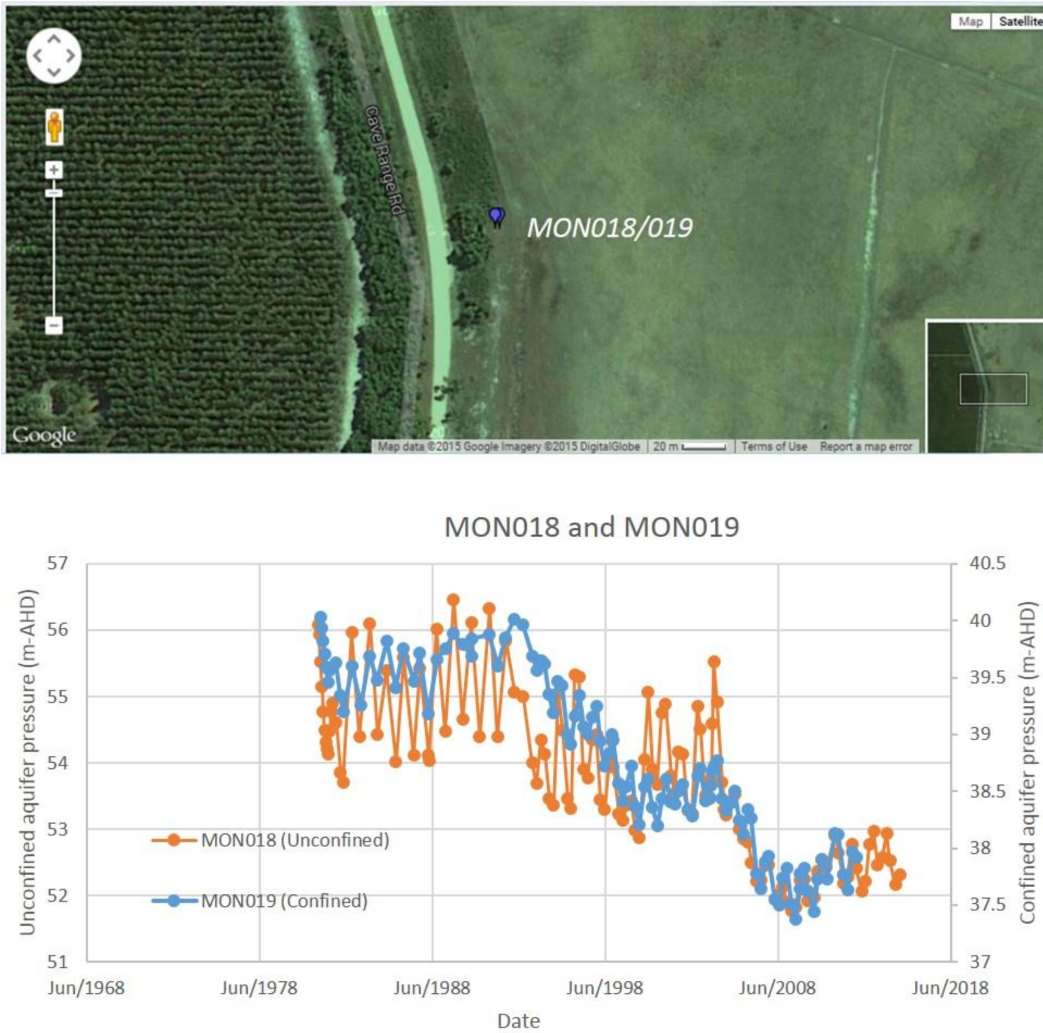


Figure 8.3 Hydrographs in the TLA and TCSA in the Monbulla management area

Monitoring wells MON019 (TCSA) and MON018 (TLA), are located are located directly next to each other and adjacent to plantation forestry, south of the Coles and Short management areas. Here a more direct relationship is observed between TLA trends (which are typical of the area for the period of blue gum growth/expansion from 2004 onwards) and hydraulic unloading response in the TCSA (Figure 8.3).

Despite this influence, the pressure level in the unconfined aquifer remains much higher than in the confined aquifer (approximately 15 m higher in 2010 measured at MON018 and MON019), therefore the potential for downward leakage to the confined aquifer in the areas east of the zero-head difference remains. Thus the declines in groundwater level in the TLA in the LLCPWA associated with forestry impacts have not necessarily had an impact upon potential downward leakage to (and recharge of) the TCSA. Further investigations, possibly with environmental tracers would be needed to confirm this.

In the Kingston management area the influence of hydraulic loading is more difficult to elucidate. Figure 26 shows hydrographs from the TLA (BOW004) and the TCSA (BOW014 and replacement bores BOW020 and BOW025) ~ 20 km south-east of the Kingston township (ie. in the artesian area of the aquifer where irrigation extraction is occurring). In the unconfined TLA, groundwater level fluctuates seasonally by approximately 0.9 m in response to seasonal rainfall/recharge (depth to groundwater at BOW004 is less than 1 m below ground). However seasonal fluctuations in the TCSA are between 6–10 m. Based on the observations in Monbulla discussed earlier, ~0.5 m of this fluctuation may be attributed to hydrostatic influences from the TLA, which may explain some of the discrepancy between measured and modelled groundwater levels in the Kingston management area. However given the significant influence of groundwater extraction on trends in the TCSA, the potential influence of hydrostatic loading cannot be quantified with any certainty based on the hydrographs.

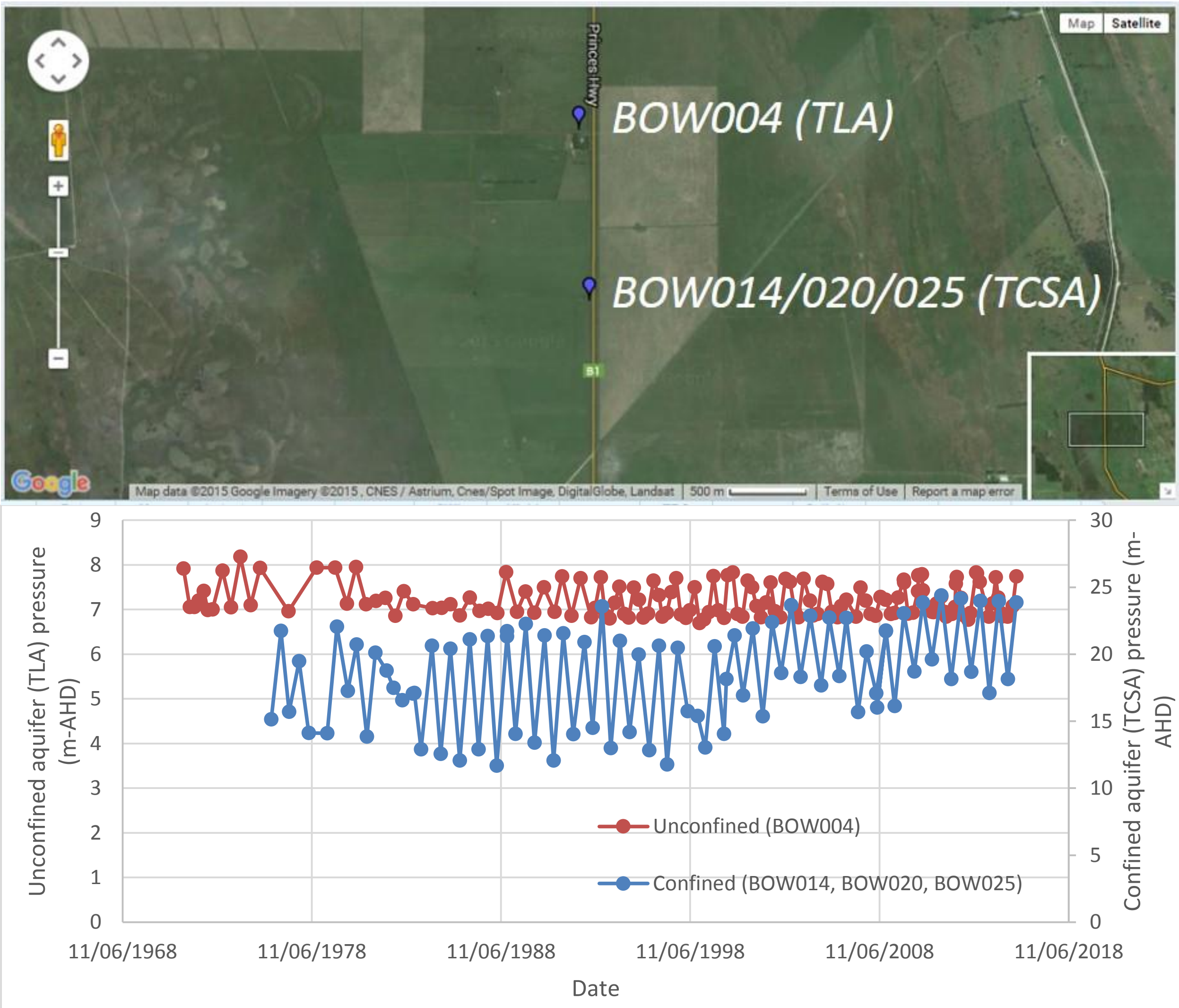


Figure 8.4 Hydrographs in the TLA and TCSA in Kingston management area

B. Refinement of the extraction schedule

The extraction schedule in the Brown (2000) model was updated by Harrington and Brown (2005) to extend until 2005. As part of this project, the extraction schedule was further extended 2013, with actual (metered) extraction from bores between 2009–10 to 2012–13 (irrigation generally occurs during summer months). The following points outline the steps taken to generate a new extraction schedule:

- Metered extraction data and associated extraction schedule came from Goyder model work (Morgan et al., 2015; Harrington and Li, 2015)
- Approach of Goyder extraction data set was to take metered extraction from four years of available data, then for previous years extraction from each bore was based on average of these for years – back to the original construction date of the bore
- Additional time was spent here reconciling this updated data set with the data set in the Brown (2000) model (Goyder model has 12 (monthly) stress periods of extraction per year while Brown model has 2 (seasonal))
- In some cases, years of no extraction from metered data (2009–13) skewed results with a cumulative effect on the volumes extracted from the model
- For example - bore ID 692302705 had extraction rates (based on metered data) of:
  - 2553 m^3/d for 2009/10
  - 1841 m^3/d for 2010/11
  - 2174 m^3/d for 2011/12
  - 0 m^3/d for 2012/13
- Hence the average extraction applied for this bore in the Goyder data set historically was 1642 m^3/d. However in the Brown (2000) model – the extraction for this bore was 2604 m^3/d – which is a plausible extraction rate based on metered data (close to the extraction rate for 2009/10). This discrepancy in extraction rates is likely to have a cumulative effect across the model domain (particularly in Kingston).
- Consequently model runs using purely the Goyder historical extraction data showed some discrepancy between observed historical (ie. pre-2009) hydrographs and modelled hydrographs (see Figure 8.5).
- Thus a new extraction schedule was generated incorporating metered data where available, and historical extraction rates based on an assessment of whether the Brown (2000) extraction rates were likely to be accurate (based on metered data) and whether or not years of no reported metered use biased this in the Goyder data set.
- The result was an extraction data set that produced a better match to groundwater levels (Figure 8.6).

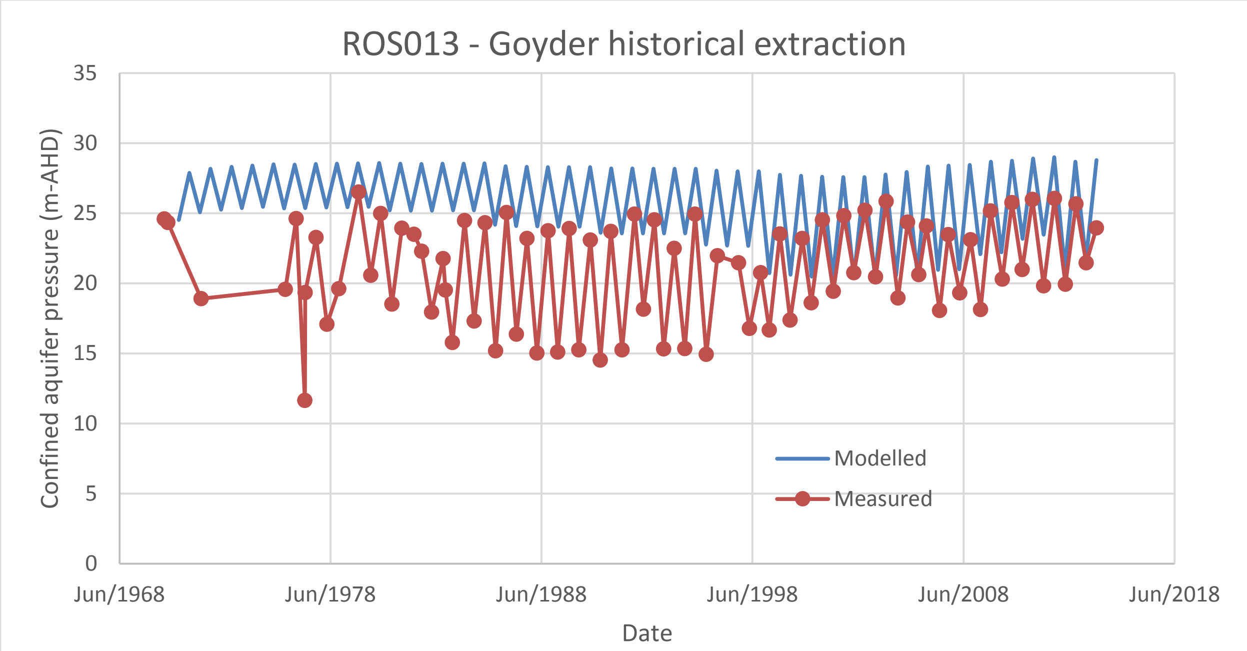


Figure 8.5 Measured vs modelled groundwater level in Kingston using the Goyder historical groundwater extraction data

