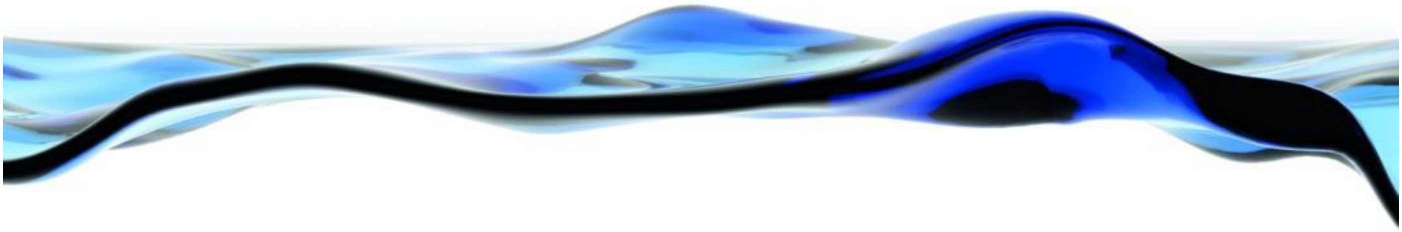
Development of a Groundwater Extraction Dataset for the South East of South Australia: 1970-2013

N Harrington and C Li



Goyder Institute for Water Research

Technical Report Series No. 15/17

www.goyderinstitute.org

Goyder Institute for Water Research Technical Report Series ISSN: 1839-2725

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia. The Institute will enhance the South Australian Government's capacity to develop and deliver science-based policy solutions in water management. It brings together the best scientists and researchers across Australia to provide expert and independent scientific advice to inform good government water policy and identify future threats and opportunities to water security.

The following associate organisation contributed to the report:

Enquires should be addressed to: Goyder Institute for Water Research

Level 1, Torrens Building

220 Victoria Square, Adelaide, SA, 5000

tel: 08-8303 8952

e-mail: enquiries@goyderinstitute.org

Citation

Harrington, N and Li, C, 2015, *Development of a Groundwater Extraction Dataset for the South East of SA: 1970-2013,* Goyder Institute for Water Research Technical Report Series No. 15/17.

Preface

South East Regional Water Balance Project Background

The South East Regional Water Balance project is a collaboration between Flinders University, CSIRO and the Department of Environment, Water and Natural Resources (DEWNR), funded by the Goyder Institute for Water Research. The project commenced in September 2012, with the objective of developing a regional water balance model for the Lower Limestone Coast Prescribed Wells Area (LLC PWA). The project was initiated following conclusions from the South East Water Science Review (2011) that, due to a number of gaps in understanding of processes that affect the regional water balance, there is uncertainty about the amount of water that can be extracted sustainably from the Lower Limestone Coast region as a whole. The review also concluded that, because of the close link between groundwater and surface water resources in the region, surface water resources and ecosystems are particularly vulnerable to groundwater exploitation.

The South East Regional Water Balance project follows on from the report of Harrington et al. (2011), which recommended that a consistent framework of models is required to support water management in the South East, with the first step being a regional groundwater flow model to:

- bring together all existing knowledge,
- address regional scale water balance questions
- provide boundary conditions for smaller scale models to address local scale questions, including those around "hotspot" areas and significant wetlands.

Harrington et al. (2011) also identified the critical knowledge gaps that limit the outcomes from a regional scale model. These included but were not limited to:

- Spatial and temporal variability in groundwater recharge and evapotranspiration.
- Interaquifer leakage and the influence of faults on groundwater flow.
- The nature of wetland-groundwater interactions
- Understanding of processes occurring at the coastal boundary
- Surface water-groundwater interactions around the man-made drainage network
- The absence of information on historical land use and groundwater extraction

The South East Regional Water Balance project has included numerous tasks that have sought to improve the conceptualisation of the regional water balance, address some of the critical knowledge gaps, incorporate this and existing information into a regional groundwater flow model and understand how this improved understanding can be used in the management of wetland water levels.

An overview of the project and its output can be found in Harrington et al. 2015 *South East Regional Water Balance Project – Phase 2. Project Summary Report.* Goyder Institute Report 15/39.

Contents

Figures

Tables

Acknowledgments

Funding for this work was provided by the Goyder Institute for Water Research, as part of the South East Regional Water Balance project. Funding was also provided by the National Centre for Groundwater Research and Training, an Australian Government initiative, supported by the Australian Research Council and the National Water Commission.

Thanks to Brenton Hodge and Saad Mustafa from the South Australian Department of Environment, Water and Natural Resources for providing the groundwater extraction data and answering numerous questions about it.

Executive Summary

As part of the Goyder Institute for Water Research funded South East Regional Water Balance project, a historical groundwater extraction dataset was produced for a large portion of the South East of South Australia. The objective of the dataset was to provide inputs for a regional groundwater flow model. The dataset is discoverable through the Australian National Data Service (ANDS) and Goyder Institute for Water Research websites, and is stored in Department of Environment, Water and Natural Resources (DEWNR) Model Warehouse.

The basis for the dataset was a metered groundwater extraction dataset for 2009-2013, provided by DEWNR. The metered dataset contained 3,812 metered groundwater extraction records. A quality check removed obvious errors and issues with inconsistent reading dates. Meter records were merged where they related to the same extraction well but different time periods. The extraction records were then assigned locations. Geographical coordinates were assigned to the meter records based on meter position data provided by DEWNR. Meter position data was not available for 1,032 wells, so the extraction volumes for these wells were distributed evenly across those wells with geographical coordinates in the corresponding groundwater management areas. This ensured that water balances were correct at least at the management area scale, but provides a source of error, particularly if this dataset is to be used in local scale groundwater models.

Extraction commencement dates were assigned to the meter records using a variety of methods with varying uncertainty associated with them. These methods included assigning the drilling dates of the associated wells provided by DEWNR (approximately 3000 meters were matched to bores in this way but only 2,811 of these had drilling dates), assigning the drilling dates of the nearest extraction well, within 500 m of the meter using a GIS matchup process, and assigning the licence activation date for the associated licence where available.

Historical groundwater extraction from 1970 to 2014 was then estimated. For the purpose of this, the average annual groundwater extraction rate for an individual bore was assumed to be constant over time. Records for the metered period (2009/10 – 2012/13) were applied to preceding years since extraction commenced at each location. This may underestimate total extraction, as irrigation efficiency has improved over time.

