4 SURFACE WATER BALANCE – MATT GIBBS

4.1 SUMMARY

The water resources of the South East are important for South Australia. These resources support a wide array of environmental assets and industry including wine, wool, meat, dairy, forestry and timber, fishing and aquaculture, vegetables and seed production. The objective of this study is to assess the impacts of rainfall and land use change on the surface water resources available to these water uses in the Lower Limestone Coast region. This has been achieved by extending previous regional water balance studies to consider the spatial variations in the important driving processes. The water balance model adopted for this study has been implemented in a Geographic Information System framework to facilitate spatial analysis of rainfall, recharge and land use information. A similar approach has been used previously to assess the effects of large scale plantation on streamflow and water allocation in New South Wales. The difference between the rainfall input and the recharge and evapotranspiration outputs has been calculated on a small grid scale to estimate the surface runoff expected throughout the region.

To test the accuracy of the water balance model, a number of suitable catchments in the South East were identified. For all catchments considered, the results indicate that the simulated surface flow volumes fall within the range of observed flows for the corresponding annual rainfall. Given that there has been no calibration associated with the development of the water balance model, the simulated results are all within the range of historical flows, and there is not a common bias in the model results, the water balance model has been accepted for the purposes of this study.

The water balance model has been used to assess the impact of changes in land use and annual rainfall on the resulting volume of surface water in the Lower Limestone Coast region. The area covered in trees has increased over the period from 1990 to 2009, especially in the south west of the study region. The catchments contributing to Drain M are the most affected by this change in land use. Based on an average annual rainfall, the outflow from Drain M has been estimated to reduce from 140 GL/year based on 1990 land use data, to 82 GL/year based on 2009 land use data. This is a significant reduction in the available water resources, and may result in significant stresses for water users in these catchments, including water dependent ecosystems.

Different rainfall inputs to the water balance were also considered as part of this study. A relatively small change in annual rainfall was found to produce more pronounced changes in the surface runoff than expected. Again considering the Drain M outlet, 40 GL of surface flow is expected based on 2009 land use and a 10% reduction in annual rainfall, however this increases to 137 GL for rainfall 10% above the annual average. Similar increases are observed across the Lower Limestone Coast region, with flow volumes based on a 10% increase in annual rainfall 2.3 times more than those derived for a 10% reduction in annual rainfall on average.

By undertaking a similar analysis, a 10% reduction in rainfall was determined to produce a 36% reduction in streamflow across the region. This has significant implications for future climate projections, which are anticipated to be declining by up to 10% on average by the year 2030 (CSIRO, 2007). If a 10% reduction of historical annual rainfall is realised as a new annual average rainfall the reduction in surface water resources will be much more significant, in a region where water resources are already limited.

It is recommended that future work should focus on quantifying the surface water demands throughout the region for all water uses, including agricultural, industrial and environmental. The local water demands can then be compared to the expected water availability presented in this report for different rainfall and land use scenarios, to assess under which scenarios the current water requirements will be met. This will allow regions of stress to be identified, and investigated further. This further investigation should involve the development of detailed models for the smaller regions, incorporating more of the important processes that will affect both surface and groundwater availability.

4.2 INTRODUCTION

The water resources of the South East are important for South Australia. These resources support a wide array of industry including wine, wool, meat, dairy, forestry and timber, fishing and aquaculture, vegetables and seed production (Wood 2010). The current understanding of the water cycle in the Limestone Coast region was assessed by Paydar et al. (2009), and the volumes identified for the regional water balance were updated as part of the South East Water Science Review (Wood 2010). From these two studies, the average volumes of water inputs and outputs to the Lower Limestone Coast region have been quantified, and provide valuable insight into the magnitude of the processes that influence the water balance on a regional scale.

However, the regional water balance approach does not consider how the availability of water will change in both time and space within the Limestone Coast. Changes in land use would be expected to have an influence on water resources, and annual variation in the rainfall input to the system will also influence the water availability. The aim of this study is to investigate how the water balance changes based on changes in both land use and rainfall.

This report focuses on the estimation of surface water availability. Surface water is a smaller portion of the regional water balance, with approximately 200 GL of surface water observed as outflows from the system on average, compared to recharge to the unconfined aquifer estimated at 1100 GL/year on average (Paydar et al. 2009). However, surface water is still an important resource for the region, as it is necessary to sustain ecosystems in the region as well as industrial uses. Also, surface water is expected to be the most susceptible to changes in the water balance, as often surface flow only occurs once the soil profile is saturated and evapotranspiration demands are met.

Land use information from both 1990 and 2009 has been considered in the analysis, which in terms of the water balance has been used to estimate the spatial distribution of evapotranspiration. The results from this analysis can be used to identify regions where the water balance has shifted over the past 20 years, and by how much. Also, both increases and decreases in annual rainfall have been considered, to estimate the resulting change in surface water availability from these variations. The results from this study provide useful information to assist with catchment management and policy development to sustain all surface water uses in the Lower Limestone Coast region.

4.3 AIM AND OBJECTIVES

The objective of this study is to extend previous regional water balance studies to consider the influence of spatial variations in rainfall and land use on the surface water resources available in the Lower Limestone Coast region.

In order to meet this overriding objective, the specific aims of this study are:

- Investigate the ability to quantify the annual variation in surface water availability in the Lower Limestone Coast using a spatial water balance approach;
- Investigate the impact of historic changes in land use on the available surface water; and
- Investigate the impact of fluctuations in annual rainfall on the expected surface water volumes, based on current land uses.

The following section outlines the methods used to address these aims and objectives.

4.4 METHODOLOGY

The water balance model adopted for this study has been implemented in a Geographic Information System (GIS) framework, to facilitate spatial analysis of rainfall, recharge and land use information. The approach has been used previously to assess the effects of large-scale plantation on streamflow and water allocation in New South Wales (Zhang et al. 2003). The previous study has been extended in this work to also incorporate recharge, which was not considered in the NSW study. The balance between rainfall input and the recharge and evapotranspiration outputs has been calculated on a cell by cell basis over the region, where the resulting difference is assumed to be observed as surface flow out of the cell. The water balance relationship was developed by Zhang et al. (2001):

where P is precipitation, ET is evapotranspiration, R is surface runoff measured as streamflow, D is recharge to groundwater, and ΔS is the change in soil water storage. In estimating catchment average water yield, it is assumed that there is no net change in catchment water storage over a long period of time (Zhang et al. 2003). Hence, the water balance equation is rearranged to compute R, given inputs of P, ET, and D. For this study, the runoff has been computed at a scale of 250 m x 250 m grid cells, with each cell potentially adopting different values for P, ET and D. In order to determine the runoff at a location, the average runoff depth over the contributing catchment area calculated is multiplied by the catchment area to produce the volume of runoff. Catchment boundaries for the region derived by DWLBC from a 10 m DEM of the South East have been adopted for this study.

The average annual rainfall for the region has been determined as the input for precipitation. There is a natural gradient in average annual rainfall over the region, with higher rainfall in the south, and decreasing further north. The long-term average annual rainfall for the period of 1961 – 1990 has been identified for all the Bureau of Meteorology (BoM) rainfall stations within the catchment boundaries. Spherical kriging has been used to interpolate the observed point observations of annual rainfall to the 250 m grid cells used in the water balance model. The resulting rainfall dataset can be seen in Figure 4.1.

To determine the mean annual evapotranspiration (ET) for the water balance model, the following Simplified Penman-Monteith equation has been used (Zhang et al. 1999):

where w is the plant available water coefficient and E_o is the potential evapotranspiration. Hence ET is computed for each grid cell based on the mean annual rainfall, potential evapotranspiration and a parameter, w, based on the land use characteristics. To determine values for E_o, a similar approach to that used to determine the precipitation grid was used to develop a grid of pan evaporation, derived from point BoM annual average observations. The pan evaporation grid has been converted to an E_o grid using the regression relationship for Mt Gambier developed by Chiew and McMahon (1992). The resulting potential evapotranspiration dataset can be seen in Figure 4.1.

The remaining input to the evapotranspiration model is the parameter w. Zhang et al. (2001) recommended values of w based on land use, with w = 0.5 for pasture, and w = 2 for trees, both native and plantation. Two land use datasets have been considered to derive the w values. For model validation, South Australia and Victoria State Land Use datasets have been used to represent the land use in 1990. The datasets are freely available from the Australian Natural Resources Data Library, and have been re-sampled from 100 m to 250 m cells size and joined together for this study, as there are a number of cross border catchments that extend from South Australia into Victoria. Most flow records begin in the 1970s, hence the 1990 dataset has been used to represent the average land use over the period of flow records and to assess the accuracy of the water balance models.

To represent the 2009 land use in the Lower Limestone Coast region the updated dataset developed by DWLBC as part of the South East Water Science Review has been adopted. This dataset does not extend into Victoria, hence the 2009 land use dataset has also been combined with the 1990 Victorian land use information to extend the land use information to cover all catchments contributing to the study region. For both land use datasets (1990 and 2009) cells associated with trees or water bodies have been assigned a value of w = 2, the remaining cells have been assigned a value of w = 0.5. The resulting plant available water coefficient datasets, for both 1990 and 2009, can be seen in Figure 4.2.

The final input required for the water balance model is recharge. A number of methods to quantify recharge were considered. Relationships between rainfall and recharge were developed by Gibbs (2010) for locations in the Lower Limestone Coast region with a shallow watertable, where the Water Table Fluctuation method is appropriate to quantify recharge. Initially, for the remaining areas (such as the border zone and the south of the region) constant recharge values recommended by Brown et al. (2006) and Latcham et al. (2007) were adopted. However, initial water balance simulations indicated that the predicted surface runoff volumes were significantly more that that observed for the catchments adopting constant recharge values.

The definition of recharge is slightly different to that commonly used in previous studies. In this case, recharge is considered a loss from the surface water system, which is not necessarily recharge to the unconfined aquifer, especially if the watertable is a number of metres below the surface. In order to account for the difference, another term was included in the water balance model, to represent extraction from the soil profile based on the land use information (Wood 2010). However, by incorporating this extraction term simulated runoff volumes were well below observed volumes, again indicating the model formulation was not appropriate.