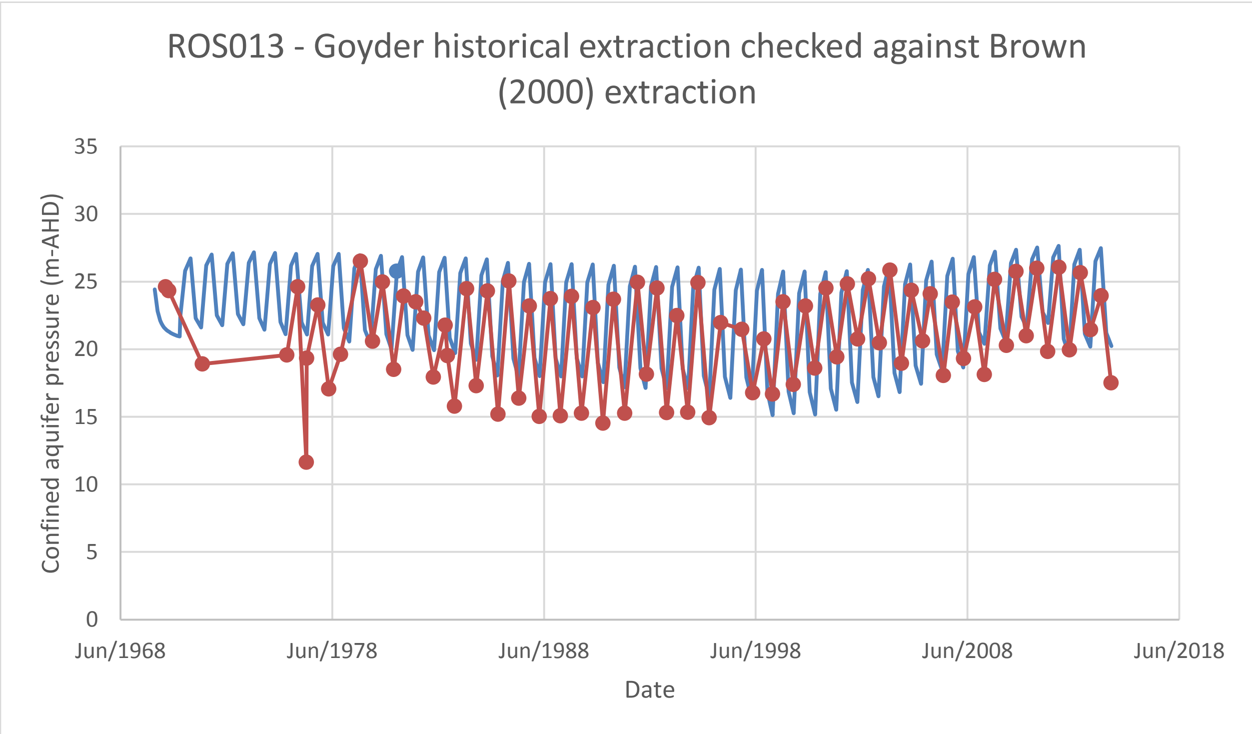
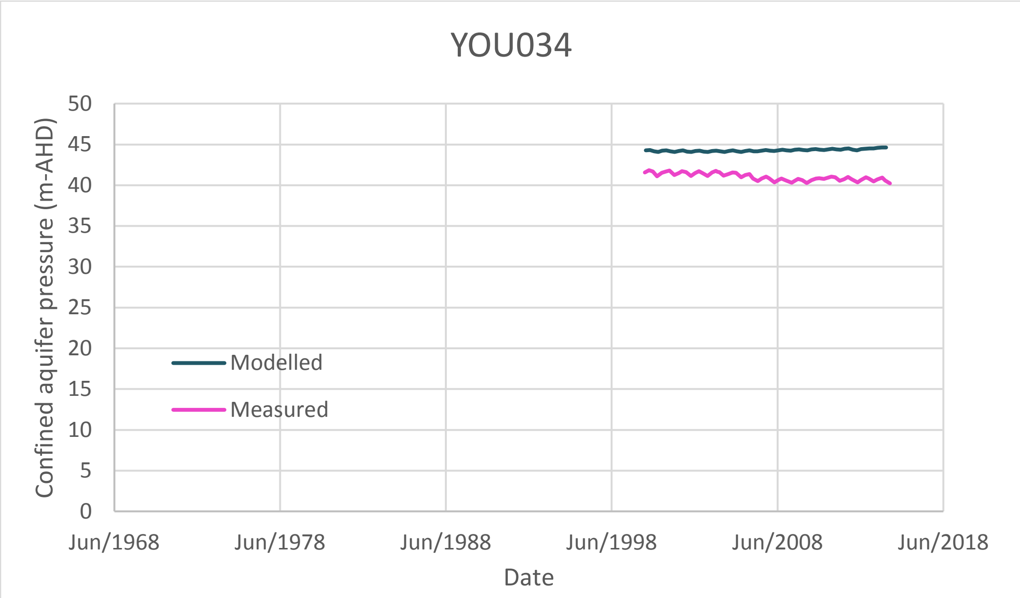
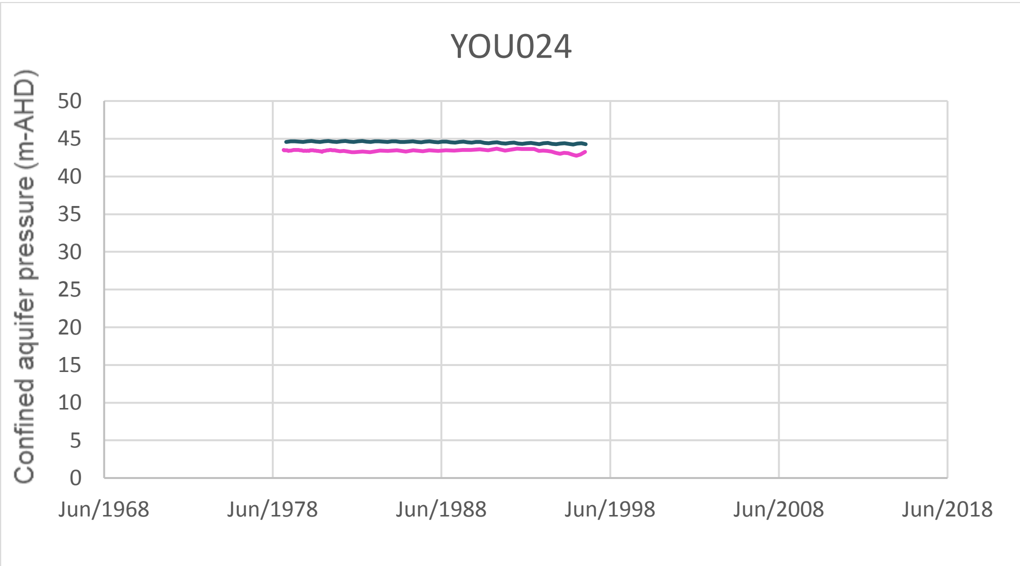


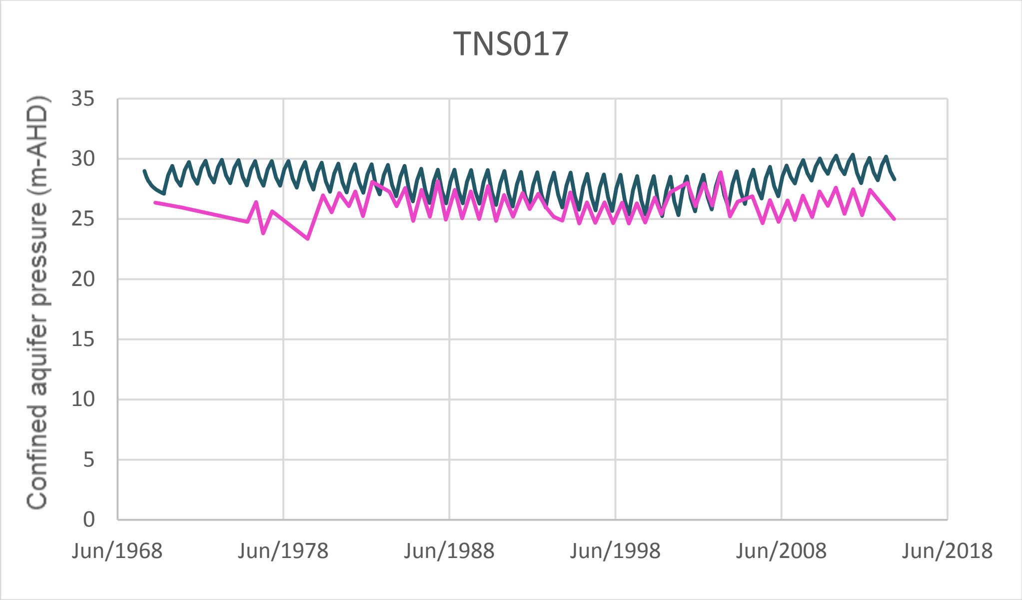
Figure 8.6 Measured vs modelled groundwater level in Kingston using Goyder metered data and Brown historical extraction data

C. Measured vs. modelled hydrograph

See Figure 2.3 for location of observations wells.