According to the manufactured dataset for the Lower Limestone Coast Prescribed Wells Area, groundwater extraction from the unconfined aquifer approximately doubled in each decade, with the exception of the 2000-2013 period, where the increase in extraction slowed down as a result of a reduction in allocations and the Millennium Drought. The pattern of increase for the confined aquifer was different, with the largest increases in groundwater extraction occurring in the 1990s and between 2000 and 2013.

1 Introduction

1.1 Background and Objectives

Effective historical calibration of groundwater flow models requires as much historical information about a system as possible extending as far back as the hydraulic observation record. In the South East of SA, this is approximately 1970. This requires an ability to model the effects of changing groundwater extraction over that time.

The centrepiece of the Goyder Institute for Water Research-funded South East Regional Water Balance Project is the development of a regional groundwater flow model. The focus of this groundwater flow model is the Lower Limestone Coast Prescribed Wells Area (LLC PWA), but the model domain covers the entire groundwater flow system that contains the LLC PWA. This extends as far north as Bordertown, and across the border into Victoria (Figure 1.1). The model simulates historical conditions since 1970.

One key input for the groundwater flow model is groundwater extraction, however, well extraction rates in South Australia and Victoria have only been monitored in recent years. Over the past 40 years in the South East of South Australia, areas of land under irrigation, and hence the volumes of groundwater extraction, have increased significantly. The lack of historical groundwater extraction information for this region was identified early in the development of this project as a significant limitation to model development (Harrington et al., 2011). Metering of extraction bores in the South East commenced under the National Water Initiative and reasonable quality metered groundwater extraction data exists from 2009/10 onwards.

To support the development of the regional groundwater flow model, a model-ready dataset of current metered groundwater extraction was required for both the South Australian and Victorian portions of the study area, as well as reasonable estimates of historical groundwater extraction back to the beginning of the model calibration period, i.e. 1970.

This report describes the development of the historical groundwater extraction dataset for the South Australian portion of the study area. This exercise formed a sub-project within Task 1 of the South East Regional Water Balance project: Development of a regional groundwater flow model. It is reported separately from the regional model development because of its potential applications outside the development of groundwater flow models. The focus of this report is on the development of the South Australian dataset. The application of Victorian groundwater extraction data in the regional model is described in the regional model report Morgan et al. (in prep.).

The objectives of this sub-project were to:

- Develop a model-ready consolidated dataset of groundwater extraction for the South Australian portion of the model domain, which includes:
    a. metered groundwater extraction data obtained from DEWNR for 2009/10 to 2012/13.
    b. estimated historical groundwater extraction from 1970 to 2014, generated based on all available information, e.g. well construction records.

The dataset produced as part of this sub-project is discoverable through the Australian National Data Service (ANDS) and Goyder Institute for Water Research websites and available through the DEWNR Model Warehouse.

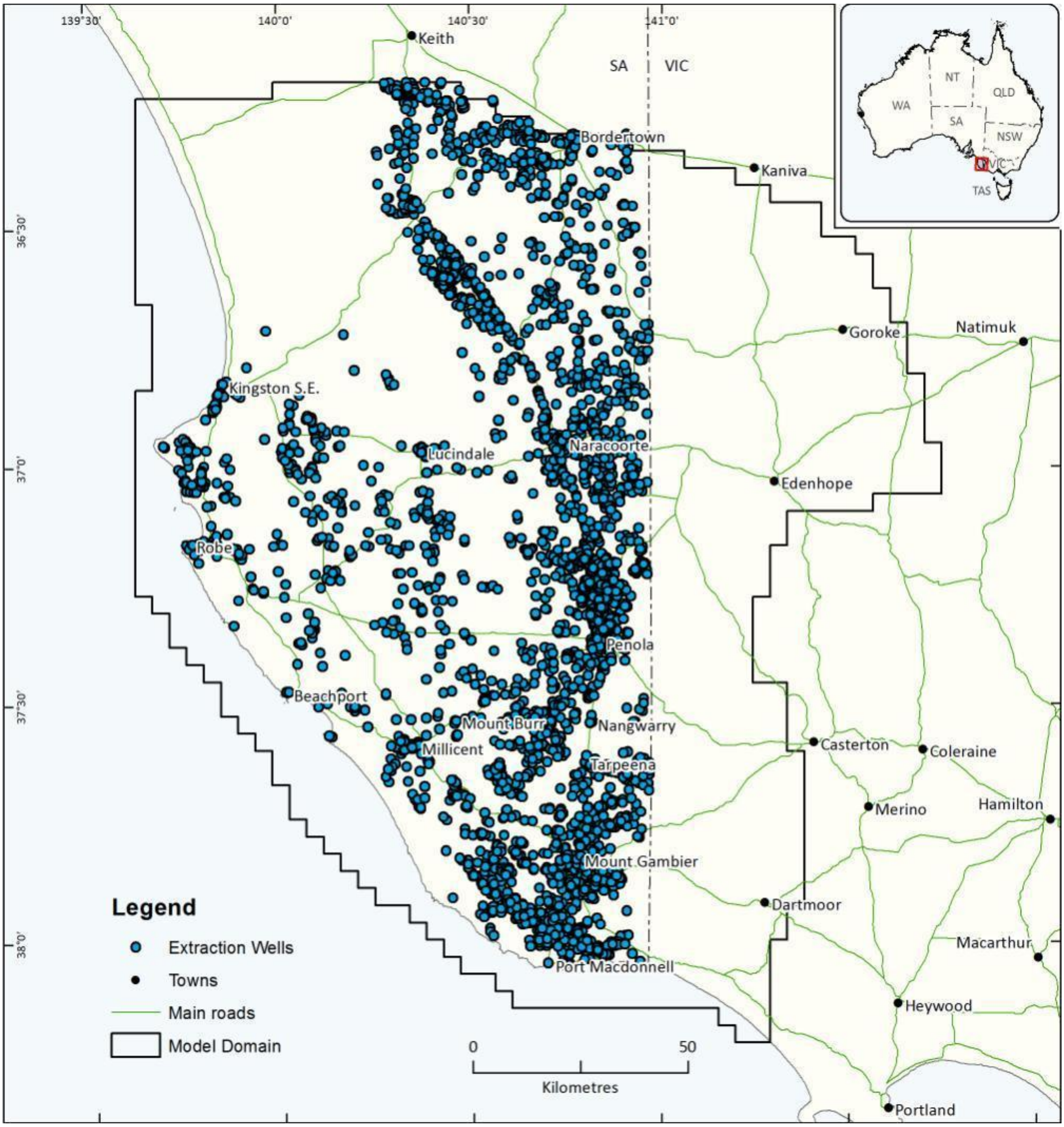


Figure 1.1 Domain of the South East Regional Water Balance Model, showing all metered groundwater extraction wells for the South Australian portion of the model domain.