Finally, the rainfall recharge relationships developed as part of the South East Water Science Review were interpolated within the shallow watertable area, and extrapolated beyond this area to cover the whole Lower Limestone Coast region. Initial analysis concluded that this approach provided the most accurate representation of observed streamflow from the water balance model, and hence has been adopted for final version of the water balance used in this study. The slope and intercept values to estimate recharge based on rainfall can be found in Gibbs (2010).

A significant advantage of the water balance model developed is that there are no model parameters to calibrate, as all input data has been derived from observations in the region. To investigate the accuracy of the water balance model, a number of suitable gauging stations have been identified to compare the results. The observed annual flow volumes and rainfall depths have been computed over the year April to March, as streamflow is often observed to persist over summer based on soil moisture conditions produced by the winter and spring rainfall.

In the following section, the accuracy of the water balance model is presented, before changes in land use and rainfall are considered to estimate the impact on surface flows.

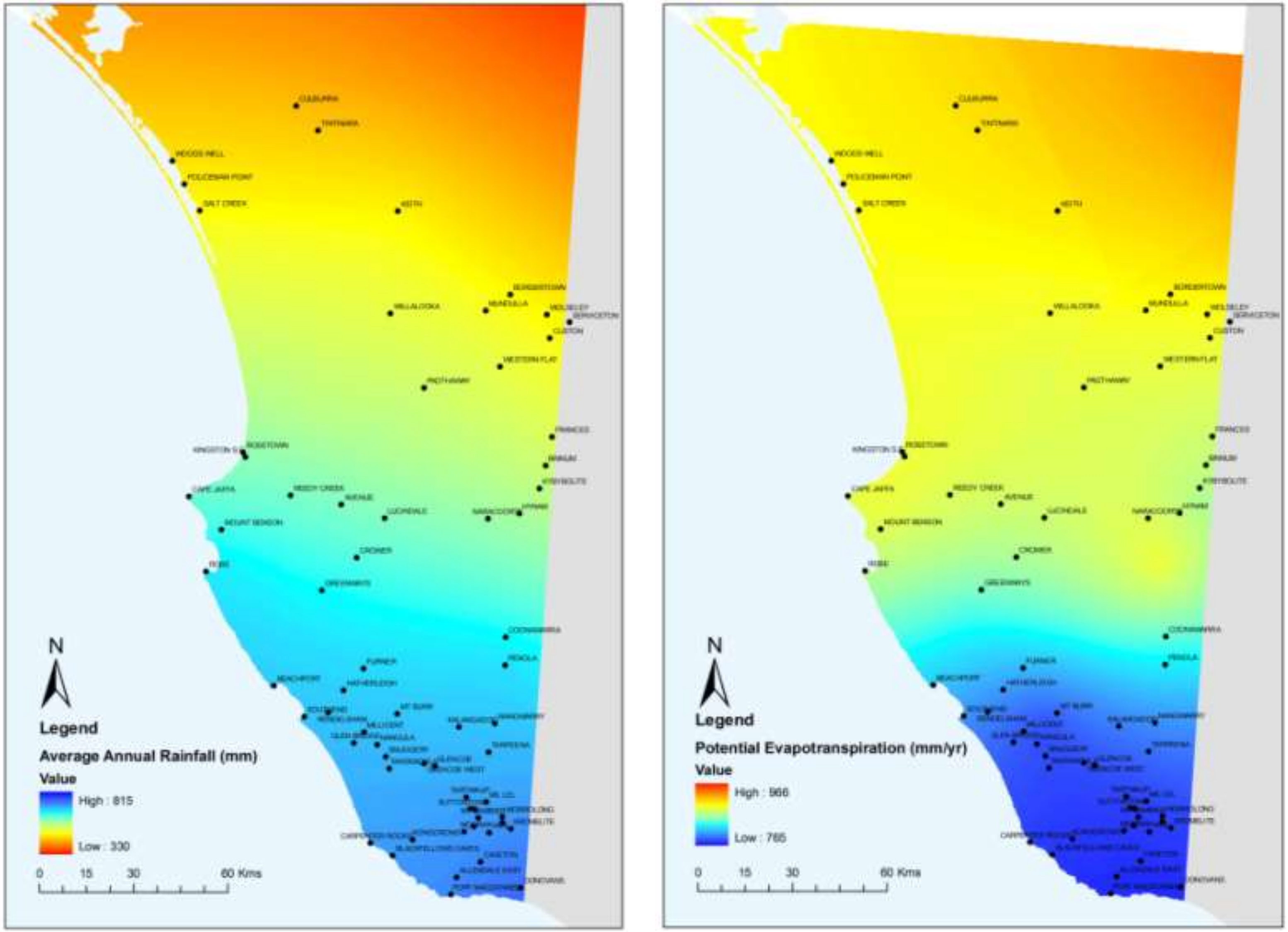

Figure 4.1 Rainfall and Potential Evapotranspiration datasets used in the model

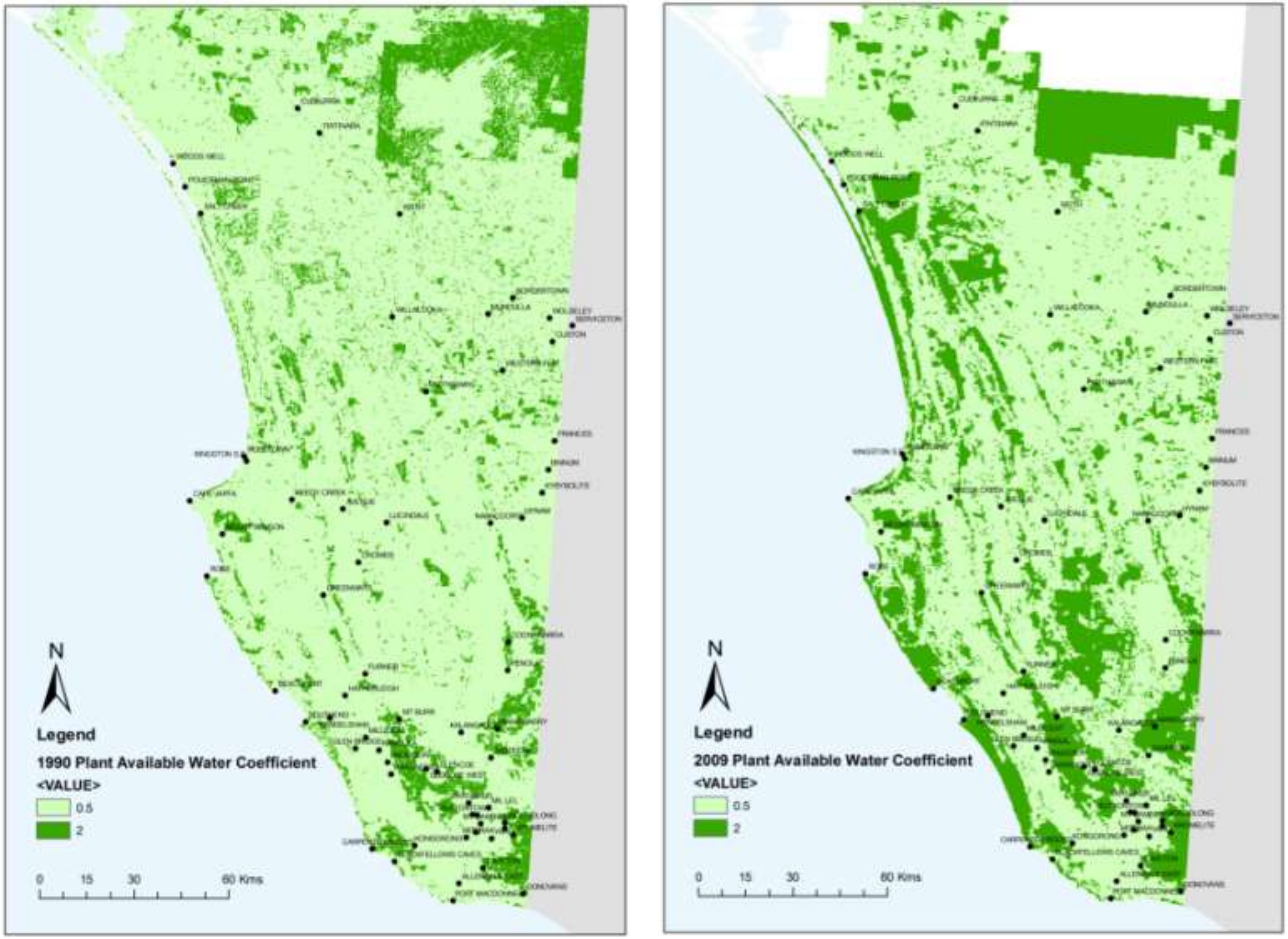

Figure 4.2 Distribution of Plant Available Water Coefficient parameter, w, based on 1990 and 2009 land use datasets

4.5 RESULTS

4.5.1 MODEL VALIDATION

As outlined in Section 3, no calibration is required for the water balance model selected for this study. To test the accuracy of the estimated annual runoff, a number of suitable catchments in the South East have been identified, which can be seen in Figure 4.3. These six catchments were selected as there is a significant flow record available for comparison, and the flow of each gauge is largely unregulated. There is a regulator at Callendale along drain M near the gauge for catchment A2390514, however this regulator has only been closed once in 1981, and possibly again in 1992. Hence, for the majority of the record this regulator does not influence the operation of the system. To the north of the catchments presented in Figure 4.3, in the Upper South East, there is an extensive drainage network that allows for diversion of water to different drains, as well as to significant wetlands storages. Hence, it is difficult to ascertain the historical flow of water for catchments further north of those selected for model validation. It should be noted that a number of the catchments considered for validation are upstream of others that have been used. For example, both A2390519 and A2390515 flow to A2390514, and all three catchments flow to A2390512. The flow records for each site have been obtained from the DWLBC Surface Water Archive.