TNS017
Confined aquifer pressure (m-AHD)
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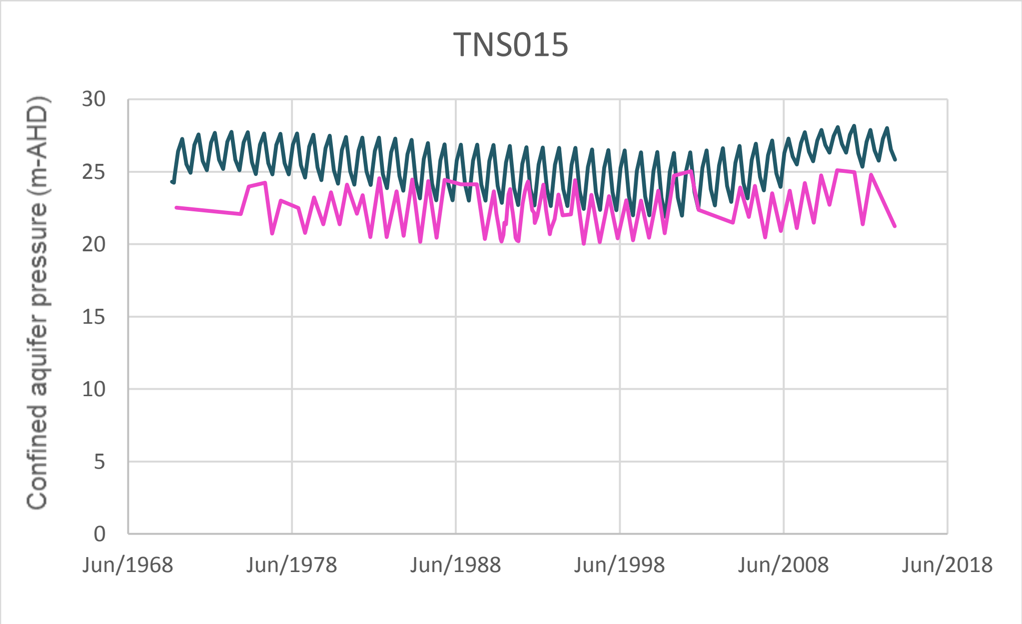
TNS015
Confined aquifer pressure (m-AHD)
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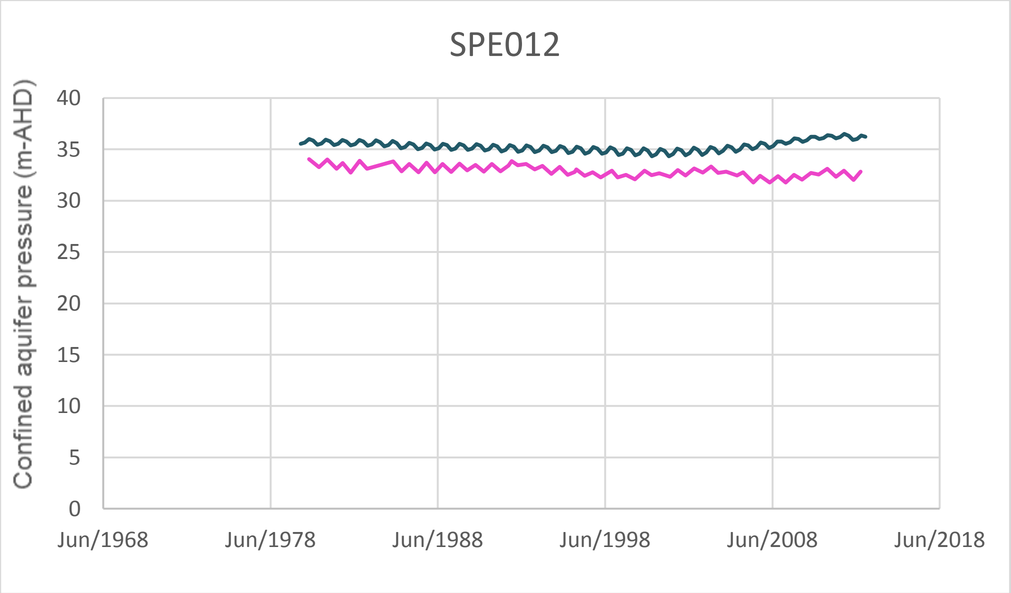
SPE012
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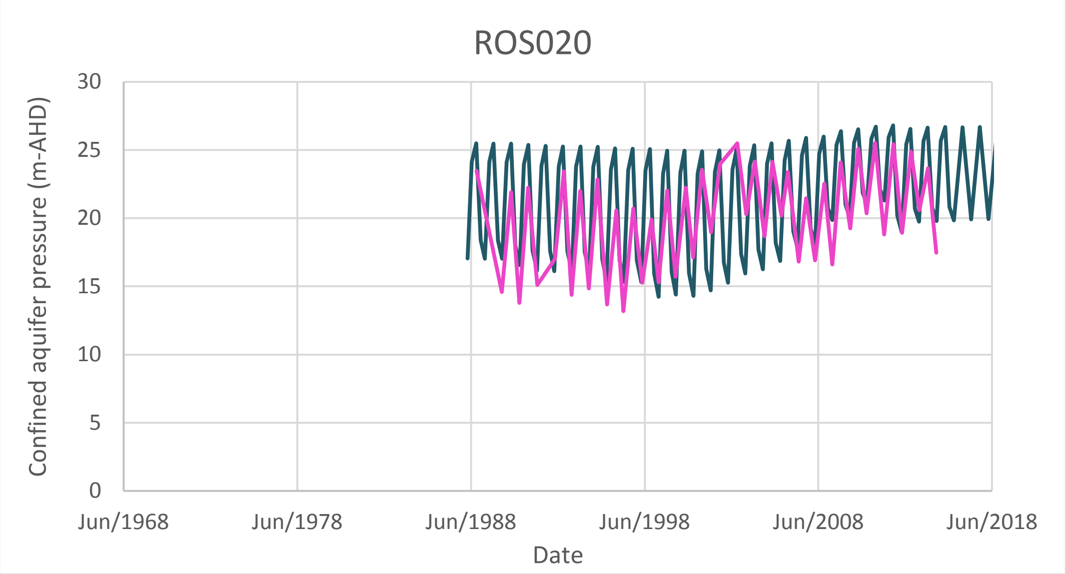
ROS020
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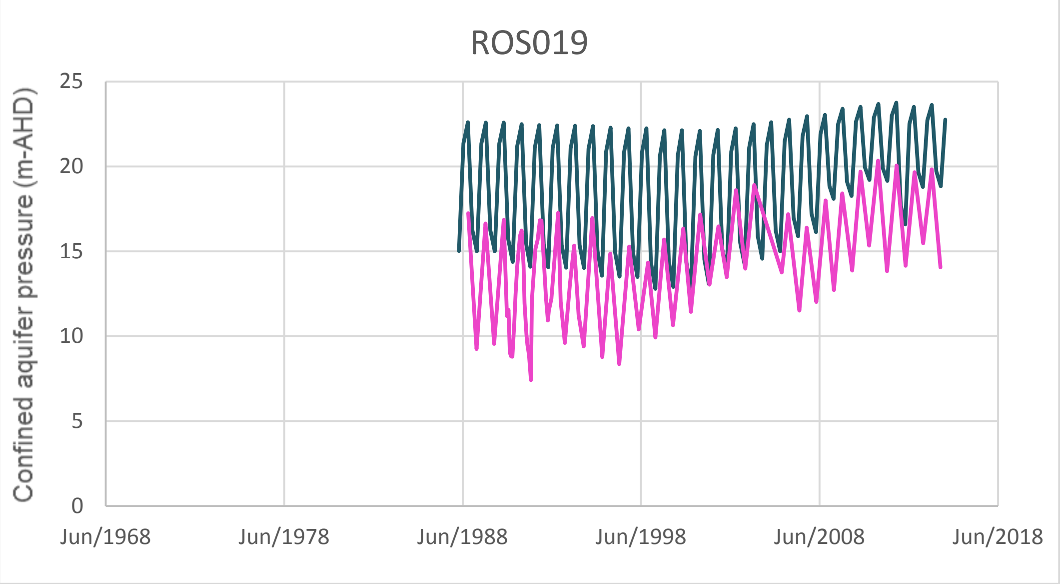
ROS019
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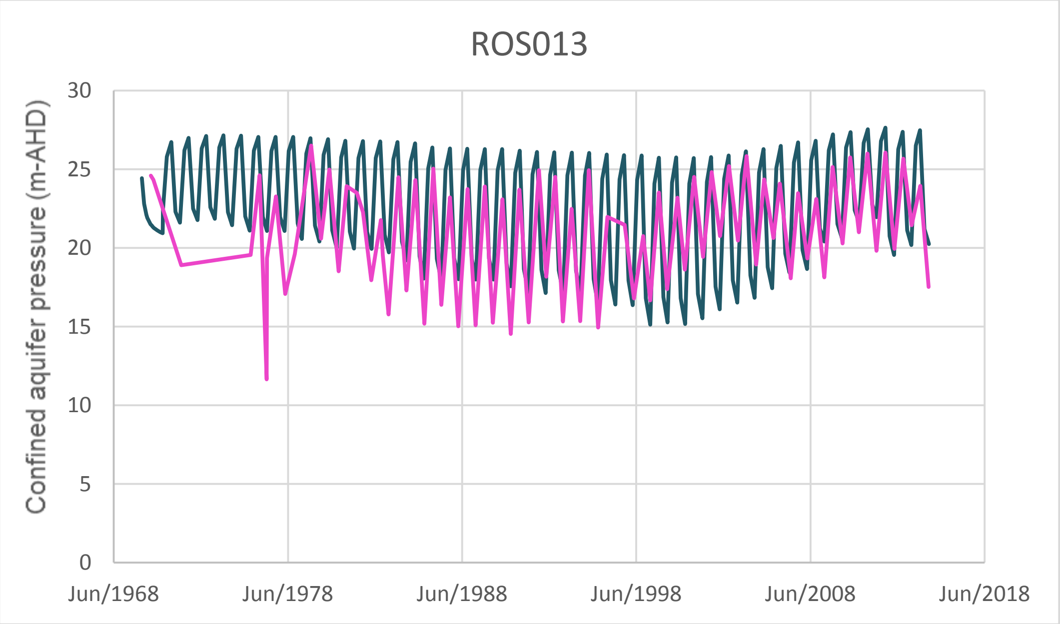
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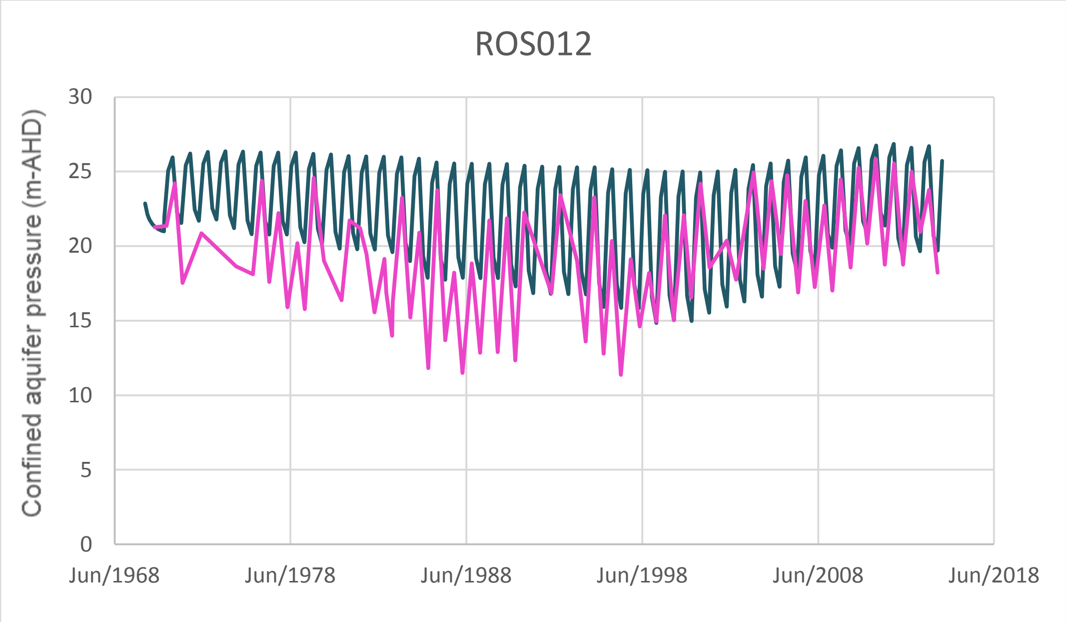
ROS012
Confined aquifer pressure (m-AHD)
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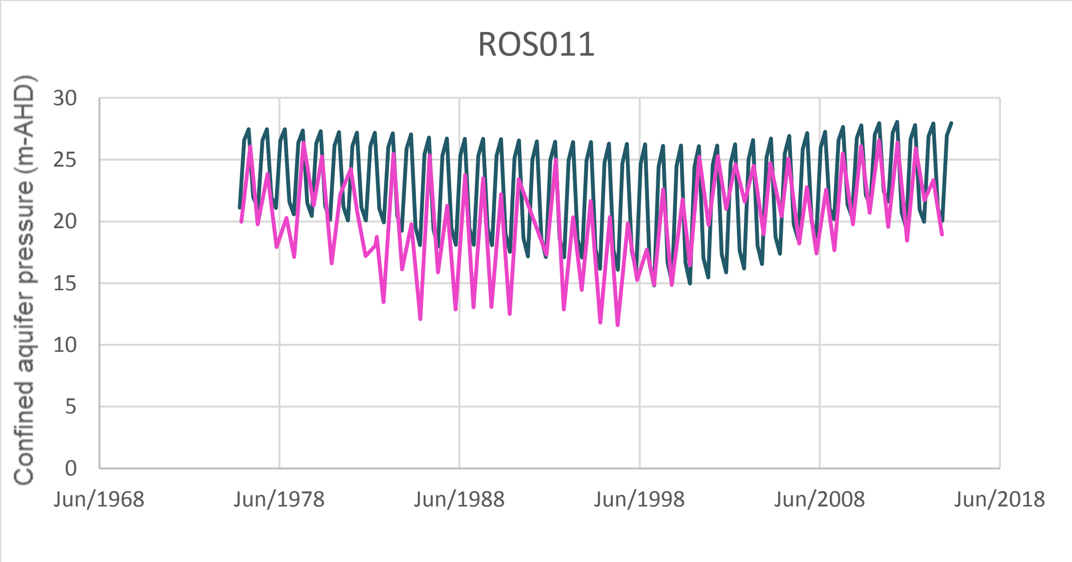
Jun/1998
Jun/2008
Jun/2018


ROS011
Confined aquifer pressure (m-AHD)
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25
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15
10
5
0
Jun/1968
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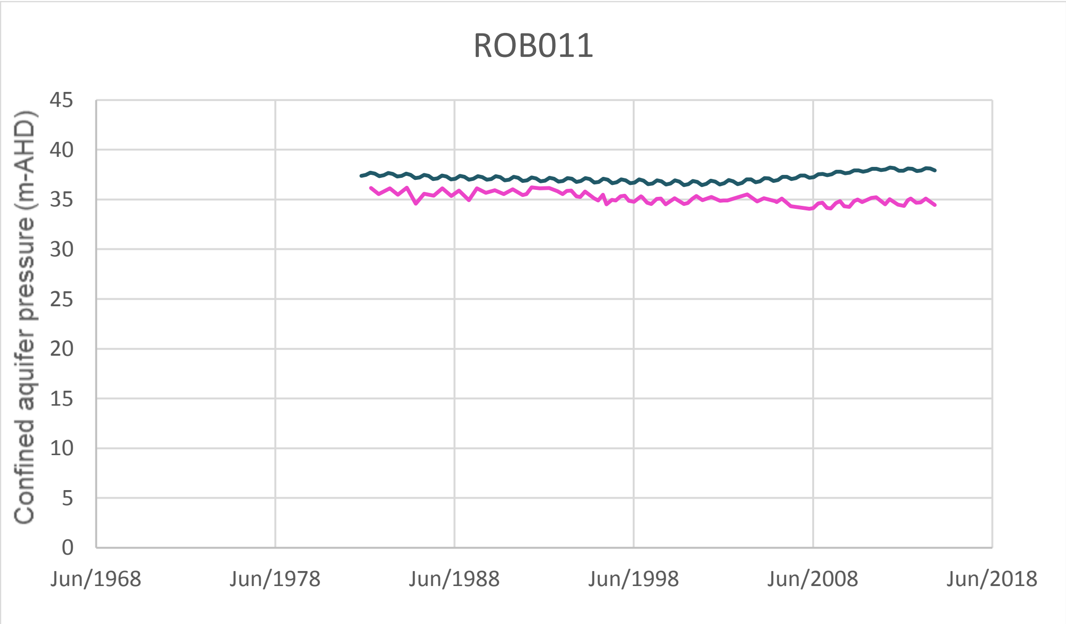
Jun/1988
Jun/1998
Jun/2008
Jun/2018