1.2 Associated Reports and Research Papers

The following reports and journal papers are also associated with the South East Regional Water Balance Project:

Technical Reports:

Harrington, N and Lamontagne, S (eds.), 2013*, Framework for a Regional Water Balance Model for the South Australian Limestone Coast Region.* Goyder Institute for Water Research Technical Report 13/14.

Morgan, LK, Harrington, N, Werner, AD, Hutson, JL, Woods, J and Knowling, M, 2015, *South East Regional Water Balance Project – Phase 2. Development of a Regional Groundwater Flow Model.* Goyder Institute for Water Research Technical Report 15/38.

Doble, R, Pickett, T, Crosbie, R, Morgan, L, 2015, *A new approach for modelling groundwater recharge in the South East of South Australia using MODFLOW,* Goyder Institute for Water Research Technical Report 15/26.

Taylor, AR, Lamontagne S, Turnadge, C, Smith, SD and Davies, P, 2015, *Groundwater-surface water interactions at Bool Lagoon, Lake Robe and Deadmans Swamp (Limestone Coast, SA): Data review.* Goyder Institute for Water Research Technical Report 15/13.

Smith, SD, Lamontagne, S, Taylor, AR and Cook, PG, 2015, *Evaluation of groundwater-surface water interactions at Bool Lagoon and Lake Robe using environmental tracers.* Goyder Institute for Water Research Technical Report 15/14.

Turnadge, CJ and Lamontagne, S, 2015, *A MODFLOW–based approach to simulating wetland–groundwater interactions in the Lower Limestone Coast Prescribed Wells Area*. Goyder Institute for Water Research Technical Report 15/12.

Barnett, S, Lawson, J, Li, C, Morgan, L, Wright, S, Skewes, M, Harrington, N, Woods, J, Werner, A and Plush, B, 2015, *A Hydrostratigraphic Model for the Shallow Aquifer Systems of the Gambier Basin and South Western Murray Basin.* Goyder Institute for Water Research Technical Report 15/15.

Harrington, N, Millington, A, Sodahlan, ME and Phillips, D, 2015, *Development of Preliminary 1969 and 1983 Land Use Maps for the South East of SA*. Goyder Institute for Water Research Technical Report 15/16.

Harrington, N, Lamontagne, S, Crosbie, R, Morgan, LM and Doble, R, 2015, *South East Regional Water Balance Project: Project Summary Report.* Goyder Institute for Water Research Technical Report 15/39.

Research Papers:

Crosbie RS, Davies P, Harrington N and Lamontagne S (2015) *Ground truthing groundwater-recharge estimates derived from remotely sensed evapotranspiration: a case in South Australia.* Hydrogeology Journal 23(2), 335-350.

Lamontagne S, Taylor A, Herpich D and Hancock G (2015) *Submarine groundwater discharge from the South Australian Limestone Coast region estimated using radium and salinity.* Journal of Environmental Radioactivity 140, 30-41.

2 Methodology

Four main stages were required to produce the groundwater extraction dataset for 1970 to 2014:

- quality checking of the metered data from 2009 to 2014
- assignment of locations to each meter
- assignment of an extraction commencement date for each meter
- estimation of consumption prior to 2009/10

2.1 Quality checking of 2009-2014 meter data

Metered groundwater extraction data was obtained from the DEWNR South East Office in Excel spreadsheet format for the years 2009/10 to 2012/13. This includes water extracted for irrigation, municipal supply, stock and industry. Note that this dataset includes surface water pumping from the Blue Lake, under an unconfined aquifer licence. A preliminary assessment of the raw dataset provided by DEWNR identified that it required quality-checking and was also not in a format that could be readily used in a groundwater model.

The following issues were addressed to quality-check the data and remove discrepancies and errors.

1) Variability in meter read period.

Although the datasets should ideally apply to irrigation years (July 1st – June 30th), the datasets for each year consisted of meter readings that were loosely based around these dates, which is not unexpected for readings made by licensees (e.g. reading periods may go from May 7th – June 1st, or August 1st – July 31st, with the odd interim reading between these times). Additional readings had also been made during the year by DEWNR employees, with these recorded, but little guidance provided regarding the implications for the final usage value that should be applied to that meter. As a result, there was a great deal of uncertainty about which readings should be used to estimate the annual extraction for a given meter.

As an initial strategy, for meters that did not have readings taken exactly on 1st July (or 30th June), readings from the closest date were used, and for some meters the closest date may be slightly outside the specified period of time (e.g. earlier than 1st July or later than 30th June). All the readings taken during the specified period of time for a given meter were summed to get the annual extraction.

2) Typographic errors, negative use values and multiple readings.

There were a number of obvious typographic errors in the dataset that required close assessment of the data (approximately 6,000 rows of data) and a number of negative volume values that could not be explained. Many of the negative volume values were small in magnitude (< 10 kL). Some large negative volume values had an “adjustment” recorded against them, and addition of the “adjustment” resulted in a positive or zero extraction value. There was also a significant number of large (>10 ML) negative use values that could not be explained, and these needed to be assessed on a case-by-case basis. In some cases, there were multiple meter readings that were close together (some resulting in negative values). As a default strategy, if the sum of uses was negative for a given meter, its total water use for that year was changed to zero. It is understood that negative values in the dataset may represent an identified reading error (S Mustafa, DEWNR, pers. comm., March 2015), however, the best way to adjust these was unclear. Assigning a usage of zero to these meters may result in an underestimate of total groundwater use.

Most of these issues required manual handling of the data.

2.2 Assigning Locations.

For use in a regional groundwater model, it was considered that meter position data could be used to represent the location of the groundwater extraction (i.e. it was considered that meters and the relevant extraction bores are generally close together relative to the scale of a regional model grid, which is of the order of 1 km x 1 km). Meter location data was provided by the DEWNR South East Office. However, there were 1032 meters that did not have position data. As it is impossible to input these as production bores into the groundwater flow model without position data, these were deleted from the preliminary dataset. However, extraction volumes for meters that did not have position data were summed for each Management Area. A number of meters also did not have Management Area information. However, they did have licence numbers, and were assigned to the same Management Area as meters listed under the same licence. These "unpositioned volumes" were divided equally amongst the meters that did have position data and added to their totals. This ensured that the overall water balance for each Management Area is correct, although it may have some impact on local-scale drawdowns.