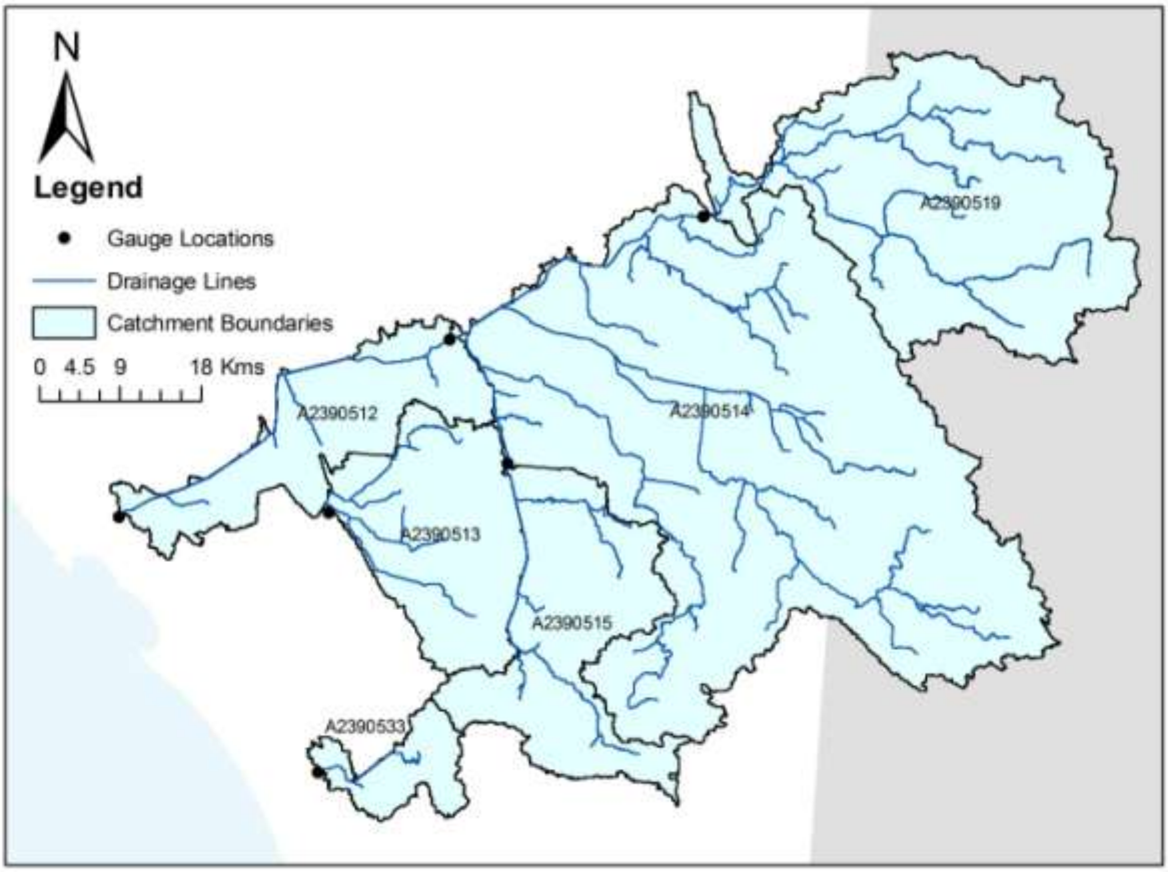

Figure 4.3 Catchments selected for water balance model validation

To estimate the evapotranspiration, the 1990 land use data has been used to determine the plant available water capacity parameter (Figure 4.2). The 1990 land use data has been used to provide an average representation of the land use over the stream flow record, most of which begin in the 1970s. The rainfall record at Naracoorte has been used for all catchments, apart from the most southerly catchment, A2309533, where the rainfall record from Tantanoola has been adopted.

The results for the comparison between simulated and observed annual volumes can be seen in Figure 4.4 and Figure 4.5, with the recorded rainfall and corresponding streamflow presented as blue diamonds for each catchment for each year, and the predicted runoff from the water balance model as the red line. Across the six catchments, the results indicate the model accuracy is acceptable, with the simulated surface flow falling within the range of observed flows. However there is large scatter in the observed runoff volumes for similar annual rainfall across all sites, indicating that annual rainfall is not the only factor that influences the observed runoff volume.

The deviation between the observed and simulated flows can be seen to change slightly across the catchments. The simulated runoff for A2390519, at Mosquito Creek, is the most accurate catchment, with the simulate flows falling close to the centre of the range of observed flows. The average flow for catchments A2390515 and A230513 is well simulated, however the model tends to over-predict the low flows and under-predict the high flows. This may be a result of the rainfall recharge relationships adopted, as these catchments are in an area that has a strong relationship between rainfall and recharge (Gibbs 2010). Hence, small recharge rates are used for low annual rainfall (which would result in higher surface flow in the water balance model), and vice versa.

For the largest catchments considered for model validation, A3290514 and A230512, the simulated flow from the water balance model is well within the range of observed flows, however the results tend to be slightly above the middle of the range of flows. Conversely, the water balance model result for the most southern catchment, A239053, tends toward the lowest observed flow records. For this catchment, this is most likely due to the extrapolated rainfall – recharge relationships overestimating the recharge for this catchment, which is close to the coast and flows into Lake Bonney, and significantly different to the region considered to develop the rainfall recharge relationships.

Given that there has been no calibration associated with the development of the water balance model, the simulated results are all within the range of historical flows for corresponding rainfall, and there is not a common bias in the model results (some catchments are slightly below the middle of the observed flows, some are slightly above) the water balance model has been accepted for the purposes of this study. In the remainder of this section, changes to the plant available water coefficient, driven by land use changes, and annual rainfall inputs, will be considered to investigate the impact on the simulated surface water availability.

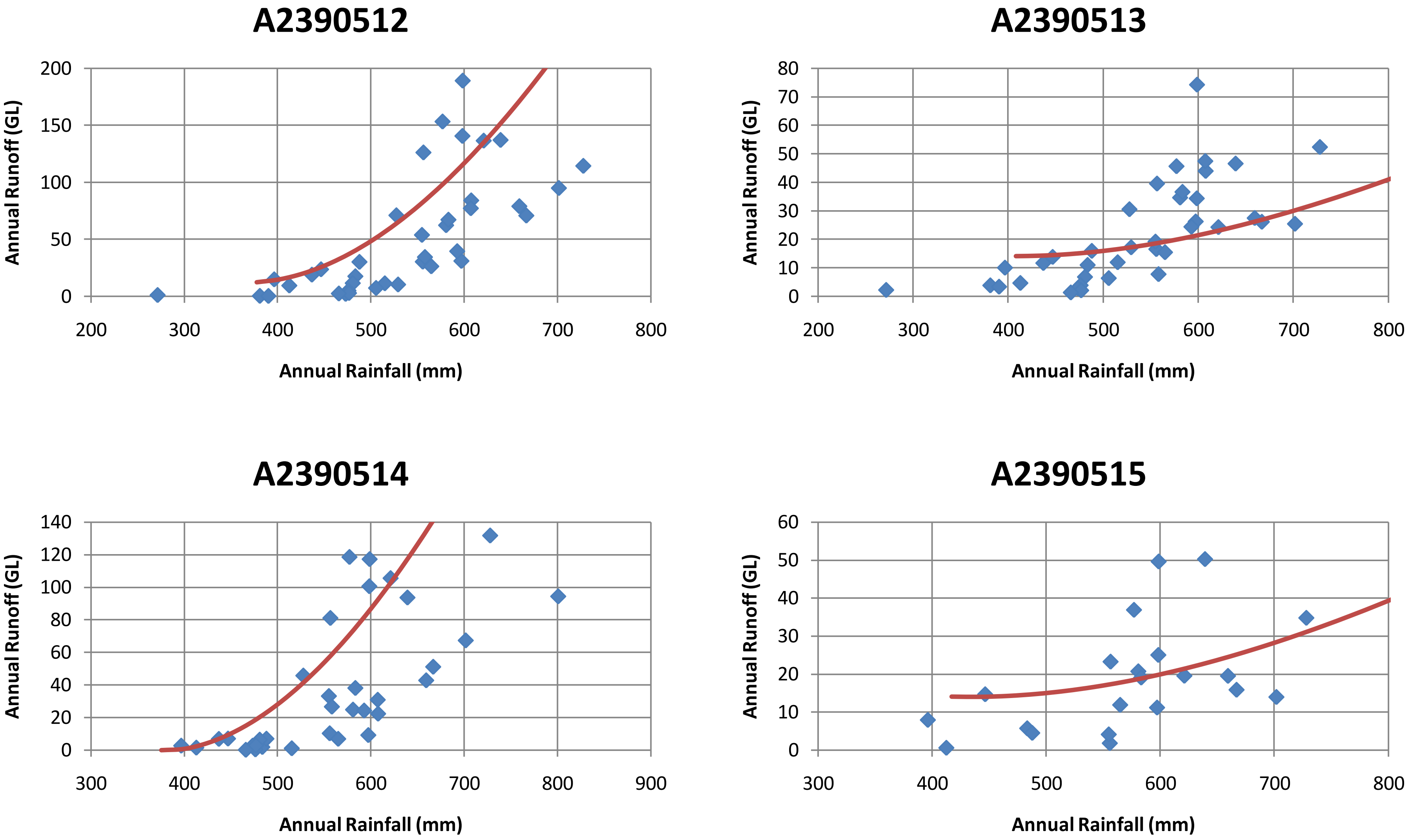

Figure 4.4 Observed annual rainfall and runoff values (blue diamonds) and corresponding water balance model predictions (red line).

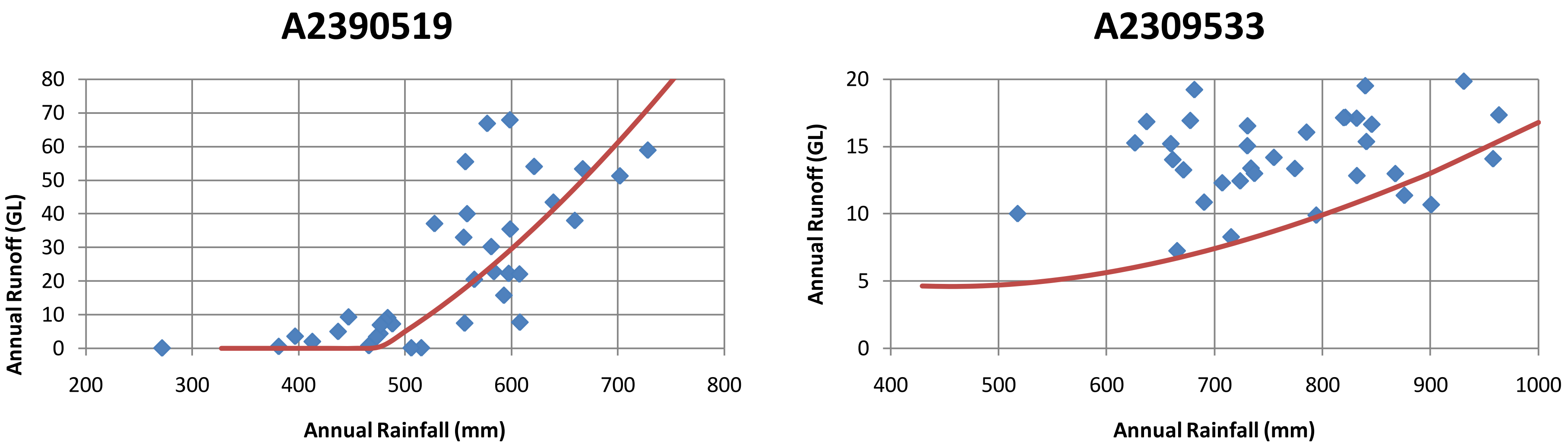

Figure 4.5 Observed annual rainfall and runoff values (blue diamonds) and corresponding water balance model predictions (red line).