ROB011
Confined aquifer pressure (m-AHD)
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25
20
15
10
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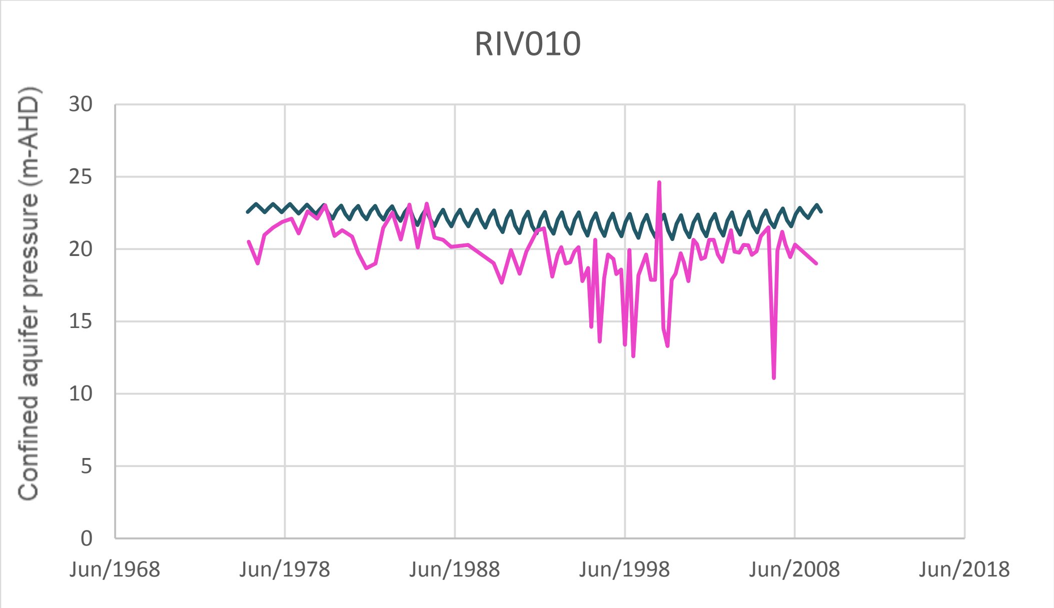
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


RIV010
Confined aquifer pressure (m-AHD)
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10
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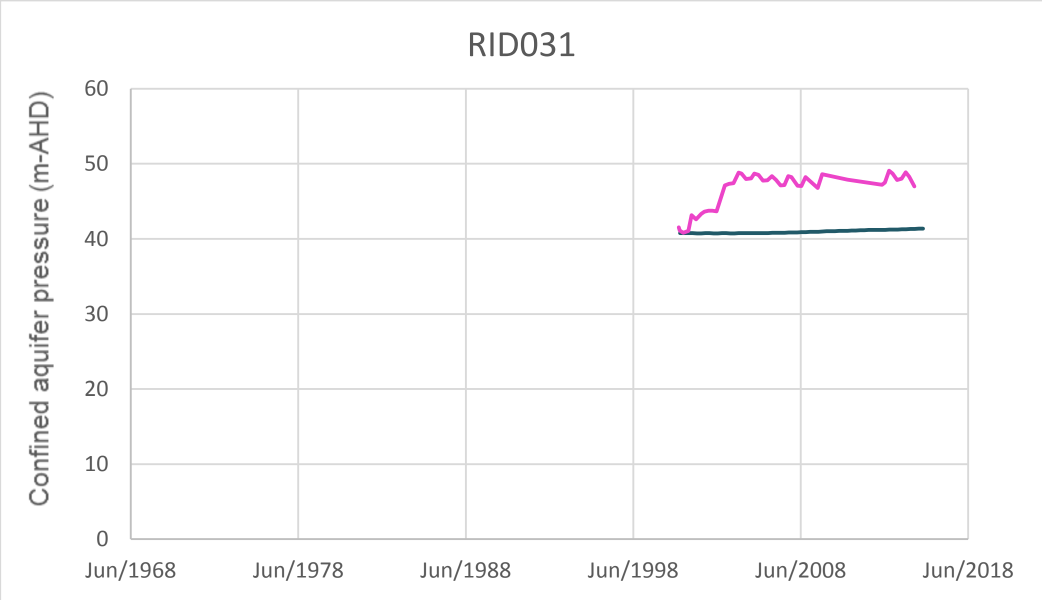
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


RID031
Confined aquifer pressure (m-AHD)
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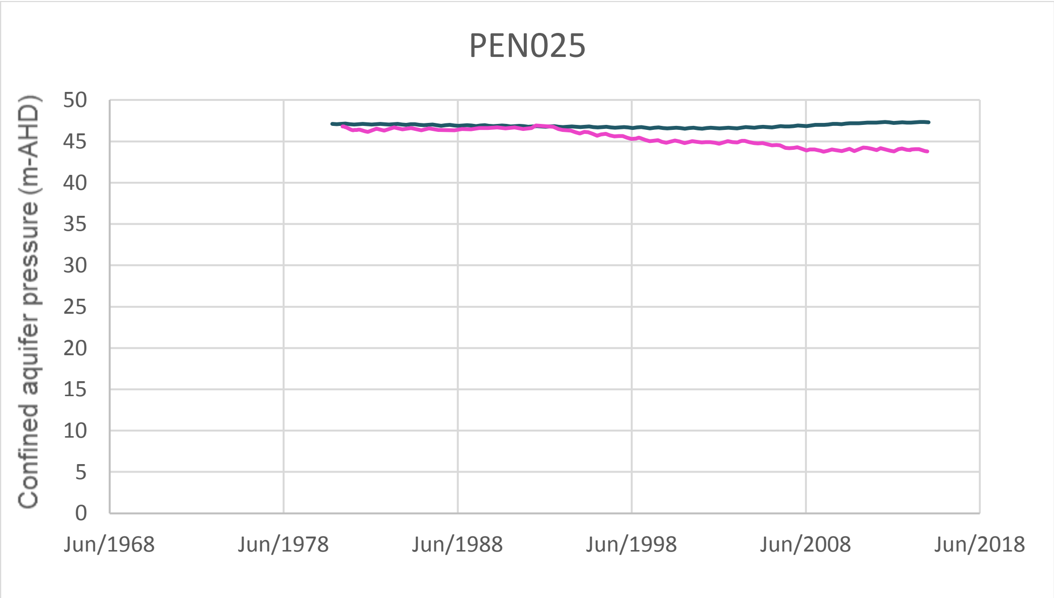
Jun/2018


PEN025
Confined aquifer pressure (m-AHD)
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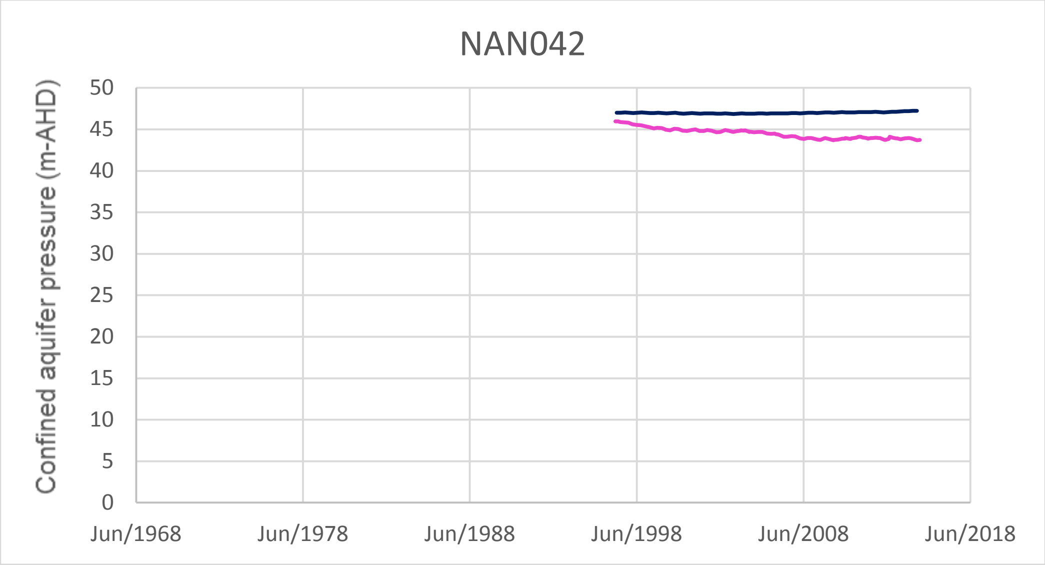
Jun/2008
Jun/2018


NAN042
Confined aquifer pressure (m-AHD)
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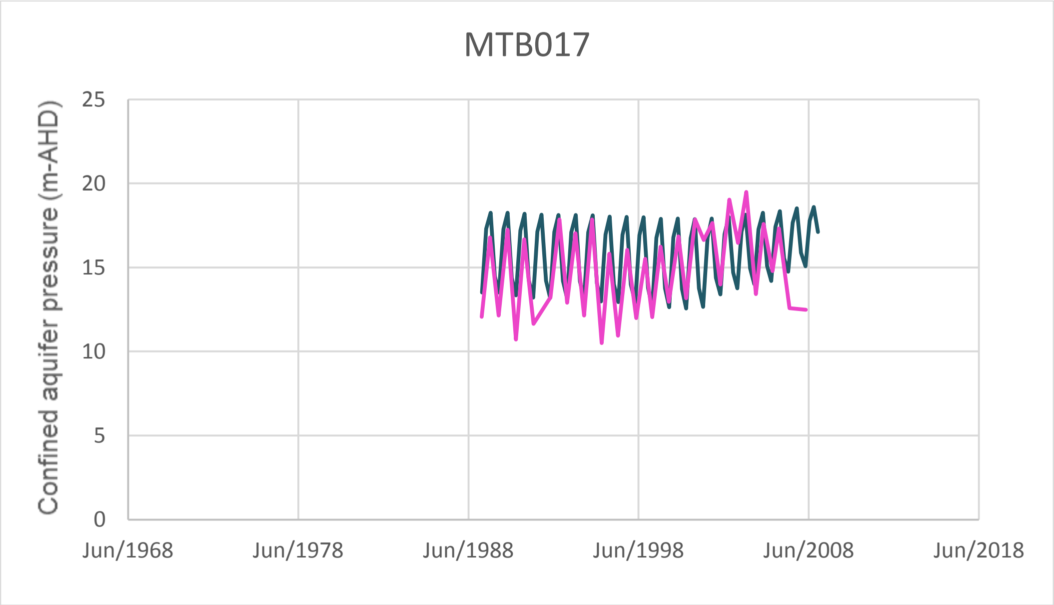
MTB017
Confined aquifer pressure (m-AHD)
25
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5
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Jun/1968
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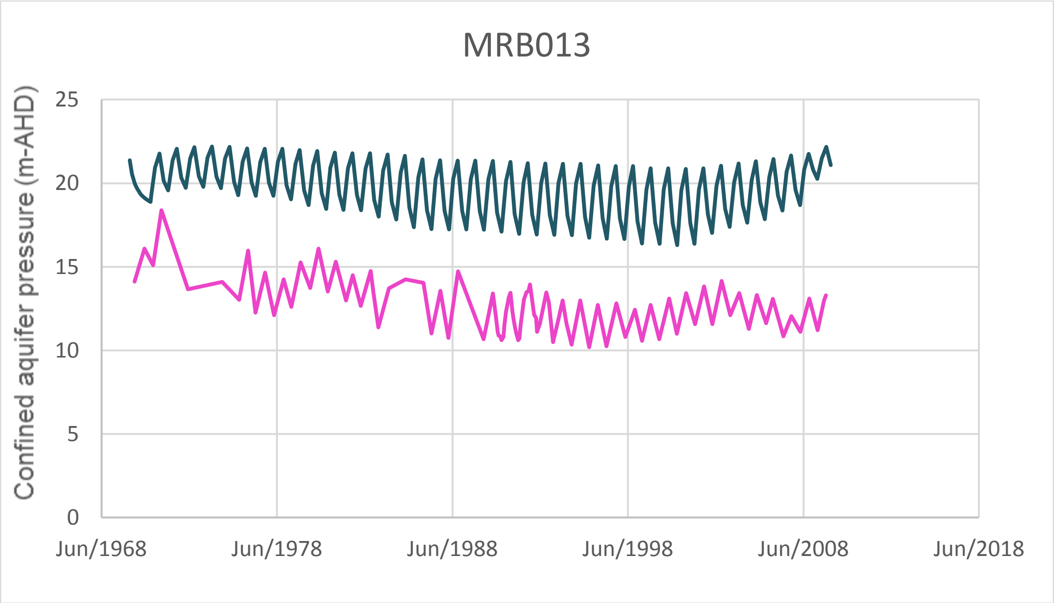
Jun/2008
Jun/2018


MRB013
Confined aquifer pressure (m-AHD)
25
20
15
10
5
0
Jun/1968
Jun/1978
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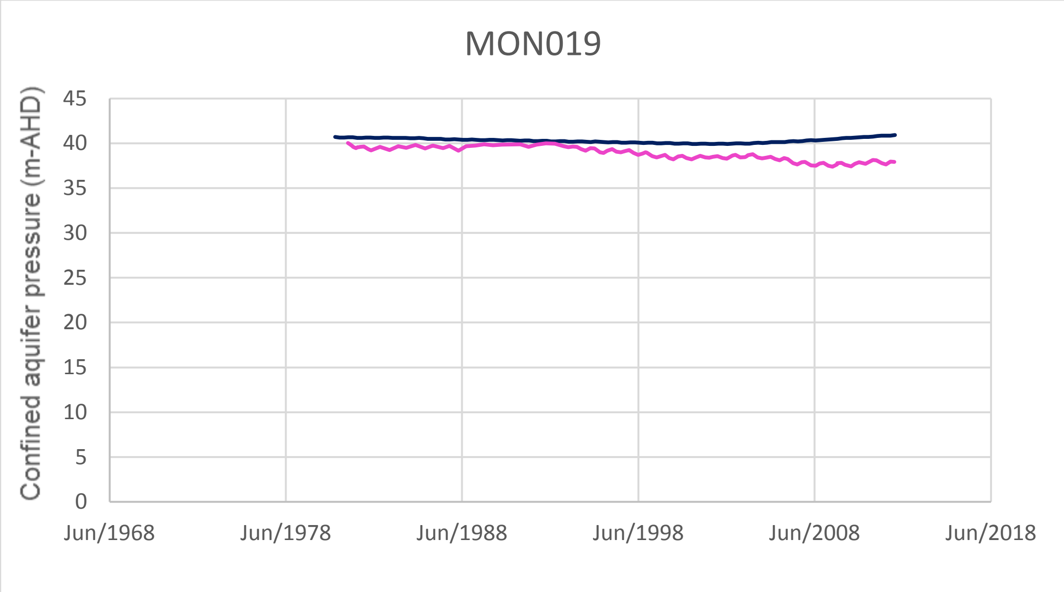
Jun/1998
Jun/2008
Jun/2018