2.3 Assigning Commencement Dates

The following process was used to add historical extraction commencement dates to the dataset:

2.3.1 ADDITION OF BORE DRILLING DATES.

For the purpose of building up a picture of historical groundwater extraction over time, activation dates for each extraction well were sought. It was considered that the most accurate representation of this would be the drilling date of the associated extraction bore. Well unit numbers associated with some of the meters were provided by the DEWNR South East Office and S. Barnett, pers. comm. (2014). This provided 2,811 "start dates" for the dataset of 3,812 records. The remaining meters were associated with an extraction bore using a spatial matchup process in ArcGIS. Meters were associated with the nearest extraction bore as long as they were within 500 m of each other. Drilling dates for the associated extraction bore were then obtained from the SA Government drillhole dataset, SA Geodata. This added 817 "start dates" to the dataset.

2.3.2 ADDITION OF LICENCE ACTIVATION DATES

Following this process, there were still a number of meters that did not have associated commencement dates (either there was no drill date for the well recorded in SA Geodata or the attempts to associate a meter with an extraction well had been unsuccessful). The next step was to obtain licence activation dates through the DEWNR licencing dataset and apply these to the meters listed under that licence. This added an additional 60 "start dates" to the dataset.

2.3.3 CONSOLIDATION OF DATA

Although this process provided activation dates for most meters, 534 meters remained without activation dates. These were dealt with as described in (6) below.

3) Consolidation of time series data – duplicate meter serial numbers.

Annual data for each meter was brought together to provide a time series. In some cases, slight variations in meter serial numbers were identified (e.g. 412345 vs 0412345), which were removed.

4) Multiple meters associated with one extraction bore.

In many cases, landholders had changed meters on a particular extraction well during the period of the dataset (2009-2013) due to, e.g. meter failure. This could be identified by two meter serial numbers with the same co-ordinates associated with the same licence. In most of these cases, one meter had readings for some of the years in the metering period, whilst the other had readings for the remainder of the years. Also, in most of these cases, only one of these meters had an activation date. The process for consolidating this data was to:

- Identify the meters that had the same licence number and same spatial co-ordinates.
- Add together the uses for each year for these meters (in some cases, a meter was changed part-way through a year and hence both meters had readings for that change-over year, which needed to be added together).
- Assign the data to the meter that had an activation date.
- Note the redundant meter serial number against this meter for future reference.
- Delete the record for the redundant meter.

This procedure also eliminated many meters without activation dates.

2.3.4 ASSIGNING "BEST GUESS" COMMENCEMENT DATES

After all of the above processes, there was still 124 meters that did not have activation dates. For these, the following process was used to assign "best guess" activation dates:

- If there were other meters associated with the same licence that did have activation dates, the earliest activation date of these was assigned.
- If this was not the case, a spatial analysis was performed and the activation date of the nearest meter was assigned to the meter in question.
- In some cases, the date of prescription of the associated Management Area was used, as indicated in the notes in the dataset.

The broad assumption behind all of these methodologies was that development of groundwater resources in certain areas may have commenced within a certain window of time, with irrigation wells in that area commencing extraction around the same time. It has been noted that these wells that have had their start dates "manufactured" should be the first ones to be considered if there appears to be problems with the historical groundwater extraction data.

5) Wells outside the model domain for the South East Regional Water Balance Model were deleted – i.e. some Management Areas cross over the boundary of the model domain.
6) Missing aquifer data.

The management area details for a meter indicated whether it was extracting from the unconfined or confined aquifer. Meters that did not contain management area details were assumed to target the unconfined aquifer.

2.4 Estimation of Historical Groundwater Extraction

A time-series groundwater extraction dataset was developed using the metered extraction data by:

1) Calculating the average groundwater extraction volume for each meter over the metered period (2009/10 – 2012/13) and assuming this average applies from the "start date" of the meter.
2) Assuming a well starts extracting groundwater at the extraction commencement determined above.

This method was applied in the development of the Wimmera CMA Groundwater Model (Sinclair Knight Merz, 2010b) and Glenelg Hopkins CMA Groundwater Model (Sinclair Knight Merz, 2010a), which cover the Victorian portion of the model domain. However, this neglects the fact that irrigation efficiency has probably improved over time.

2.5 Public Water Supply Wells

A number of the pumping commencement dates for the wells with Public Water Supply use types are not likely to represent the actual commencement of pumping for that public water supply. The commencement dates are generally based upon the drill dates of the associated bore, and many of these have been replaced over the history of the water supply, with commencement date in the 1990s or 2000s. In this case, the start date listed would represent the drilled date for the replacement well and the actual commencement of pumping would be much earlier than this.

2.6 Surface Water Extractions from Blue Lake

Extraction of surface water from Blue Lake for Mt Gambier's town water supply increased steadily from 1900 to 1965 and has remained between 3,000 ML/y and 4,000 ML/y since 1965 (**Error! Reference source ot found.**). As Blue Lake contains predominantly unconfined aquifer groundwater and is, indeed a "window" into the groundwater system, this extraction can be considered to be synonymous with a groundwater extraction from a production bore. There is an unconfined aquifer licence (licence number 11230) associated with Blue Lake pumping wells. Extraction of surface water from Blue Lake is included in the metered groundwater extraction dataset described above under this licence number, in the same format as for the other metered extractions. However annual extraction data for Blue Lake is also available for the period 1891 to present, and this is provided in a separate worksheet in the Excel dataset (S. Mustafa, DEWNR, pers. comm., 2013).

2.7 Extractions for the Kimberley Clark pulp and paper mills (Millicent and Tantanoola)

The Kimberley Clark Tantanoola and Millicent pulp and paper mills opened in the 1960s and groundwater extraction peaked at 60 ML/day in the 1990s (Kimberley-Clark Australia and New Zealand, 2012; J. Lawson, DEWNR, pers. comm. 2014). Since then, water use has been gradually reduced and reached 30 ML/day just before the closure of the Tantanoola Mill in 2011 (Kimberley-Clark Australia and New Zealand, 2012); J. Lawson, pers. comm. 2014). The current rate of extraction is between 8 ML/day and 10 ML/day, with annual data available since 2003.

Because of the different temporal information available about the pulp mill extractions, the data is not included in the main metered extraction spreadsheet but as a separate worksheet within the same Excel file. Annual extractions for the eight production bores are provided from 2003/04 to 2013/14. Prior to this, total groundwater extraction is assumed to be 60 ML/d, spread evenly across all eight production bores. Monthly data provided for the 2012/13 and 2013/14 water years showed that extractions are extremely constant on a monthly basis and hence annual extraction values provided can be spread evenly across the year.