4.5.2 MODEL SCENARIOS

Given the acceptable results of the water balance model developed presented in Section 4.1, in this section a comparison between surface water availability based on 1990 and 2009 land use datasets is presented, before the change in surface flows for changes in annual rainfall is considered.

4.5.2.1 Impact of a Change In Land Use

The spatial variation in the plant available water coefficient has changed significantly from 1990 to 2009, as seen in Figure 4.2. Some of the variation may be due to mapping differences, with more native vegetation represented in the more resent dataset. This is likely to be the case for the differences seen in the north west of the study region. The majority of the changes in the plant available water coefficient in the southern third of the study region are produced by the introduction of plantation forestry.

The runoff volumes predicted based on both the 1990 and 2009 land use datasets can be seen in Figure 4.6. The long-term average rainfall dataset has been used for both cases. The main change to the simulated runoff volumes can be seen toward the south west corner of the region, where a number of catchments have shifted down one or two volume categories, for example from the 20 to 35 GL, or even the 35 to 50 GL, range to the bright green 10 to 20 GL range.

The difference between the 1990 and 2009 runoff volumes are presented in Figure 4.7, as both the change in volume and as a percentage change. For the majority of the northern catchments, the change in surface water is less than 10 GL per year, or less than 20%.

The biggest decrease in the surface water volumes between 1990 and 2009 are in the southern catchments contributing to Drain M. The outlet of Drain M can be seen as the only catchment rainfall in Figure 4.7 that has a reduction of more than 35 GL/yr based on an average annual rainfall. As a percentage difference, two of the catchments that contribute to Drain M have decreased by over 50%, and the only other catchment with this magnitude of decrease is directly below Drain M, one of the catchments used for validation, A2390513.

The rainfall input and recharge output from the water balance are the same for both the 1990 and 2009 scenarios. The only difference is the plant available water coefficient grids (Figure 4.2) which are used to determine the evapotranspiration output from the water balance. A change in the parameter from $w = 0.5$ to 2 leads to an increase in evapotranspiration, and therefore a decrease in surface runoff after applying the water balance equation. The spatial water balance analysis undertaken in this study has allowed the effect of this change in land use on the volume of surface water lost from the Lower Limestone Coast region to be estimated.

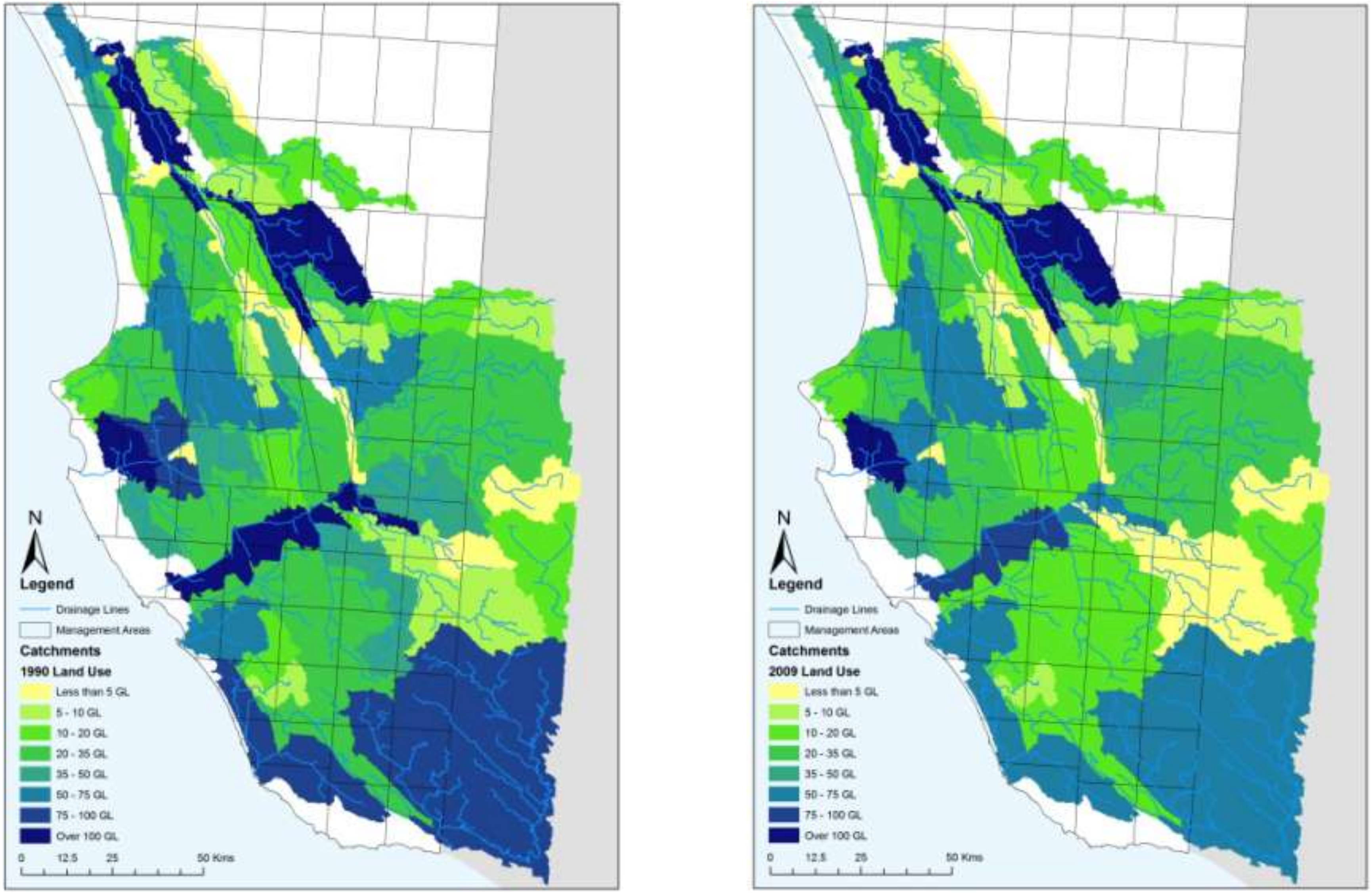

Figure 4.6 Runoff (GL) expected from average annual rainfall based on 1990 land use (a) and 2009 land use (b)

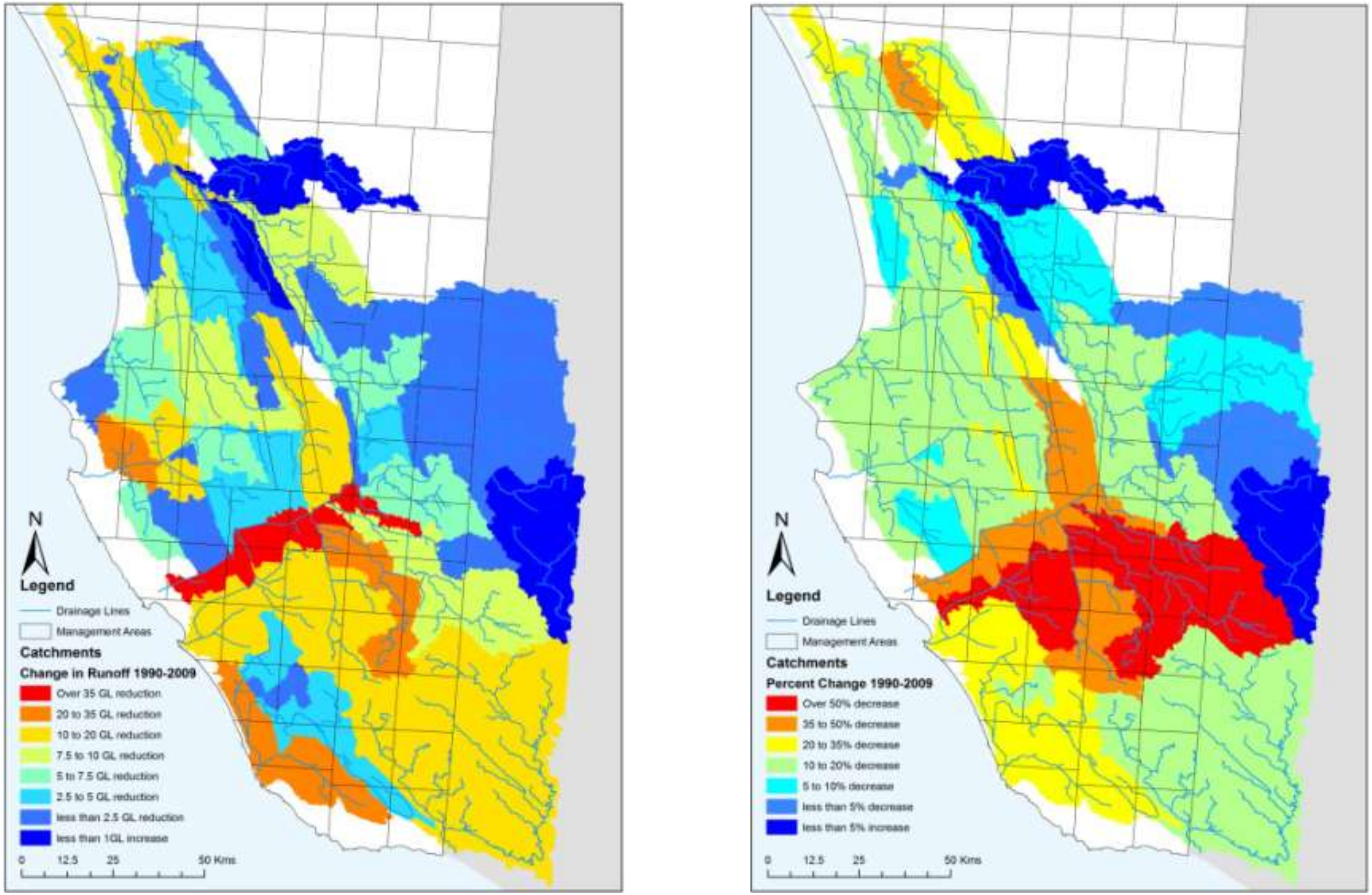

Figure 4.7 Change in runoff between 1990 and 2009 presented as a difference GL (a) and percentage (b)

4.5.2.2 Impact of a Change In Rainfall

The impact of fluctuations in annual rainfall has also been considered as part of this study. The 2009 plant available water coefficient data set has been used for all analyses in this section, and the rainfall dataset has been changed by ±10%, as well as decreased by 25% to represent a very dry year.