MON019
Confined aquifer pressure (m-AHD)
45
40
35
30
25
20
15
10
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Jun/1968
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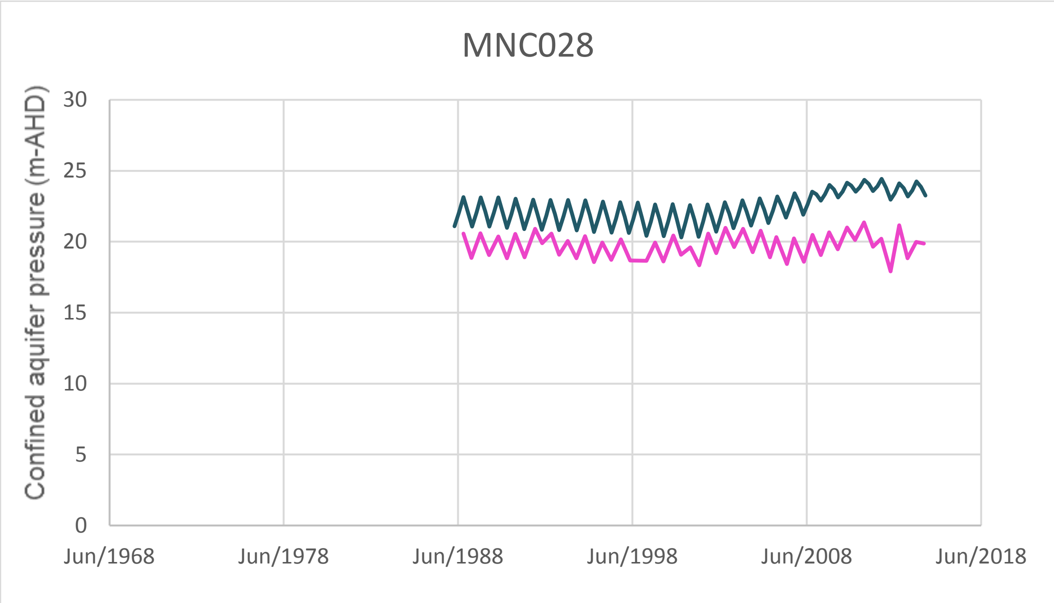
Jun/1998
Jun/2008
Jun/2018


MNC028
Confined aquifer pressure (m-AHD)
30
25
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15
10
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0
Jun/1968
Jun/1978
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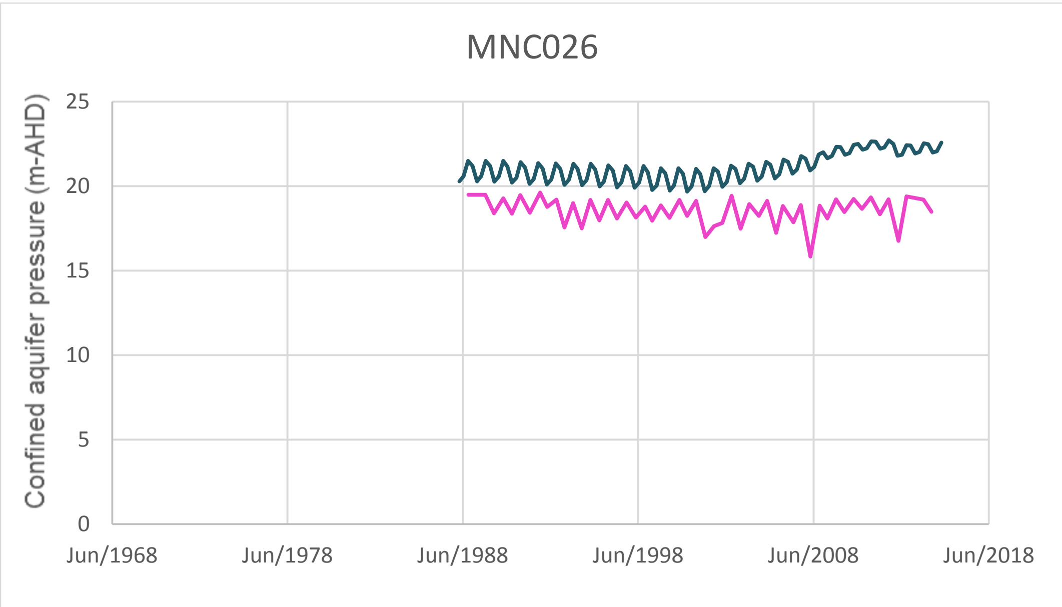
Jun/2008
Jun/2018


MNC026
Confined aquifer pressure (m-AHD)
25
20
15
10
5
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Jun/1968
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Jun/1988
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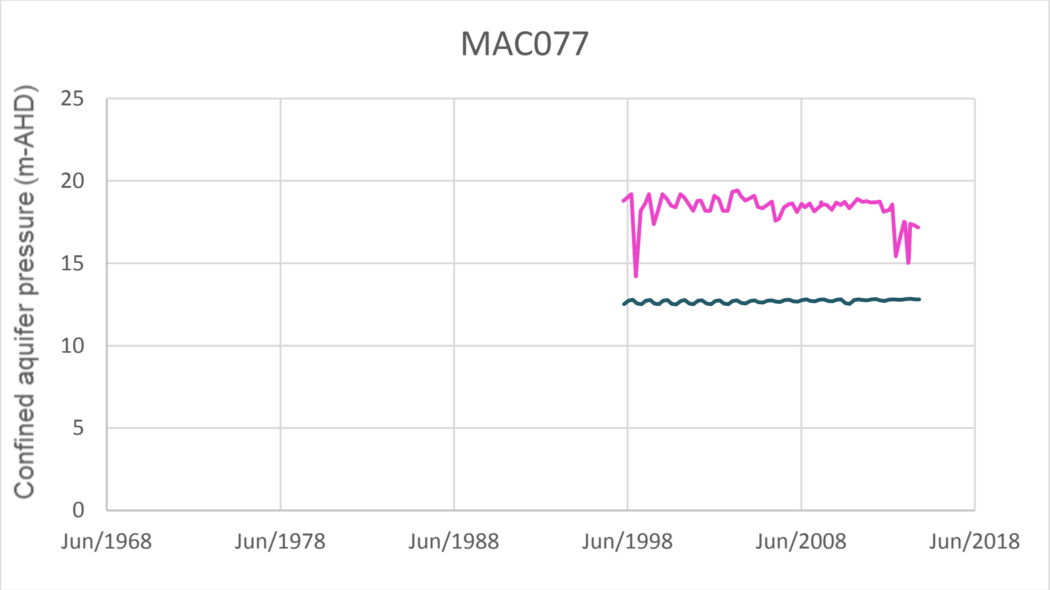
Jun/2008
Jun/2018


MAC077
Confined aquifer pressure (m-AHD)
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15
10
5
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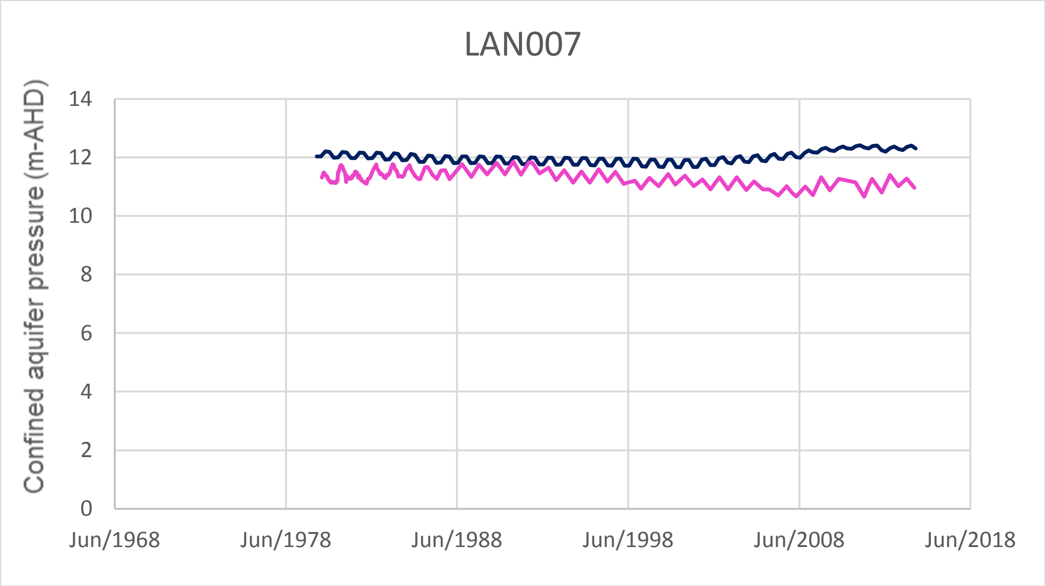
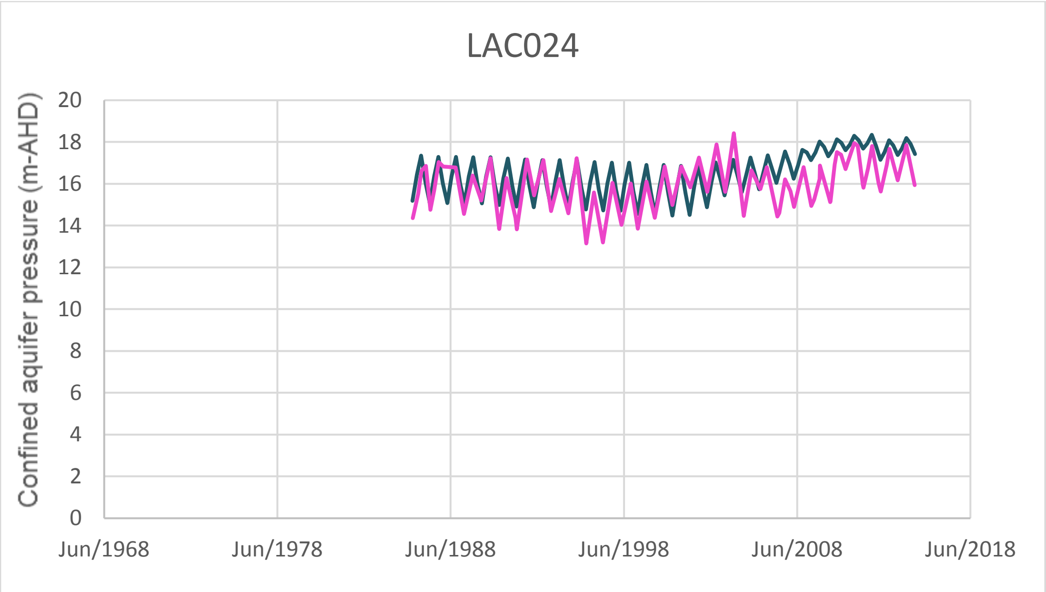
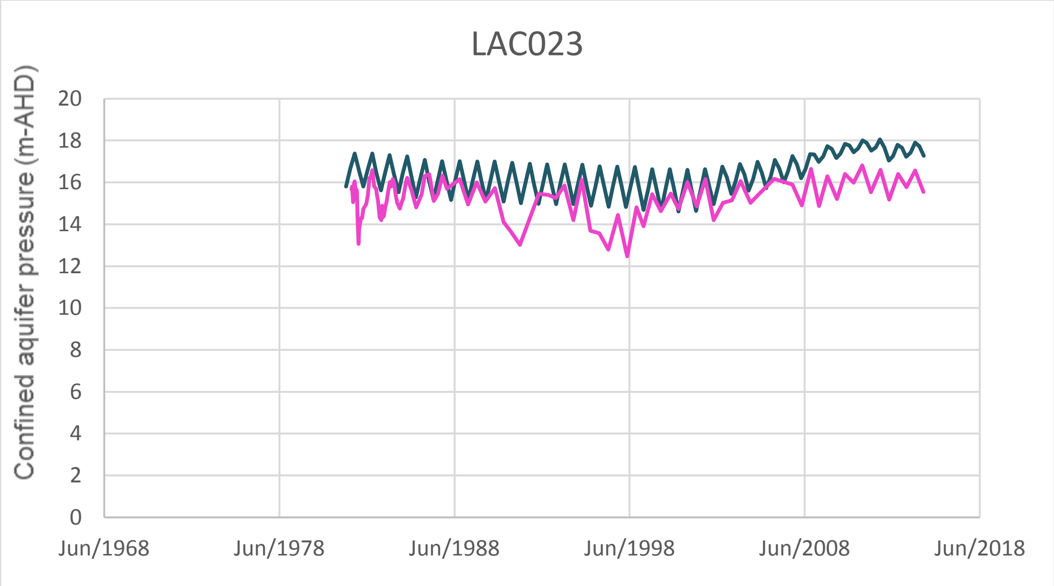
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


LAN007
Confined aquifer pressure (m-AHD)
14
12
10
8
6
4
2
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


LAC024
Confined aquifer pressure (m-AHD)
20
18
16
14
12
10
8
6
4
2
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