3 Results

Table 3.1 compares the total groundwater extraction from the quality-checked dataset and the values reported by DEWNR in Annual Water Use reports for the same management areas studied. The objective of this comparison was to determine whether the modifications made to the dataset significantly changed the regional extraction values from those previously reported by DEWNR. The table also shows the magnitude (as both a total and as a percentage of total calculated use) of the groundwater extraction for which no co-ordinates could be assigned and hence this was averaged across the wells for the relevant management area.

Table 3.1 Regional scale comparison between groundwater extraction estimates from the modified metered extraction dataset (2009-2013) and extraction values reported by DEWNR using the un-modified metered dataset.

	2009/10	2010/11	2011/12	2012/13
Total Use (calculated)	353,888	243,834	353,886	342,918
Total Use (DEWNR reported)	379,852	245,556	328,333	371,143
Absolute Difference (as % of calculated Total Use)[#]	24	2.2	7	11.6
Use for wells with no co-ords (un-positioned wells)(A)*.	46,797	3,545	974	2,446
(A) as % of Total Use (calculated)	13	1.5	0.3	3.3
Difference if un-positioned wells are included in calculations (as % of calculated Total Use)	**8**	**0.8**	**10**	**9**

[#] Absolute differences are the sum of the absolute (non-negative) differences for each management area, so that positive and negative differences cannot cancel each other out. Hence, the value shown in this row does NOT relate to the difference between the two rows above.

* These uses are divided equally amongst other meters in the same Management Area to reduce the impact of this on the regional water balance.

Historical estimates of groundwater extraction made by “historical extrapolation” of the metered extraction data for each Management Area are compared with historical estimates developed from landholder supplied Annual Water Use Returns, where these were available, in Figure 3.1. These are the only historical groundwater extraction estimates available and are based upon the collation of landholder-supplied estimates made using the old Irrigation Equivalent System, as described in Chapter 8.8 of the

Phase 1 report (Harrington et al., 2013). This data was previously reported by DEWNR (and predecessors) in Annual Water Use Reports, as referenced in Harrington et al. (2013). Some extra data for the Padthaway PWA is also included, as IE data for this PWA was available from as early as 1985/86. The earliest data available for other PWAs was from 1997/98.

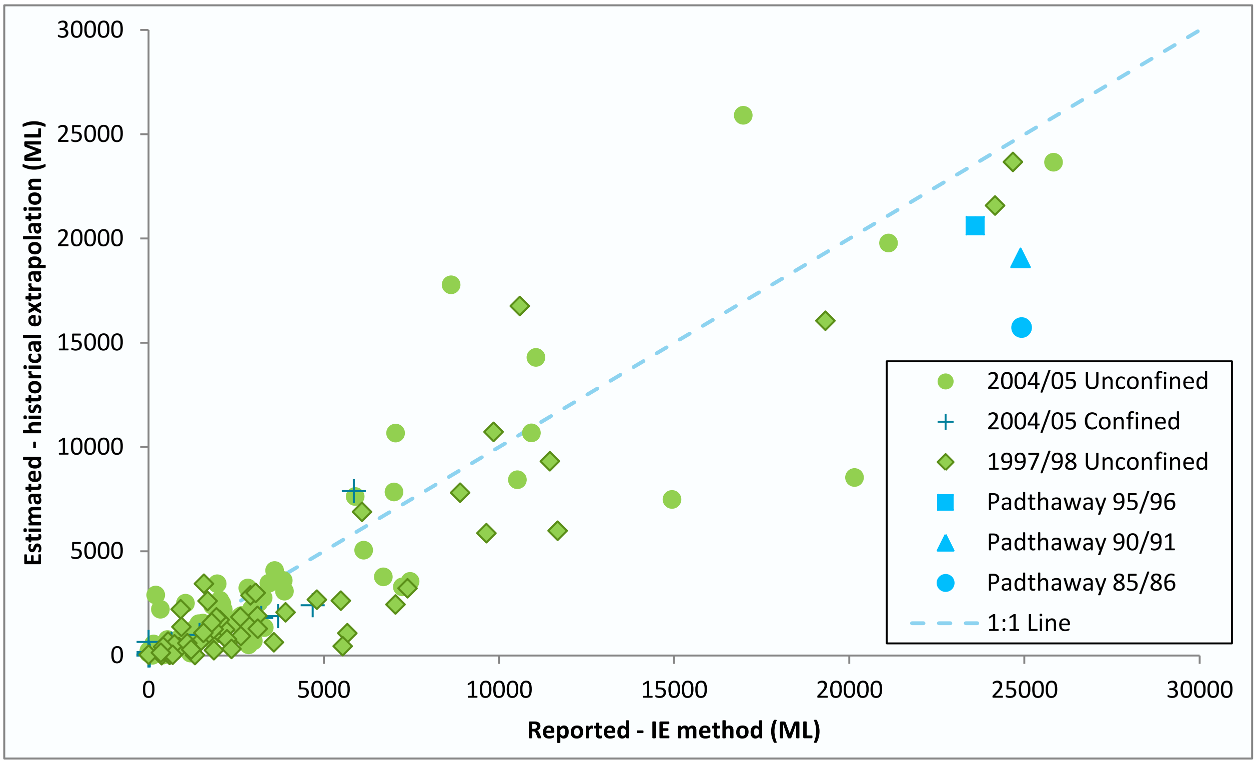


Figure 3.1 Comparison between historical groundwater extraction estimates from "historical extrapolation" of the metered extraction data and Irrigation Equivalent data for each Management Area.

Figure 3.1 shows that, in general, the method using current metered data (and annual averages for wells derived from this data) underestimates historical groundwater use compared with the Irrigation Equivalent (IE) estimates, with a few exceptions. This is not unexpected, as irrigation efficiencies are known to have improved over the past decade, although it must be noted that the likely errors associated with estimates made using the IE method are at least as high as those associated with the historical extrapolation of metered data.

Reasons for the discrepancies could be sought on the Management Area scale, based upon historical irrigation practices for those areas and related information, however, this is unlikely to greatly improve our ability to determine historical extraction.