The streamflow volume resulting from a decrease in the annual rainfall of 25% can be seen in Figure 4.8, a decrease in the annual rainfall of 10% in Figure 4.9, and an increase in the annual rainfall of 10% in Figure 4.10. The results can be compared with Figure 4.7(b), which presents the streamflow volume resulting from an average annual rainfall based on current land use.

For a dry year, 25% below the annual average, very little streamflow is observed across the region, with many of the catchments indicating flow of less than 5 GL/year, even catchments with large contributing areas. The catchments that represent the largest contributing areas and flowing out to sea are generally in 20 to 35 GL range. The average rainfall case presented in Figure 4.7(b) show the same catchments generally have outflows of more than 50 GL, representing a considerable decline across the region.

The runoff simulated from rainfall 10% below the long-term average can be seen in Figure 4.9, and 10% above the long-term average rainfall in Figure 4.10. A significant difference can be seen between the two figures, indicating that relatively small changes in annual rainfall produce pronounced changes in the surface runoff expected. Again considering the Drain M outlet, 35 to 50 GL is expected to flow down Drain M to Beachport based on rainfall 10% below the 1960 – 1990 average, however this increases to over 100 GL based on rainfall 10% above the average. Considering the simulated values of 39 GL and 137 GL, respectively, this represents an increase by a factor of 3.5. Similar increases are observed across the Lower Limestone Coast region, with flow volumes based on a 10% increase in annual rainfall 2.3 times more than those derived for a 10% reduction in annual rainfall on average.

A slight anomaly can be seen in Figure 4.8, which suggests that the volume is reducing as flow moves downstream along Drain M. This catchment can be seen as the catchment flowing out to sea, shaded yellow in Figure 4.8, indicating flow less than 5 GL/yr. However, two catchments upstream of this catchment are shaded light green, indicating flow between 5 – 10 GL/yr from these catchments contributing to the Drain M outlet catchment. The water balance equation calculates the depth of runoff (mm) at each cell in the region. To compute the volume of flow resulting from the contributing catchment area, this area is multiplied by the average runoff depth to produce the total volume. As the average runoff is computed over a much larger area for the downstream catchment, and the runoff from the upstream cross border catchments is significantly less, the resulting calculated volume for the downstream catchment is also less for this particular case. This result is not observed in Figure 4.7, Figure 4.9 or Figure 4.10, suggesting that the recharge rates calculated based on the lowest rainfall case is too low for these two catchments, and hence the resulting surface flow is over estimated (as identified in Section 4.1).