LAC023
Confined aquifer pressure (m-AHD)
20
18
16
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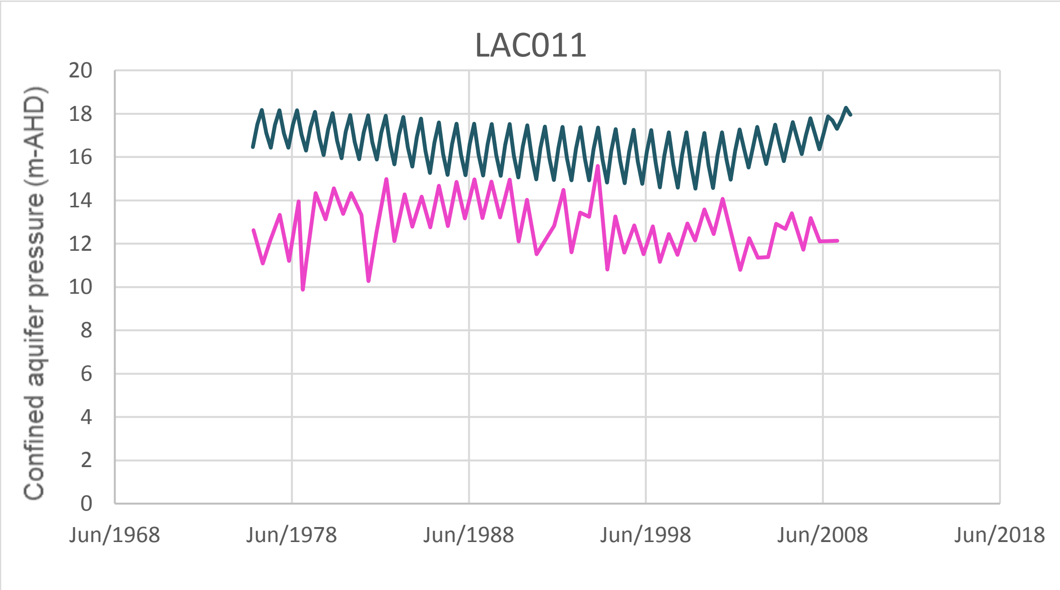
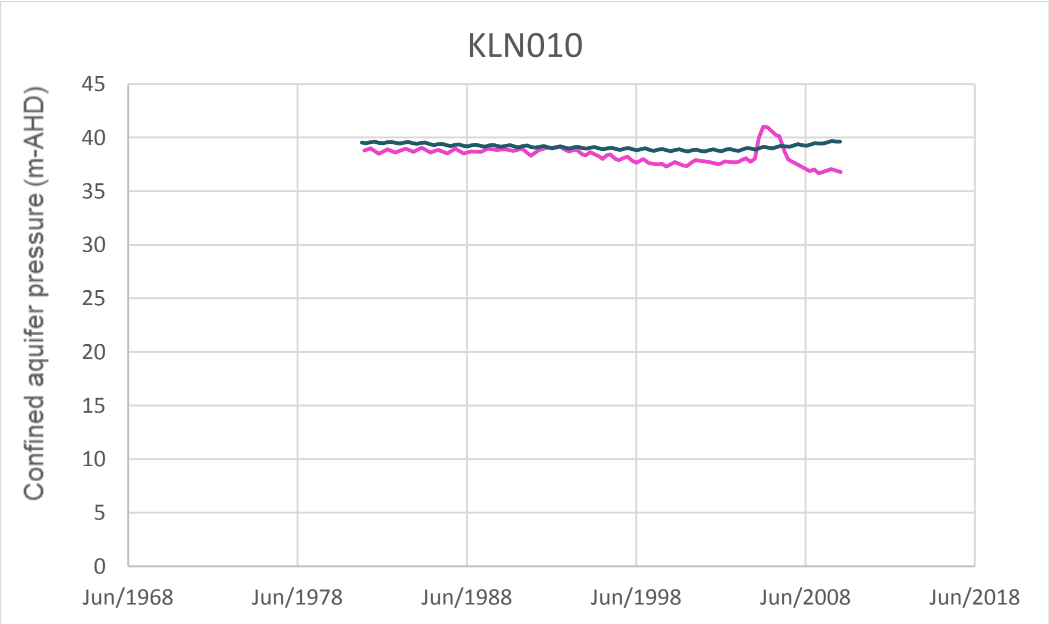
12
10
8
6
4
2
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


LAC011
Confined aquifer pressure (m-AHD)
20
18
16
14
12
10
8
6
4
2
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


KLN010
Confined aquifer pressure (m-AHD)
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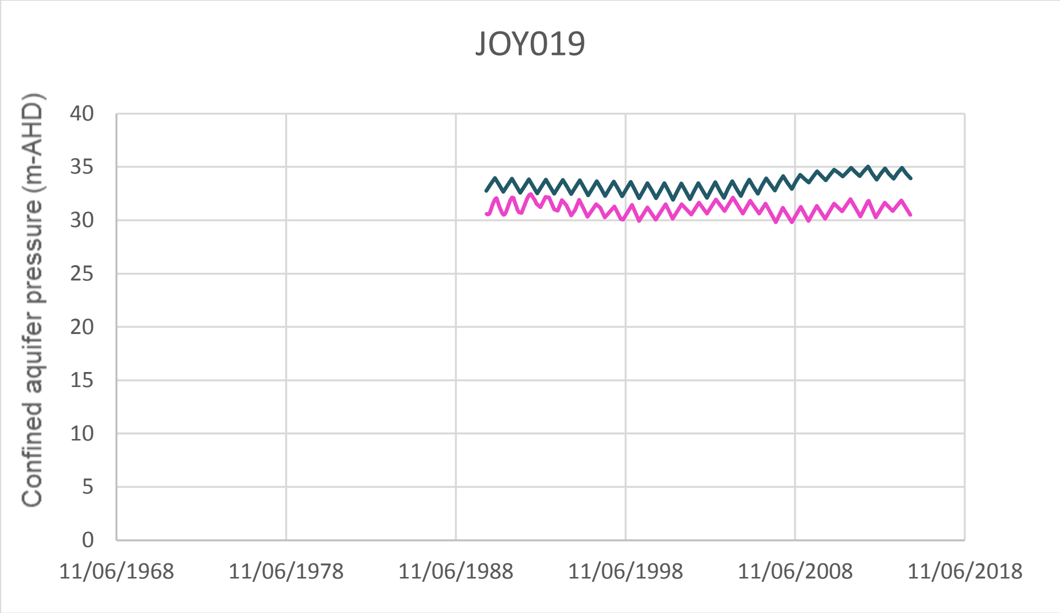
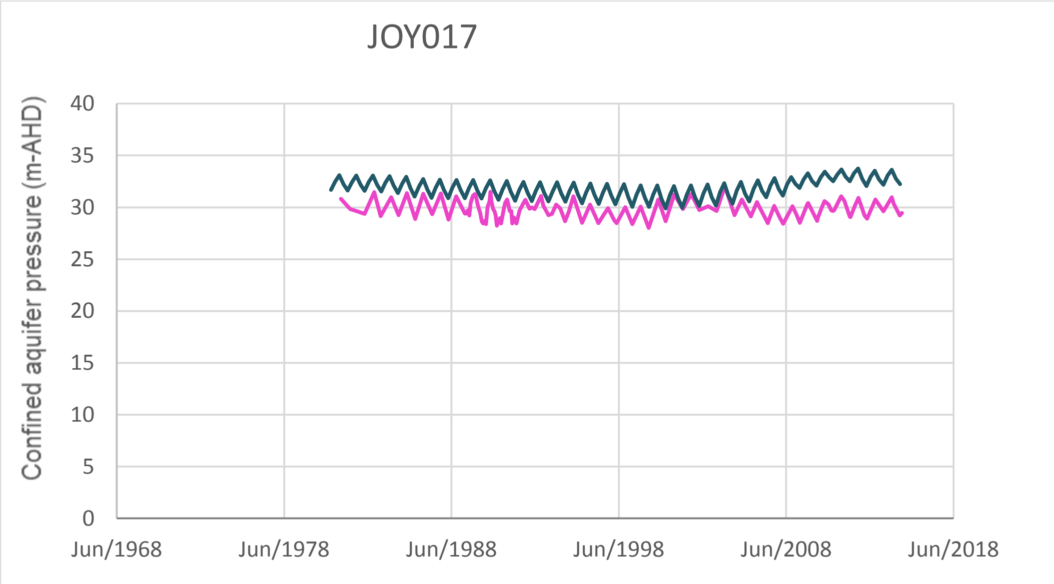
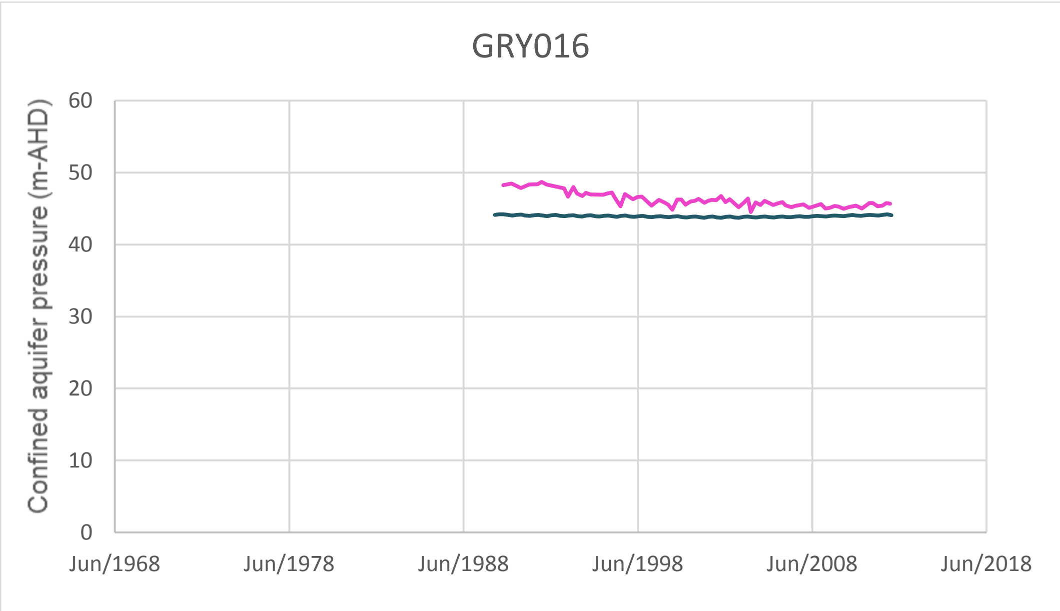
25
20
15
10
5
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


JOY019
Confined aquifer pressure (m-AHD)
40
35
30
25
20
15
10
5
0
11/06/1968
11/06/1978
11/06/1988
11/06/1998
11/06/2008
11/06/2018


JOY017
Confined aquifer pressure (m-AHD)
40
35
30
25
20
15
10
5
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


GRY016
Confined aquifer pressure (m-AHD)
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50
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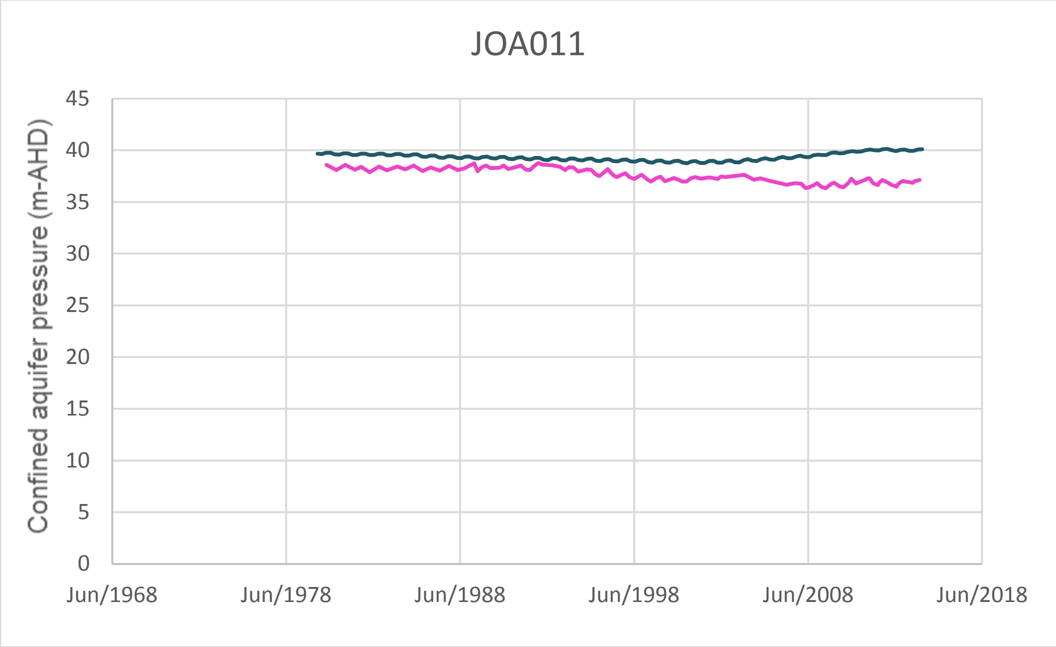
30
20
10
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