The majority of licenced groundwater extraction wells are for irrigation purposes, so comparison of their historical locations, based on the extraction "commencement dates" assigned as above, with historical maps of irrigation areas can provide some insight into the accuracy of the database. The earliest available digital historical land use map, which is for 1998, was compared with the locations of the groundwater extraction wells that were identified through the methodology described above to be present in 1998. A process of eliminating extraction wells if they have an irrigation use type but are not within a certain distance of an irrigated area could be undertaken to refine the dataset. However, uncertainties in the mapping of irrigated land uses do not warrant such an action at this stage. Figure 3.3 shows the same comparison for 2008 and the increase in the density of groundwater extraction bores over the ten year period is evident in the two maps.

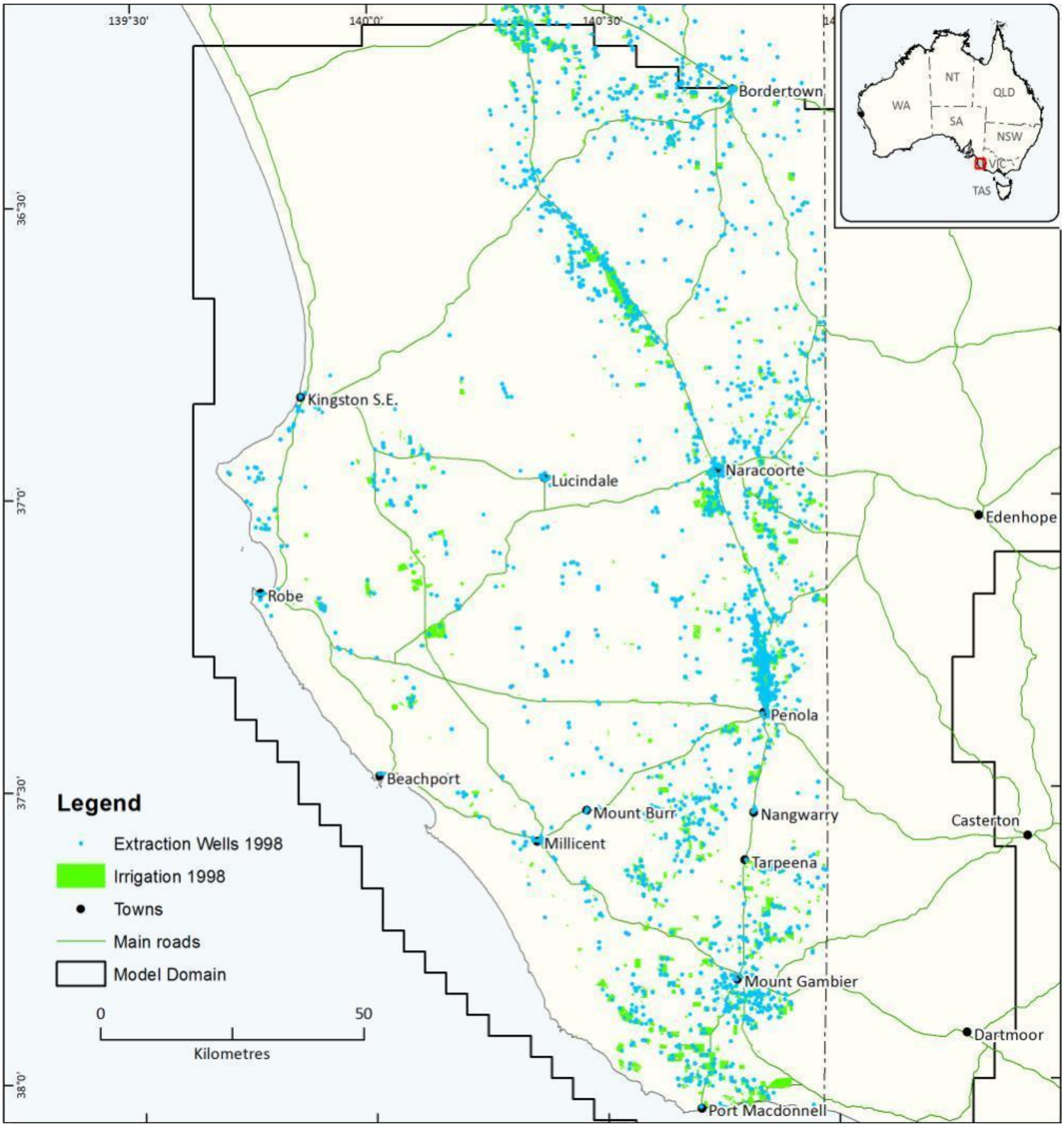


Figure 3.2 Locations of 1997/98 irrigation wells compared with the irrigation areas identified in the 1998 land use map.