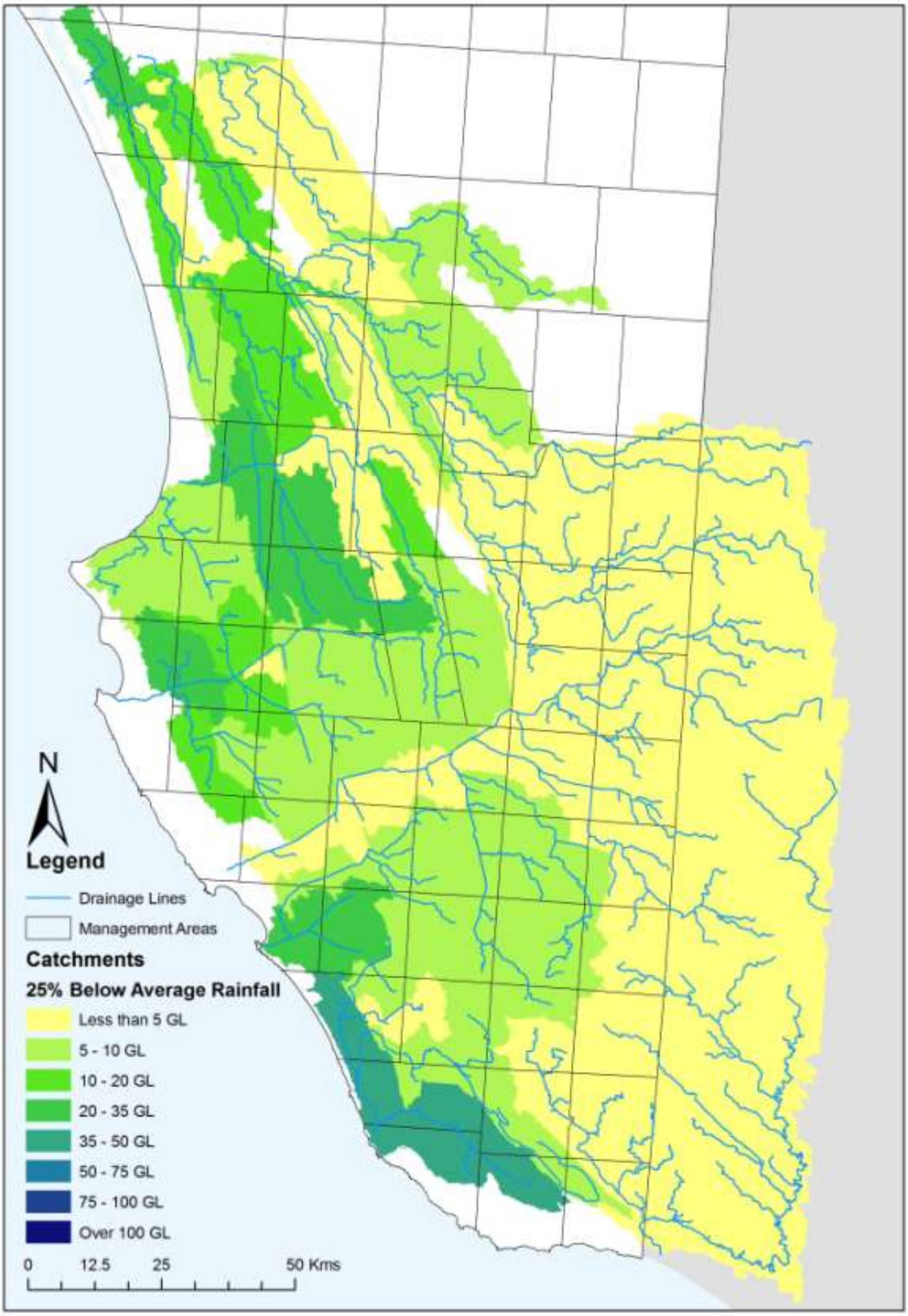

Figure 4.8 Runoff predicted for rainfall 25% below long-term average

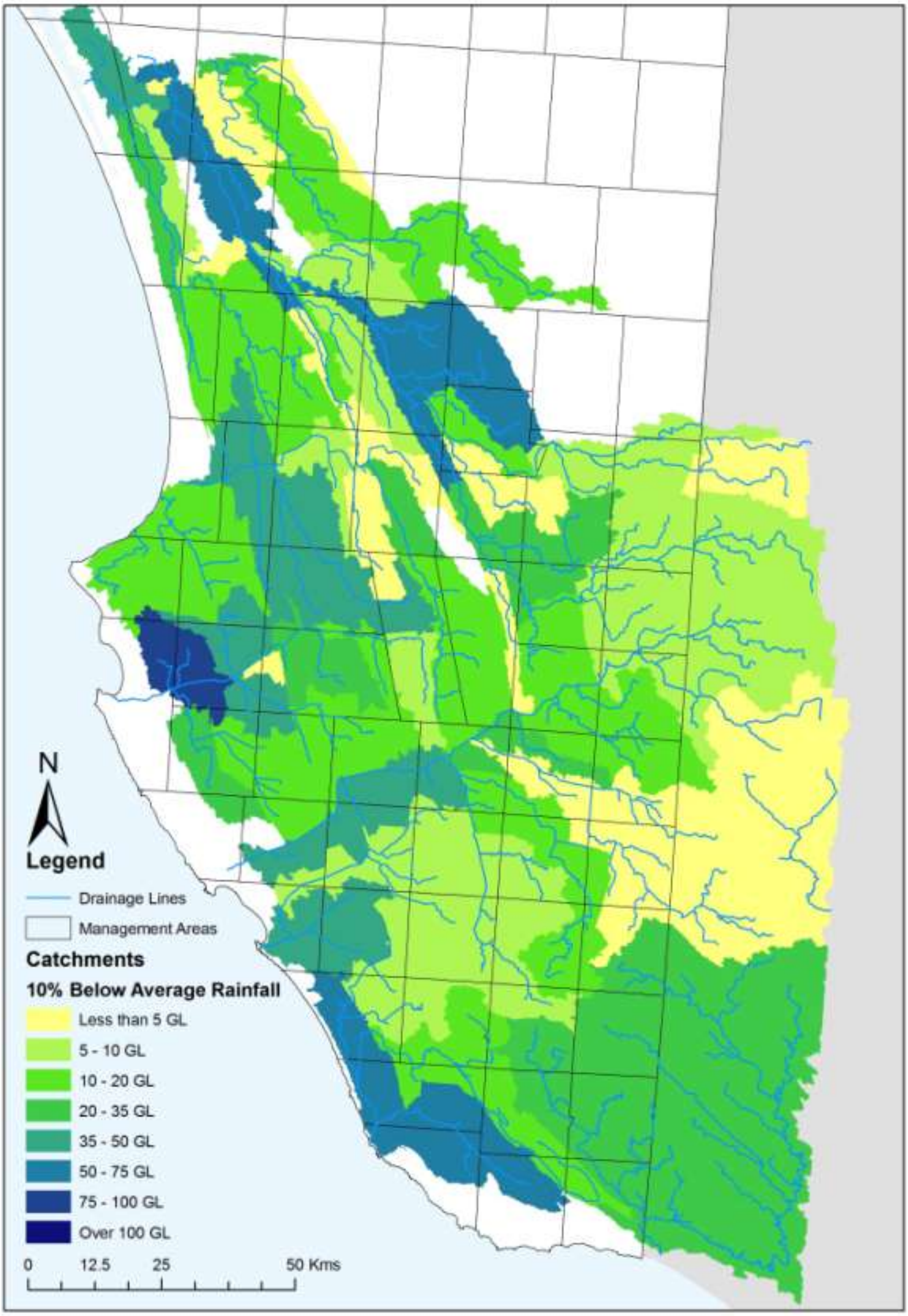

Figure 4.9 Runoff predicted for rainfall 10% below long-term average

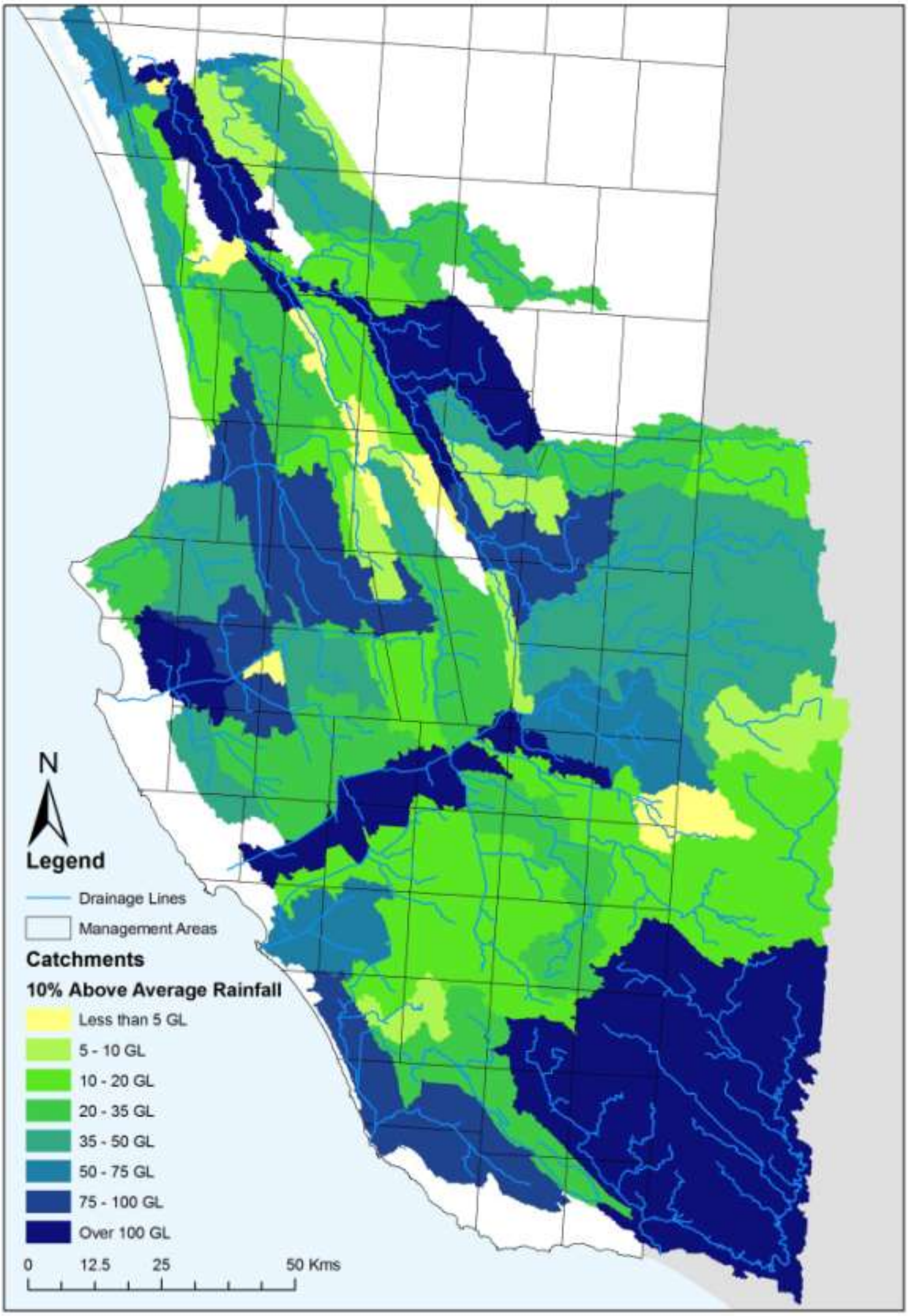

Figure 4.10 Runoff predicted for rainfall 10% above long-term average

4.6 DISCUSSION

The spatial variation in rainfall, evapotranspiration and recharge over the Lower Limestone Coast region has been considered in order to estimate the resulting surface runoff volumes over the region. The results have highlighted the significant impact changes in land use and climate have on the expected annual volume of stream flow.

The results presented in Figure 4.6 emphasise the impact a change in land use can have on the availability of surface water resources. As would be expected, a change in land use from pasture to forestry results in increased evapotranspiration, and hence reduced streamflow. This study has quantified the magnitude of this reduction, with the major land use change observed in catchments that contribute to Drain M. Based on an average annual rainfall, the outflow from catchment A2390512 reduced from 141 GL/yr based on 1990 land use data to 82 GL/yr based on 2009 land use data. This is a significant reduction in the available water resources, and may result in increased stress for water users in these catchments, including water dependent ecosystems and wetlands.

Similarly, a small change in annual rainfall produced significantly higher changes in the surface runoff. For example, averaged across the Lower Limestone Coast region, flow volumes based on a 10% increase in annual rainfall were 2.3 times more than those derived for a 10% reduction in annual rainfall. Similarly, by comparing Figure 4.7 and Figure 4.9, a 10% reduction in the annual rainfall produced a 36% reduction in stream flow volume averaged across all catchments considered. This is a significant impact in the context of a potentially drier future climate. As part of the South East Water Science Review, Thyer (2010) developed stochastic rainfall series for the South East based on a historic climate, and a 10% reduction in the mean annual rainfall to take into account climate change predictions for the year 2030 (CSIRO 2007). If these projections were realised, and the future average rainfall is 10% less than that historically on average, the water balance results indicate that the effects on streamflow are likely to be much more substantial. A reduction in surface flow volume in the order of 36% is likely to result in significant stresses for all water uses in the Lower Limestone Coast.

The water balance modelling approach adopted in this work has extended previous studies to consider the spatial variation in the process controlling the water balance across the study region. However, a number of assumptions are made in order to implement the simple water balance equation. Many of these assumptions produce the variation in the observed rainfall runoff relationships seen in Figure 4.4 and Figure 4.5. It is assumed that there is no net change in catchment water storage over a long period of time (Zhang et al. 2003). However, changes in the soil moisture would be expected to affect the runoff in subsequent years. For example, if the previous year was very wet, the soil profile would be expected to be relatively saturated for the following year, and as a result more runoff would be expected for the same annual rainfall. The opposite would also be expected to be true, where if the previous year was very dry reduced runoff would be expected the following year, as more rainfall is required to saturate the soil profile before streamflow can commence.

As part of the assumption that there is no net change in catchment water storage over a long period of time, changes in the groundwater table are not considered. However, these changes would also be expected to influence the observed streamflow, especially at locations with a shallow watertable. To consider changes in groundwater levels and soil moisture in water transport models is much more complex, and it is likely that detailed numerical models considering coupled surface and groundwater interactions and variably saturated flow on a much smaller time scale would be required to accurately represent the processes occurring for a region such as the Lower Limestone Coast, with shallow watertables and very flat catchments.

The potential evapotranspiration grid used in this study has been held constant for all analyses presented in this report. However, the mean annual evapotranspiration would also fluctuate year to year, and may be expected to be correlated with the annual rainfall, where very dry years correspond with higher than average evapotranspiration, and vice versa. Also, as part of the actual evapotranspiration model, the accuracy of the water balance model may be able to be improved by calibrating the values used for w for each land use, as this is an empirical parameter and only typical values have been adopted for this study. However, even without calibrating this parameter, the water balance results were within the bounds of the observed runoff volumes, as seen in Figures 4.4 and 4.5.

4.7 CONCLUSIONS AND RECOMMENDATIONS

This report has extended previous water balance studies to consider the impact of spatial variation in rainfall, recharge and land use information on the water balance in the Lower Limestone Coast region of South Australia. It is useful to quantify the variation in surface water volumes available within the region, not only to consider the inputs and outputs from the system as a whole as previously undertaken.

There have been significant land use changes in the South East over the period 1990 to 2009, with large areas of plantation forestry introduced to the region. The implication of this land use change in the context of the spatial water balance is an increase in evapotranspiration, and therefore a decrease in the surface runoff observed. The most significant land use changes have occurred in the southern third of the study area, in catchments that contribute flow to Drain M. Based on an average annual rainfall, the outflow from Drain M is estimated to be reduced from 141 GL/year based on 1990 land use data to 82 GL/year based on 2009 land use data. This is a significant reduction in the available water resources, and may result in significant stresses for water users in these catchments, including water dependent ecosystems.

Variation in the annual rainfall input to the water balance was also considered. For very dry years, 25% below the annual average, it is estimated that there is very little surface water available in the South East, with much of the region yielding less than 5 GL of runoff, even at catchments with large contributing areas. Relatively small changes in annual rainfall were observed to produce a much larger change in the expected surface water volumes. Averaged across the region 2.3 times more water (by volume) is expected from a year with 10% above average rainfall compared to that from a year with 10% below average rainfall.

By undertaking a similar analysis, a 10% reduction in rainfall was determined to produce a 36% reduction in streamflow across the region. This has significant implications for future climate projections, which anticipate a decline in average annual rainfall up to 10% by the year 2030 (CSIRO, 2007). If a 10% reduction of historical annual rainfall is realised as a new annual average the reduction in surface water resources will be much more significant, in a region where these water resources are already limited.