JOA011
Confined aquifer pressure (m-AHD)
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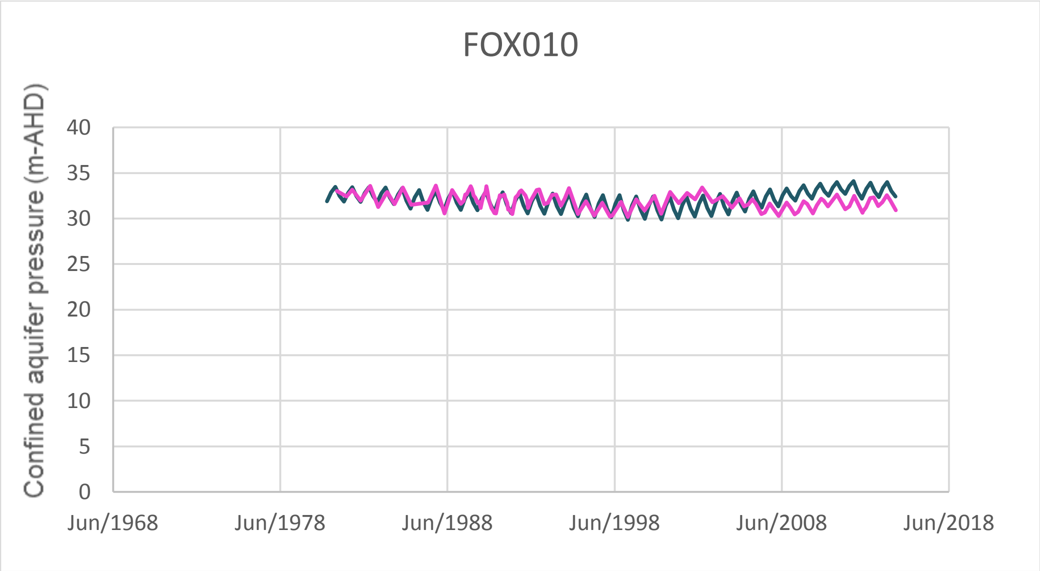
35
30
25
20
15
10
5
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


FOX010
Confined aquifer pressure (m-AHD)
40
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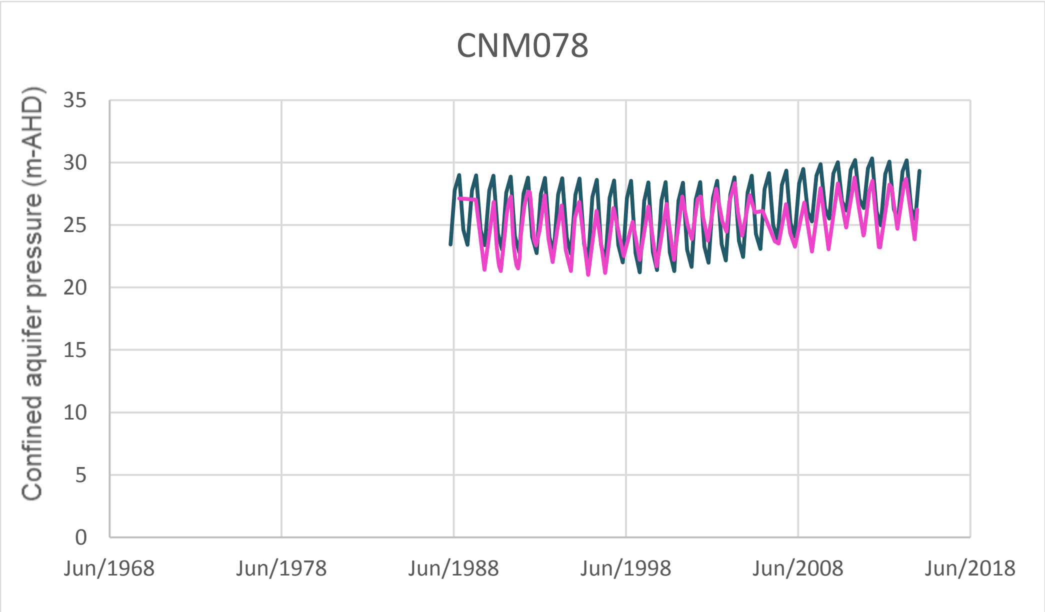
30
25
20
15
10
5
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


CNM078
Confined aquifer pressure (m-AHD)
35
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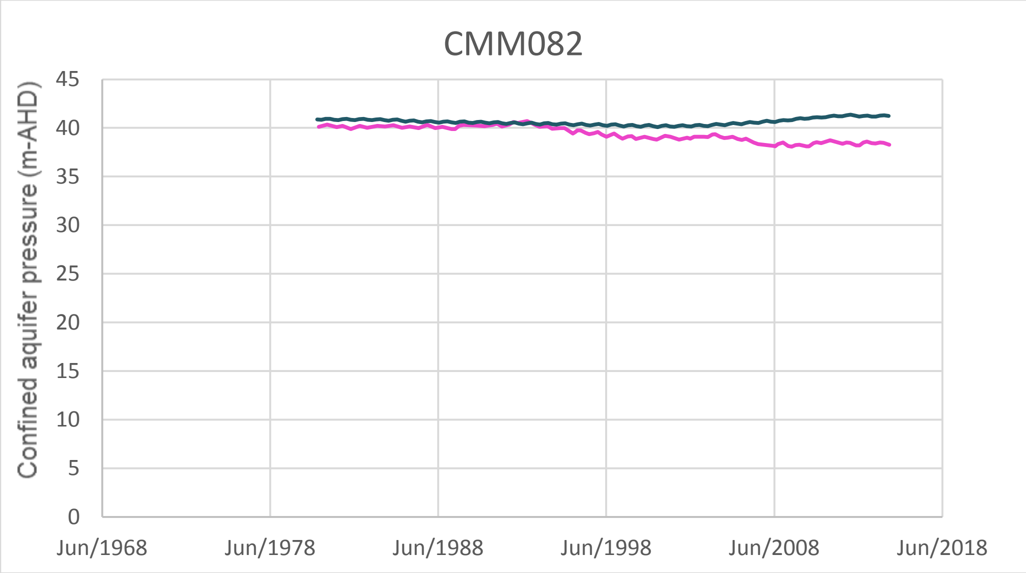
25
20
15
10
5
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


CMM082
Confined aquifer pressure (m-AHD)
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20
15
10
5
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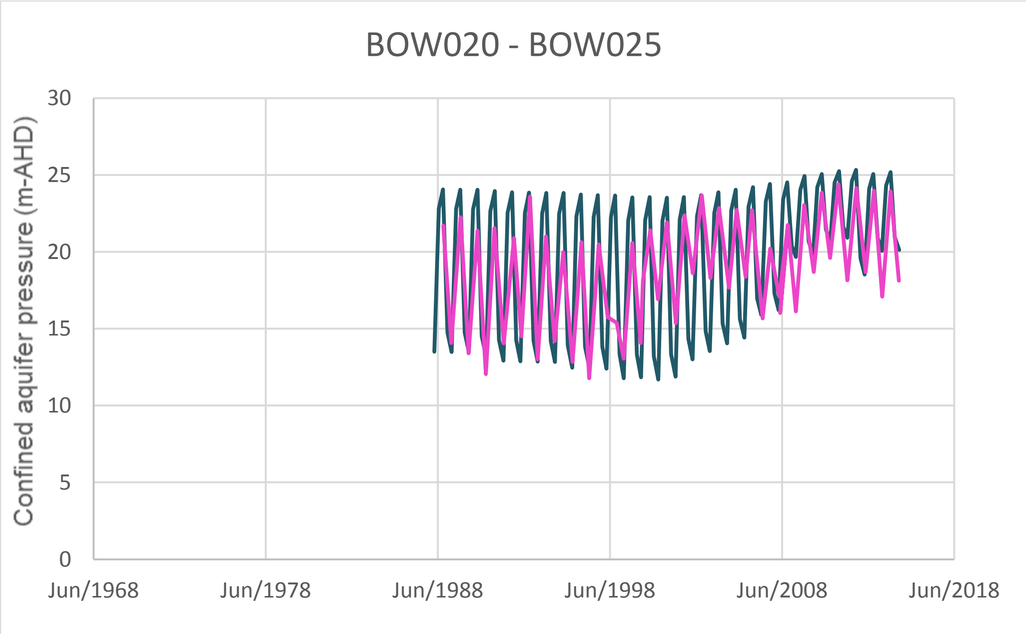
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


BOW020 - BOW025
Confined aquifer pressure (m-AHD)
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15
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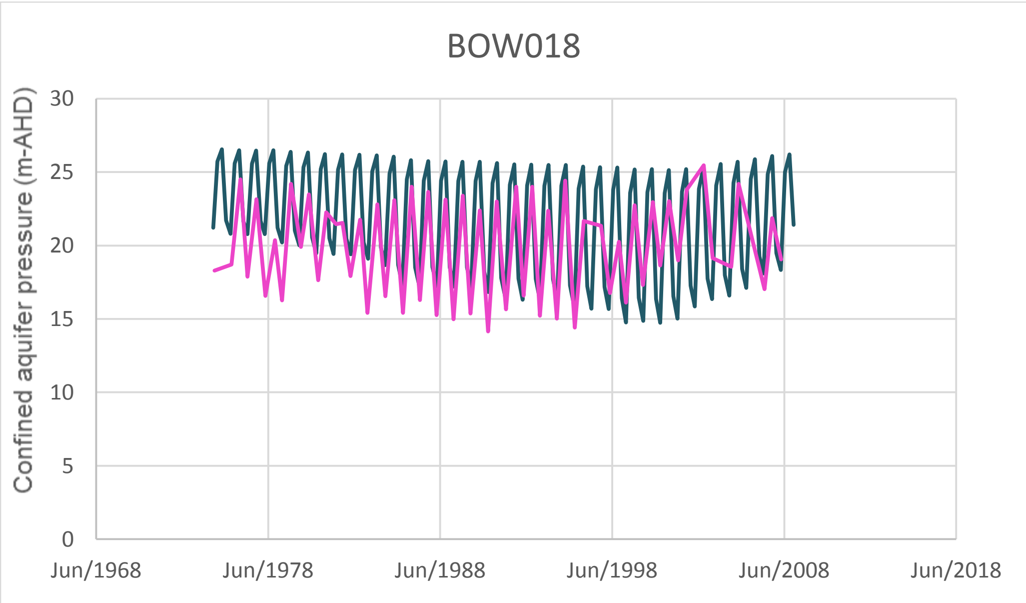
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


BOW018
Confined aquifer pressure (m-AHD)
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25
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Jun/1968
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Jun/1988
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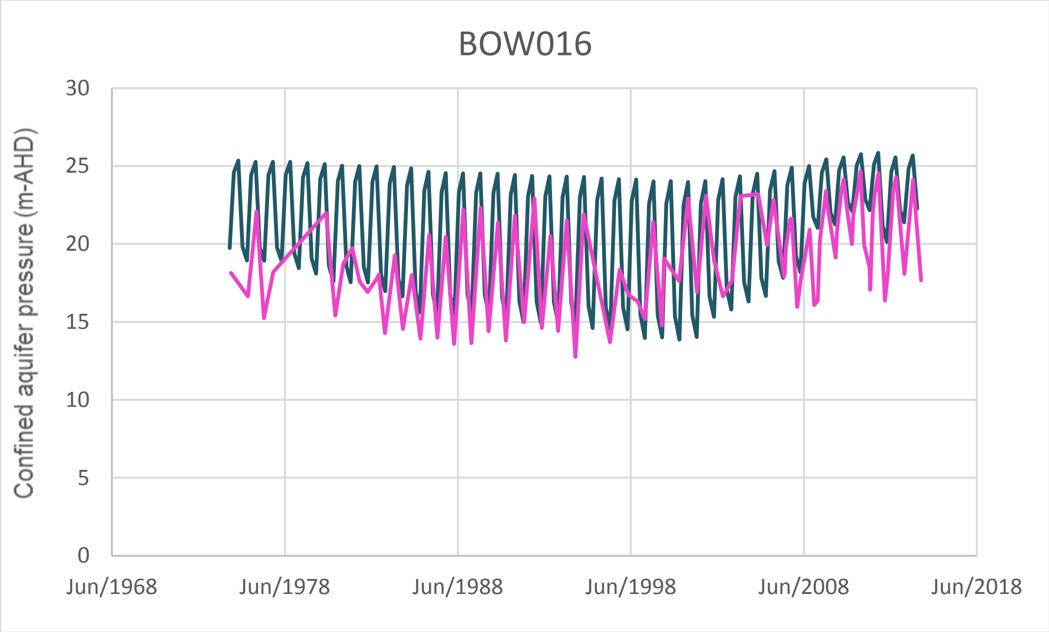
Jun/2008
Jun/2018