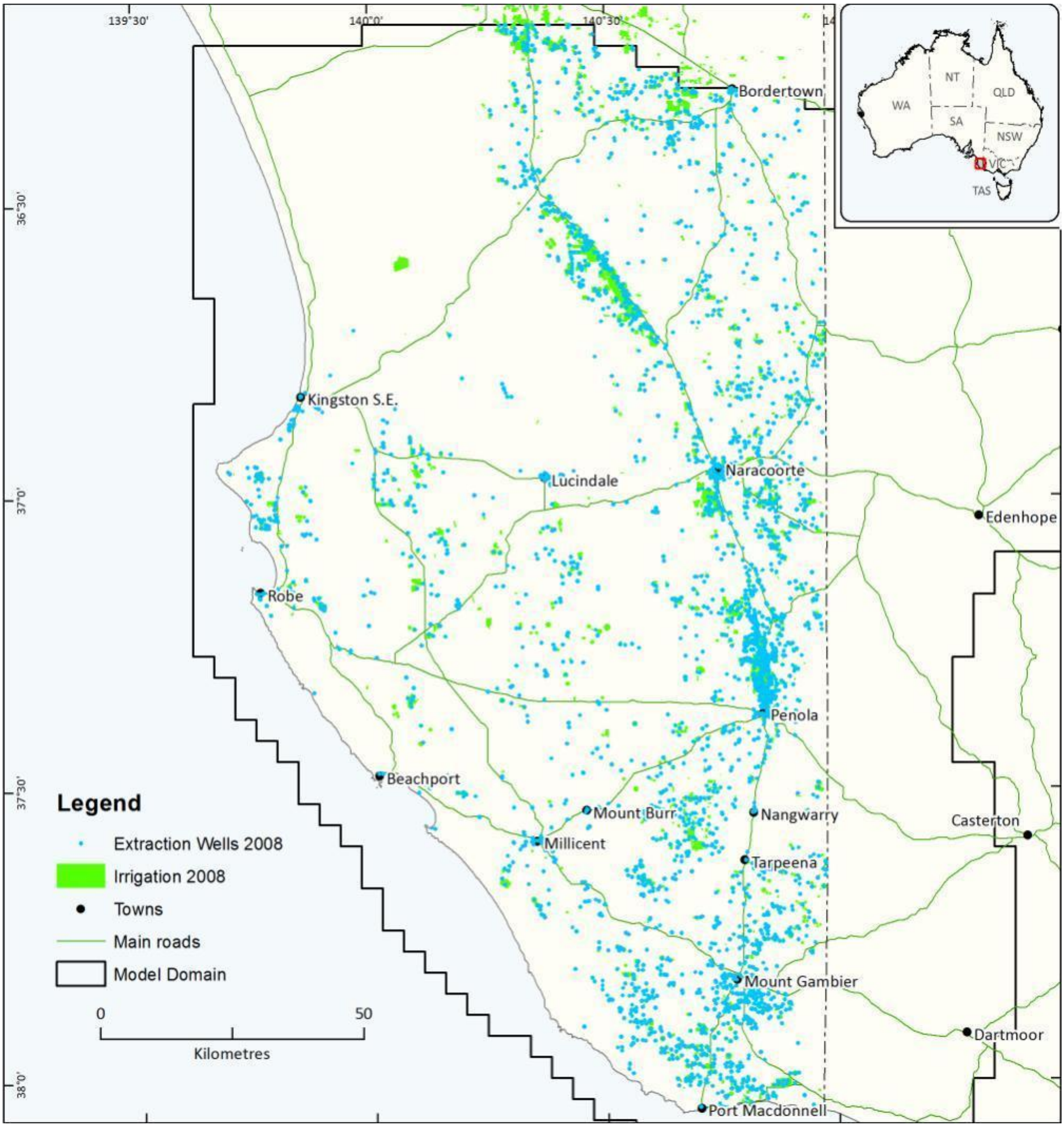


Figure 3.3 Locations of 2007/08 irrigation wells compared with the irrigation areas identified in the 2008 land use map.

Figure 3.4 summarises the historical data produced, showing total groundwater extractions at the beginning of each decade for the unconfined and confined aquifers, for both the whole study area of the South East Regional Water Balance project and the Lower Limestone Coast PWA. The '2013' values are based on the 2012-13 metered dataset, whilst the values for other years are based on the dataset created as described in Section 2.4. The graph shows an apparent increase in groundwater extraction in the Lower Limestone Coast PWA from 1970 to 2013, from 21 GL/yr to 194 GL/yr for the unconfined aquifer and 1 GL/yr to 14 GL/yr for the confined aquifer. Groundwater extraction from the unconfined aquifer approximately doubled in each decade, with the exception of the 2000-2013 period, where the increase in extraction had slowed down. The pattern of increase for the confined aquifer is slightly different, with the largest increases in groundwater extraction occurring in the 1990s and between 2000 and 2013.

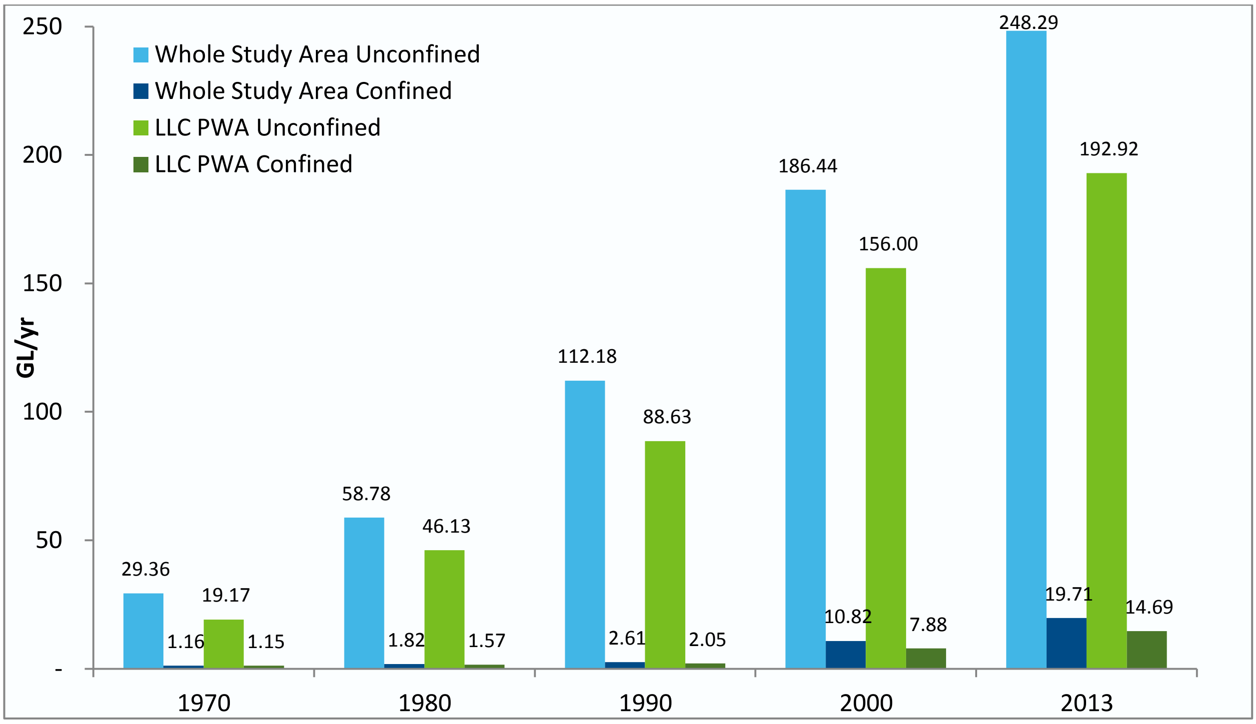


Figure 3.4 Estimated decadal groundwater extraction (GL/yr) from the unconfined and confined aquifers for both the whole study area of the South East Regional Water Balance project and the Lower Limestone Coast PWA.

4 Discussion

4.1 Summary and Limitations

The metered groundwater extraction dataset produced through this project is in Microsoft Excel spreadsheet format and includes:

- Metered groundwater extraction data for the 2009/10 – 2012/13 irrigation years, modified as described in Section 2. This includes data on: Licence Number, Meter Serial Number, Management Area, meter OR irrigation bore co-ordinates, assumed irrigation “start date”, metered use for the years 2009/10 – 2012/13, average use for that period and some comments on changes that were made to the dataset associated with various meters, or the method of assigning a meter “start date”.
- The extraction data includes values for wells with no position data, divided equally among and added to wells in the same Management Area, as described in Section2.
- Management Area-scale comparisons between historical estimates derived from the metered data, and estimates from compilations of Annual Water Use Returns, where available.
- Groundwater extraction by the Kimberley Clark pulp and paper mills at Snuggery (near Millicent) and Tantanoola. This dataset was provided separately by DEWNR, has a different format from the metered licenced extraction data, and is included in a separate worksheet within the Excel dataset.