It is recommended to quantify the surface water demands throughout the region for all water uses, including agricultural, industrial and environmental. Environmental demands should include both supporting important ecosystems and watercourses as well as ensuring important processes remain at sustainable levels, such as recharge to the unconfined aquifer. The local water demands can then be compared to the expected water availability presented in this report for different rainfall and land use scenarios, to assess if, or under which scenarios, water requirements will be met. This analysis will allow regions of stress to be identified, and investigated further.

To further investigate any regions of stress identified, more advanced modelling techniques may be required. This should include incorporating the processes that produce the variability in surface runoff for similar annual rainfall, such as soil moisture, groundwater contributions and the temporal aspects of the rainfall input. For much of the region, the groundwater level is shallow, and likely to have significant interactions with the surface water processes for parts of the year. Incorporating all of these processes into a modelling framework is likely to be difficult, and fully coupled models considering the variably saturated zone may be required to quantify all surface water processes accurately.

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5 REGIONAL WATER BALANCE – Cameron Wood

5.1 INTRODUCTION

The water resources of the South East are important for South Australia. These resources support a wide array of industry including wine, wool, meat, dairy, forestry and timber, fishing and aquaculture, vegetables and seed production. Given the absence of any reliable surface water sources in the region, groundwater is the dominant source of water for agriculture and industry. Furthermore, groundwater is the primary source of water for town supply and stock and domestic use throughout the region. There are signs of groundwater resource stress in the region, and while a number of actions have been taken to address management issues, fundamental problems remain and knowledge gaps exist.

A shallow unconfined aquifer is the source of much of this groundwater. A number of investigations have been conducted in the past to investigate the groundwater resources of the South East, and these have allowed us to construct a water balance for the region which outlines the key processes.

The water balance shows an overall positive change in water storage in the region, which does not necessarily reflect recent trends in groundwater levels. Key points to consider here are:

- The components of the water balance are based on long term averages of processes such as rainfall, recharge and evapotranspiration. Groundwater level declines have only been observed over the past 10-15 years, therefore the temporal scale used in this water balance is a potential issue.
- There is some uncertainty in estimates of groundwater extraction, given the lack of metered extraction data over the long term.
- No estimates of sub-marine groundwater discharge exist, therefore a potentially large output from the system is not quantified.
- Surface water processes have been included in the balance given their acknowledged interaction with groundwater in the South East. However, the level of interaction has not been quantified, therefore assumptions have been made based on available data.
- For the entire South East, the overall difference in the water balance is considered to be within the limits of uncertainty for the data used.
- The use of a regional spatial scale masks hot spot areas.

Knowledge gaps still exist in our understanding of the system, particularly relating to temporal changes in key processes (eg. recharge, extraction for pumping etc), the degree of surface water – groundwater interaction, and the magnitude of submarine groundwater discharge. As a result, this water balance should be viewed as a preliminary assessment of water availability in the region, and more detailed modelling be conducted in the future to reduce uncertainty.

5.2 AIMS AND OBJECTIVES

The aim of this document is to provide a conceptual overview of the water cycle in the South East, with a particular emphasis on groundwater given its importance. A broad water balance will also be presented to identify key processes in the water cycle. Furthermore, limitations in the current understanding of water resources in the South East will be identified.

5.3 GEOGRAPHICAL CHARACTERISTICS OF THE SOUTH EAST OF SOUTH AUSTRALIA

The South East Natural Resources Management Region occupies approximately 28,120 km^2. The climate is typically characterised by hot dry summers and cool wet winters. Mean annual rainfall varies across the region, ranging from approximately 450 mm/y in the north to 800 mm/y in the south. Potential evapotranspiration ranges from 1400 mm/y in the south to 1800 mm/y in the north (Brown et al., 2006).

Geologically, the region is comprised of two major basins, the Murray Basin in the north and the Otway Basin in the south (Figure 5.1). Both structures are characterised by an upper unconfined aquifer (the Tertiary Limestone Aquifer — the Gambier Limestone in the Otway Basin and the Murray Group Limestone in the Murray Basin). Both formations are separated from an underlying confined aquifer (the Tertiary Confined Sand Aquifer which is the Dilwyn Formation in the Otway Basin and Renmark Group in the Murray Basin) by a clay aquitard. Overlying the unconfined aquifer throughout much of the region is a series of north-west trending Quaternary beach-dune ridge systems, separated by a series of inter-dune corridors (Love et al., 1993).

Historically, the dune ranges prevented the development of any well defined streams in the South East. Given the shallow depth to groundwater in much of the western and southern areas, this meant that much of the region was at least seasonally inundated with surface water in the form of lakes, wetlands, swamps, and groundwater-fed springs. However artificial drainage, which commenced in the 1860s, has greatly reduced the number of surface water ecosystems in the South East (Harding, 2009).

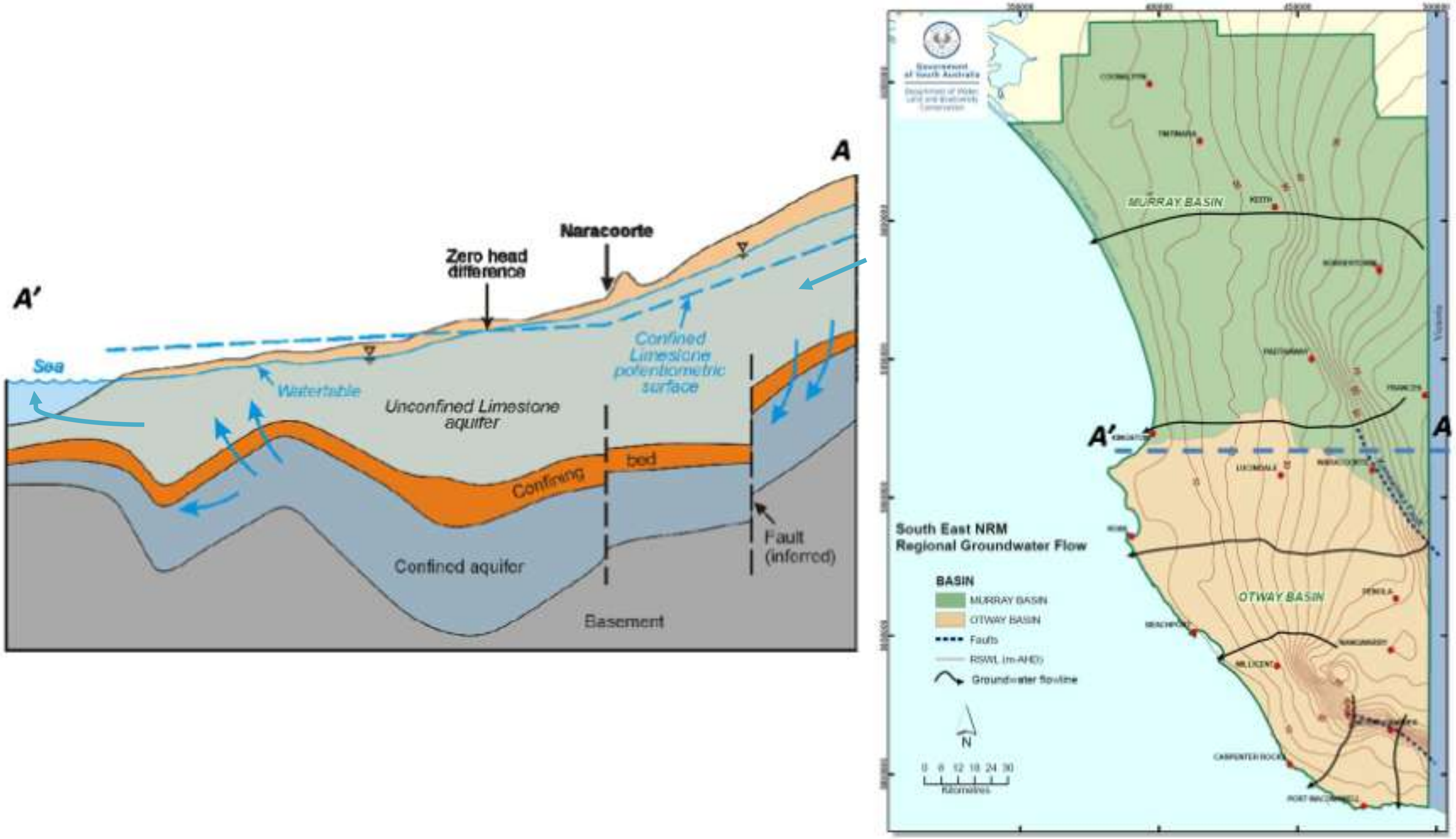

Figure 5.1 Conceptual model of groundwater flow in the South East (cross section on the left adapted from that in Paydar et al, 2009)

5.3.1 GROUNDWATER

5.3.1.1 Unconfined aquifer

For management purposes, the Tertiary and Quaternary aquifers are grouped as one unconfined aquifer unit, and are the source of most groundwater extraction in the South East region. Regional groundwater flow is to the west (towards the coastline) for much of the area and to the south to south-west in the southern half of the Otway Basin (again, towards the coast, see Figure 5.1). Love et al. (1993) presented a conceptual model of the groundwater flow system in the Gambier Embayment of the Otway Basin, including a summary of regional recharge patterns. Based on hydraulic and hydrochemical measurements along two transects parallel to the groundwater flow direction in the north and south of the area, Love et al. (1993) describe a system where flow in the unconfined aquifer is dominated by local recharge and discharge, rather than recharge in one end of the basin and lateral flow through the rest of the basin.