BOW016
Confined aquifer pressure (m-AHD)
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25
20
15
10
5
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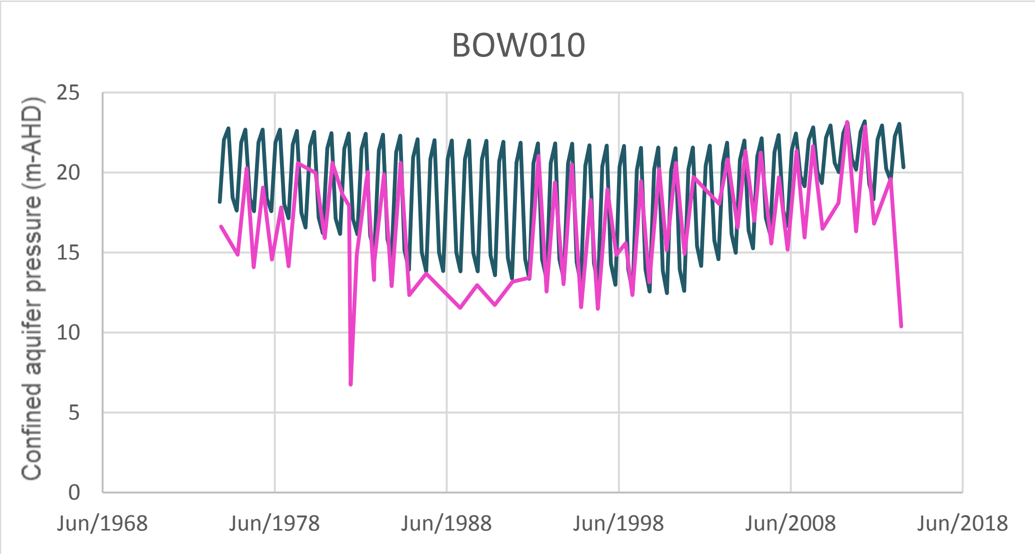
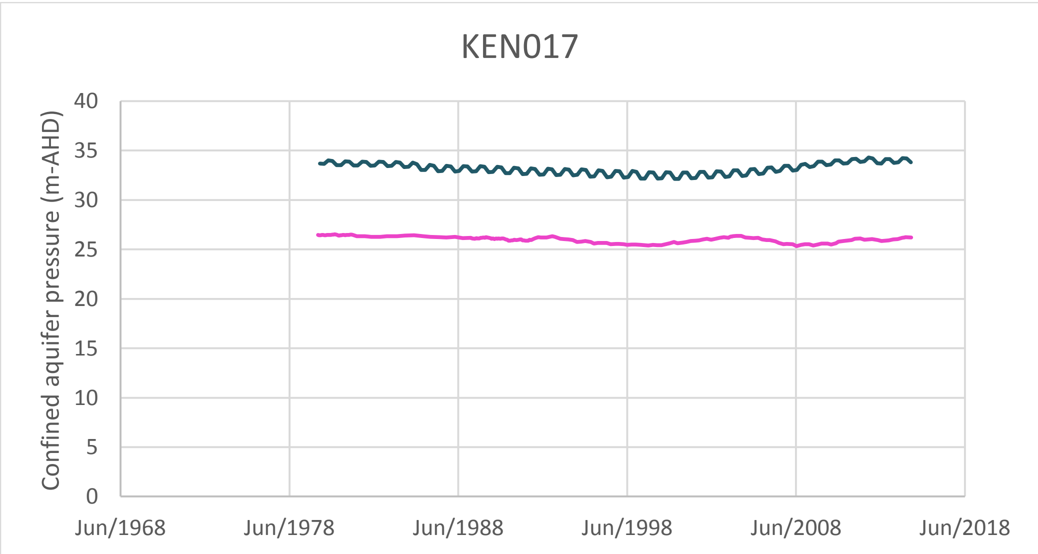
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


BOW010
Confined aquifer pressure (m-AHD)
25
20
15
10
5
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


KEN017
Confined aquifer pressure (m-AHD)
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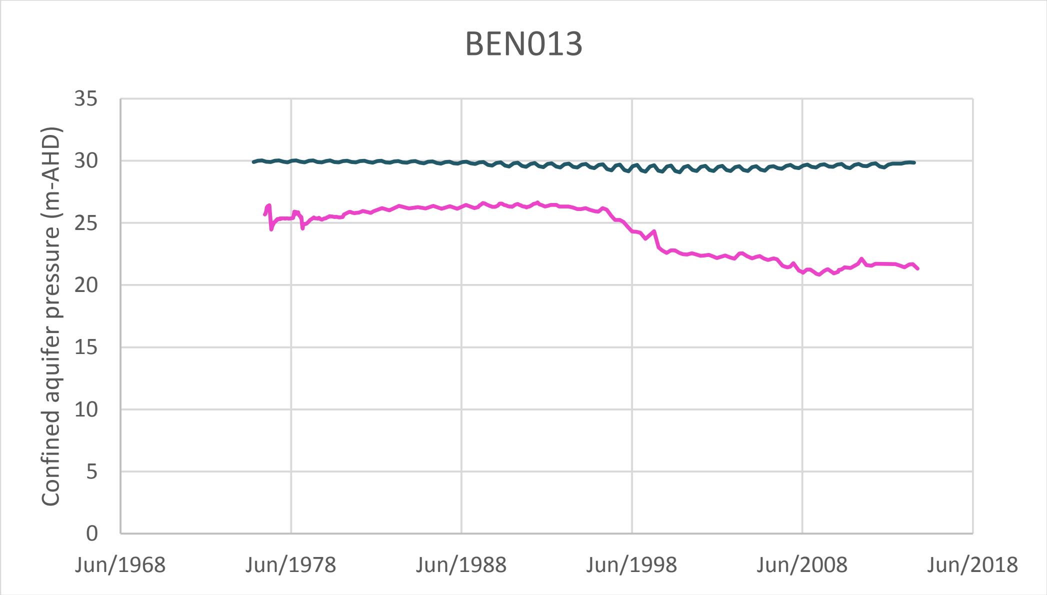
35
30
25
20
15
10
5
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018


BEN013
Confined aquifer pressure (m-AHD)
35
30
25
20
15
10
5
0
Jun/1968
Jun/1978
Jun/1988
Jun/1998
Jun/2008
Jun/2018

D. Difference between surface elevations in the refined Brown (2000) model and the Morgan et al. (2015) model

The scenarios presented in Section 4 of this report give the likely impact of different groundwater extraction volumes on the extent of artesian conditions in the TCSA. These are calculated by subtracting the modelled groundwater pressure level in the TCSA from the ground surface elevation in the model. However as outlined in Section 3.2, the ground surface elevation in the refined Brown (2000) model does not necessarily give the most accurate surface elevation (due to interpolation that occurs when importing elevation data in Visual MODFLOW). This means the artesian extents presented have an inherent error.

To assess the potential error, the surface elevation of the Morgan et al., (2015) model (where every 1 km x 1 km model cell is assigned an elevation based on the mean value given by the DEM) was subtracted from the surface elevation of the refined Brown (2000) model. Figure 8.7 shows the results. Areas of large discrepancy can be seen for elevated dune ranges and the Mt Burr Ranges (green areas indicate higher elevation in the Morgan et al., (2015) model, red areas indicate higher elevation in the Brown (2000) model).

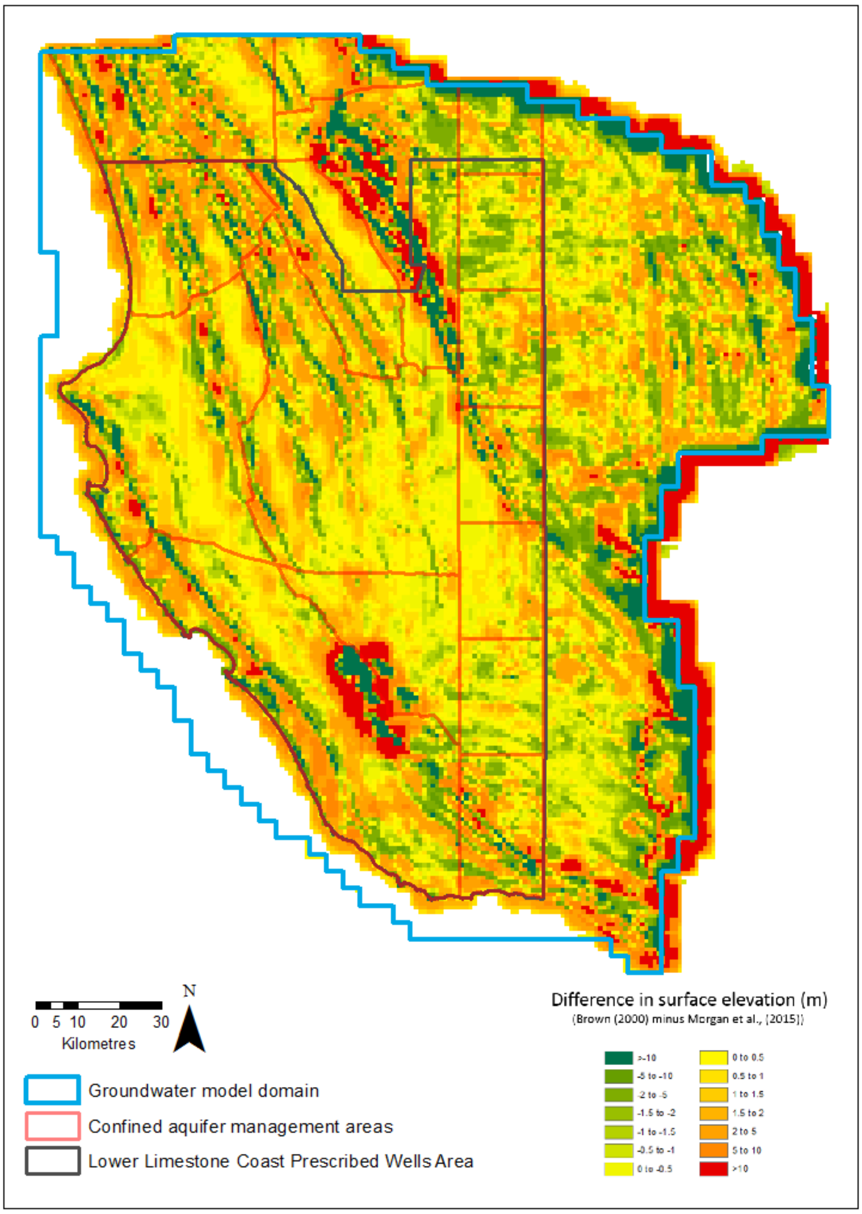


Figure 8.7 Difference in model surface elevation between refined Brown (2000) model and Morgan et al. (2015) model

Figure 8.8 shows the differences in the Kingston management area, with irrigation wells also shown. For parts of the irrigation area, the elevation difference (and thus potential error in derived artesian extent) is less than 0.5 m. However for other parts of the area, the error is up to 3m. This means the calculated artesian extents may be in error by up to 3 m. In Scenarios 2, 3 and 4, this means the fringes of the calculated artesian zone may be in error. Thus the modelled results, while a likely indicator of the impact of different extraction scenarios, should be viewed with this potential error in mind. Further work would be required to refine the elevation surface, and this was considered beyond the scope of this project.

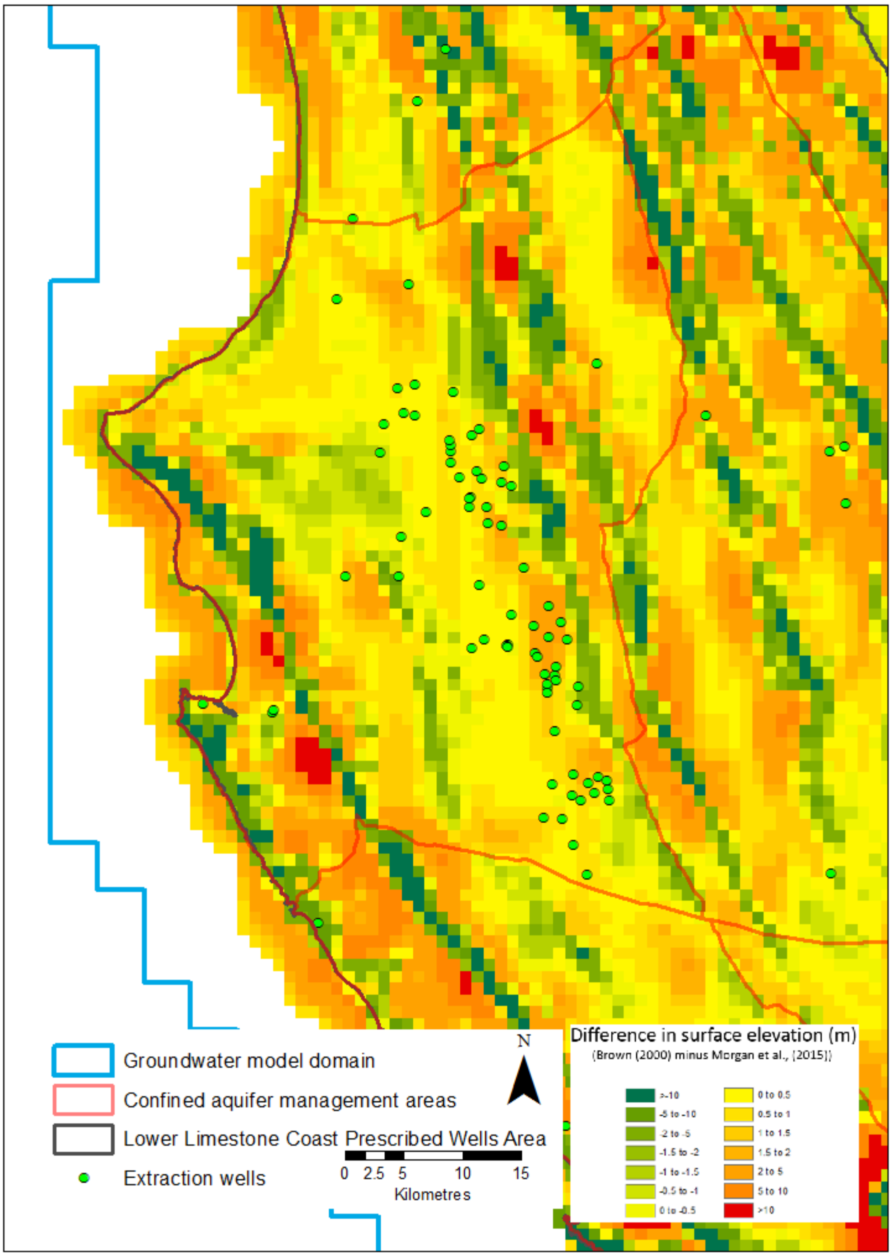


Figure 8.8 Kingston management area: difference in model surface elevation between refined Brown (2000) model and Morgan et al. (2015) model

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