Due to the broad assumptions made to convert the original dataset into a useable product for groundwater modelling, the uncertainties in the values provided in the final dataset are large. However, care has been taken to ensure that all assumptions made and methodologies used to develop the dataset are logical and reasonable, and this dataset now represents the best currently available. The limitations of the dataset should be clearly understood by all primary and secondary users and can be listed as follows:

- Annual extraction values for each meter often do not apply exactly to the period July 1st – June 30th, but can vary by up to a month either side of these dates. This may introduce uncertainty of up to the order of a ML for some wells.
- A large number of anomalous values, including negative values, and duplicate readings (e.g. by both licensees and DEWNR staff, where both were retained in the dataset) were dealt with to the best of our ability based upon our understanding of how the data was collected, however this introduces random uncertainty that may be up to tens of ML for some bores.
- 1,032 meters did not have spatial co-ordinates associated with them, but did have a Management Area assigned. Their extraction values have been accounted for in the regional estimates by distributing them amongst the other wells in the same Management Area. This is considered to be sufficient for regional scale water balance modelling, but may impact the outcomes of local scale modelling. These meters do not exist explicitly in the final dataset and their details can be found in Master meter spreadsheets for all years v3.xlsx.
- There is large uncertainty in extraction “start dates” assigned to the meters. In order of increasing uncertainty, these were assigned to the 3,812 meter records by:
    - Assigning the drilling dates of the associated wells provided by DEWNR (approximately 3000 meters were matched to bores in this way but only 2,811 of these had drilling dates).
    - Assigning the drilling dates of the nearest extraction well, within 500 m of the meter using a GIS matchup process (882 meters were matched up to bores using this method, of which 817 had drilling dates).
    - Assigning the licence activation date for the associated licence where available (i.e. not all licences have activation dates listed for them). Note that the uncertainty of this is that there may have been some wells that were operational before licencing was introduced. This added approximately 60 “start dates” to the dataset.

- For the 124 meters that still remained without a “start date”, these were assigned using: the earliest “start date” of the other meters on the same licence (i.e. where a licence activation date had not been available), the “start date” of the nearest meter with a start date, or the date of prescription of the associated Prescribed Wells Area.

4.2 Recommendations

4.2.1 FUTURE COLLECTION, QUALITY CONTROL AND ARCHIVING OF METERED GROUNDWATER EXTRACTION DATA

Because of the large area and sheer number of meters present, it is recognised that collation of an accurate dataset on groundwater extraction is labour intensive and therefore difficult to achieve. However, our experience with this dataset allows us to make the following recommendations for the development and maintenance of the dataset for use in technical investigations, if this is to be one of its objectives:

- A database manager should be assigned to be responsible for data entry, with time allocated for quality checking.
- A log should be kept of mid-season meter readings that are carried out as a quality control measure by DEWNR staff, with notes that are detailed enough for the person entering the data to be able to interpret how this should change the final use value if required.
- All manual reading data should be entered or reviewed at the close of the metering period (with the notes included) with the final annual use calculated based on this ***at the time of entry***. Currently the dataset contains readings only, including the duplicate readings, with no final annual use calculated. There is some notation provided about whether an adjustment is required but this is often ambiguous and difficult for a third party who is not involved in the data collection to interpret. Requiring the end-users of the data to make these adjustments provides large opportunities for errors to be made based on misinterpretation.
- At the close of the meter period, and once the data is entered, a standard quality control process should be undertaken, where, for example (1) all negative and anomalous use values should be reviewed. Anomalous values could perhaps be identified based on a percentage change from a historical trend. (2) Random records (an agreed percentage of the whole dataset) should be checked against the records that led to the estimated use value, with a report made of the number of errors discovered.
- Cost-effective ways should be explored for the development of the dataset of meter positions (and/or associated extraction bore positions, depending on what is logistically feasible), and extraction start dates.

4.2.2 TO IMPROVE THE HISTORICAL ESTIMATES

The historical estimates of groundwater extraction provided in this report are the best currently available. However, there is further work that could be done to improve these, particularly at local scales. For example:

- Refining the information on bore commencement dates based on historical land use maps (i.e. adjusting the locations of bores based upon land uses that would have required groundwater extraction e.g. irrigation, industrial and recreational.
- Adjusting the records for Public Water Supply wells based upon anecdotal evidence of extraction commencement dates and town sizes.
- Adjusting values for irrigation extractions within Management Areas based upon anecdotal evidence of historical irrigation practices. i.e. changes to more efficient practices.
- Developing a method to scale the historical data based upon climate (rainfall and evapotranspiration).

References

Harrington N, Li C, Woods J, Barnett S, Lawson J, Plush B and Skewes M (2013) Data review and conceptual model. In: Harrington N and Lamontagne S (eds) Framework for a regional water balance model for the South Australian Limestone Coast Region. Goyder Institute for Water Research Technical Report Series No. 13/14. http://www.goyderinstitute.org/uploads/South_East_Water_Balance_Final%20for%20web_high.pdf

Harrington N, Wood C and Yan W (2011) Lower South East Water Balance Project Phase 1 - Review of the Conceptual Model and Recommendations for a Modelling Approach. Department For Water Technical Report No. 2011/12. Adelaide. https://www.waterconnect.sa.gov.au/Content/Publications/DEWNR/DFW_TR_2011_12.pdf

Kimberley-Clark Australia and New Zealand (2012) Kimberly-Clark's Waste Water Reduction Strategy. Viewed 29th Jan 2015, <http://www.kimberly-clark.com.au/en/sustainability/planet/climate-change-global-warming/water/>.

Morgan, LK, Harrington, N, Werner, AD, Hutson, JL, Woods, J and Knowling, M, In prep., *South East Regional Water Balance Project – Phase 2. Development of a Regional Groundwater Flow Model.* Goyder Institute for Water Research Technical Report. 15/XX

Sinclair Knight Merz (2010a) Glenelg Hopkins CMA Groundwater Model. Final Model Development Report.

Sinclair Knight Merz (2010b) Wimmera CMA Groundwater Model.

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department for Water, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.