Recharge is predominantly through rainfall infiltration, with groundwater levels in many shallow unconfined observation wells displaying a close relationship with rainfall patterns. In the north of the area, there is a general pattern of recharge associated with topographic highs (Bridgewater Formation) and discharge in inter-dunal lows (Padthaway Formation). Local recharge patterns exist in the south of the area as well. However, the topography is flatter with less developed beach-dune sequences in the south, resulting in the local groundwater flow cells not being as deeply developed as in the north. Along the SA-Victoria border, lateral through-flow of groundwater occurs. Bradley et al. (1995) estimated between 92 and 98 GL/y of groundwater enters the South East via this process. A proportion of this volume of water used to be included in the allocation of groundwater in the Border Zone, however more recently allocations have been made based on estimates of rainfall recharge (Walker et al, 2001). The underlying principle in allocating a percentage of rainfall recharge, is that aquifer through-flow should be maintained throughout the system and salt accumulation prevented. Several studies have investigated rainfall recharge processes in the South East over the past 40 years. Generally, recharge ranges from up to 200 mm/y in the southern areas to 15 mm/y in the drier northern areas (Brown et al, 2006). Drainage from irrigation, especially in areas where flood irrigation is practiced, can also provide recharge to the unconfined aquifer, depending on the depth to groundwater.

Groundwater discharge may occur via a number of processes. Extraction of water for irrigation purposes is a significant component of discharge in the water balance. The volume of groundwater recharge that occurs in the South East is used as a guide in allocating groundwater from the unconfined aquifer. Currently, up to 90% of the estimated volume of recharge is allocated, and recharge volumes are based on long term averages (Brown et al., 2006). Currently, licensed use of groundwater for irrigation and industrial purposes is <50% of that allocated.

Discharge may also occur in groundwater springs (typically in costal areas), groundwater fed drains, and through sub-marine groundwater discharge. Direct extraction of groundwater by plantation forestry has also been acknowledged as a significant component of discharge in the southern half of the region.

Figures 5.2a and 5.2b displays the trend in groundwater levels in the South East over the period 2003-2008, and 2004-2009. As can be seen, the majority of the area shows at least some decline in overall groundwater level trend, likely due to reduced rainfall recharge in recent years, and the impacts of land use. The most pronounced declines are in the intensive irrigation areas of Stirling and Padthaway, and in areas of large scale hardwood forestry plantation (the Coles and Short management areas). In the shallower watertable areas however, particularly the west of the Upper South East, groundwater levels have shown a recovery in the past year due to greater winter rainfall.

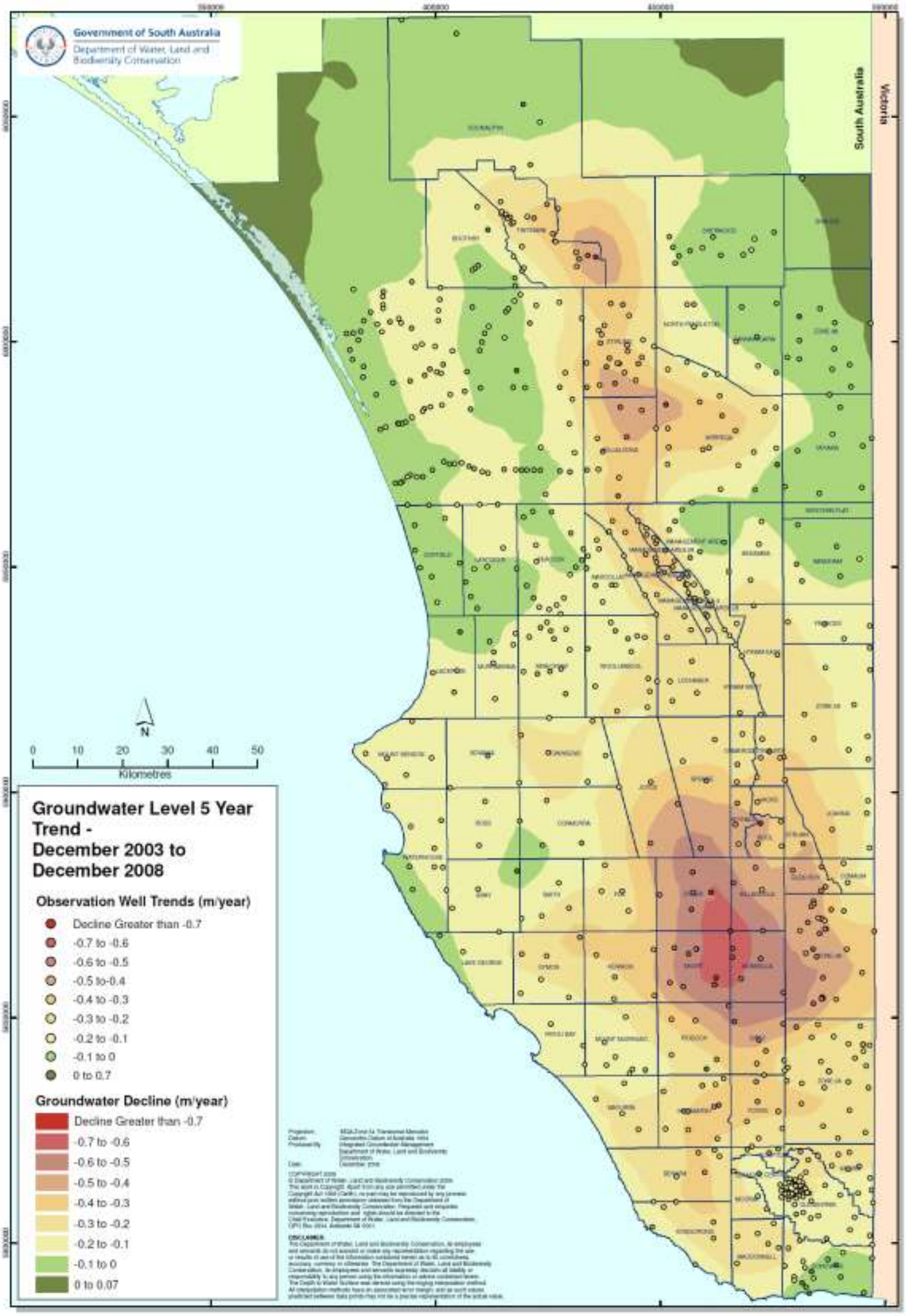

Figure 5.2a Five year trend maps for groundwater levels in the unconfined aquifer (2003-2008)

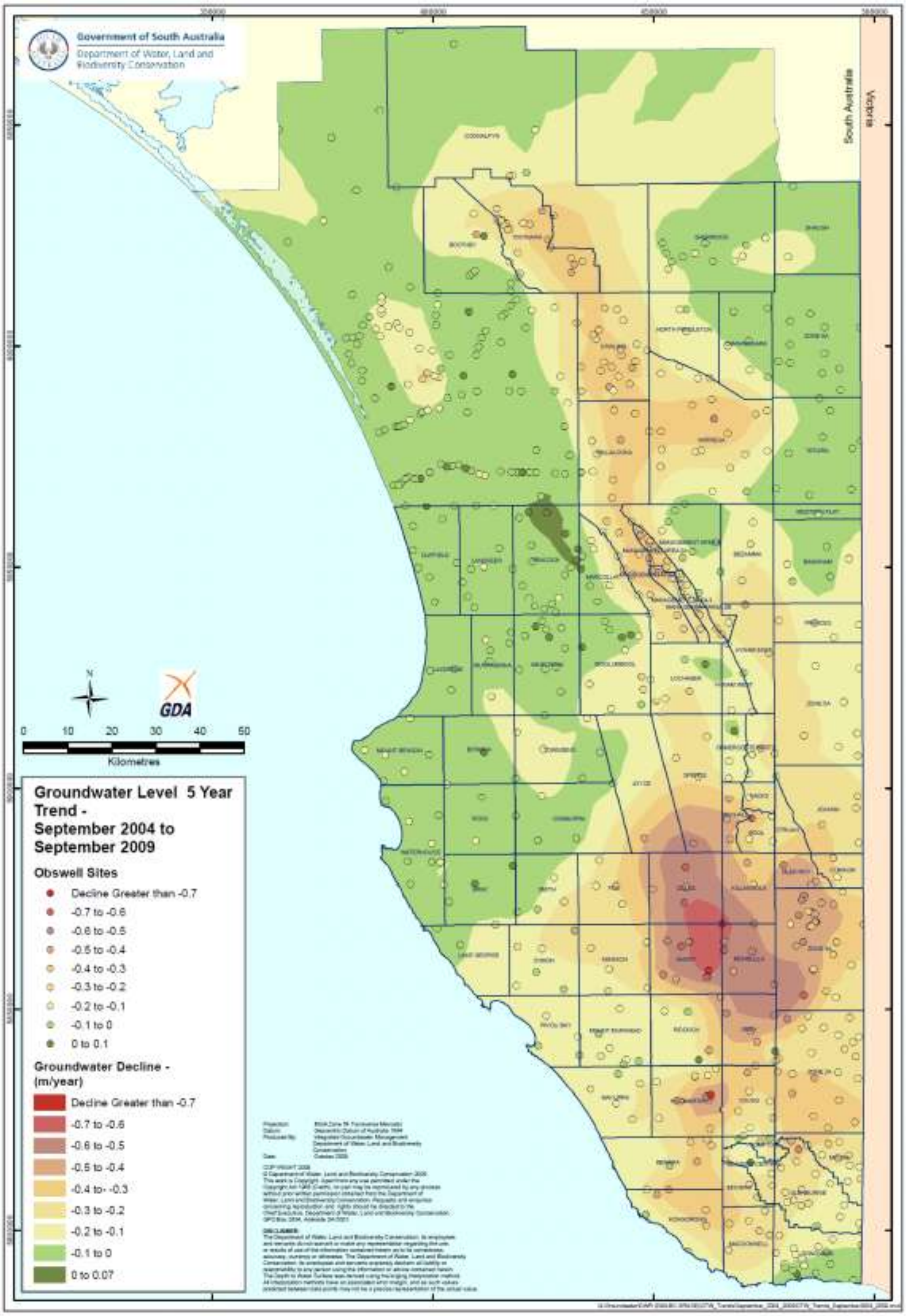

Figure 5.2b Five year trend maps for groundwater levels in the unconfined aquifer (2004-2009)

Groundwater salinity (expressed as total dissolved solids in mg/L) in the unconfined aquifer varies from ~100 mg/L to >15,000 mg/L. Figure 5.3 displays salinity measured in observation wells across the region in Spring 2009. As can be seen, groundwater salinity is generally higher in the upper South East, and lower in the Lower Limestone Coast region, however higher salinities are observed here too. The variation in groundwater salinity (amongst other factors) dictates land use across the region, with irrigated pasture and vineyards being present in areas of lower salinity, and more salt tolerant crops such as lucerne being produced in higher salinity areas.

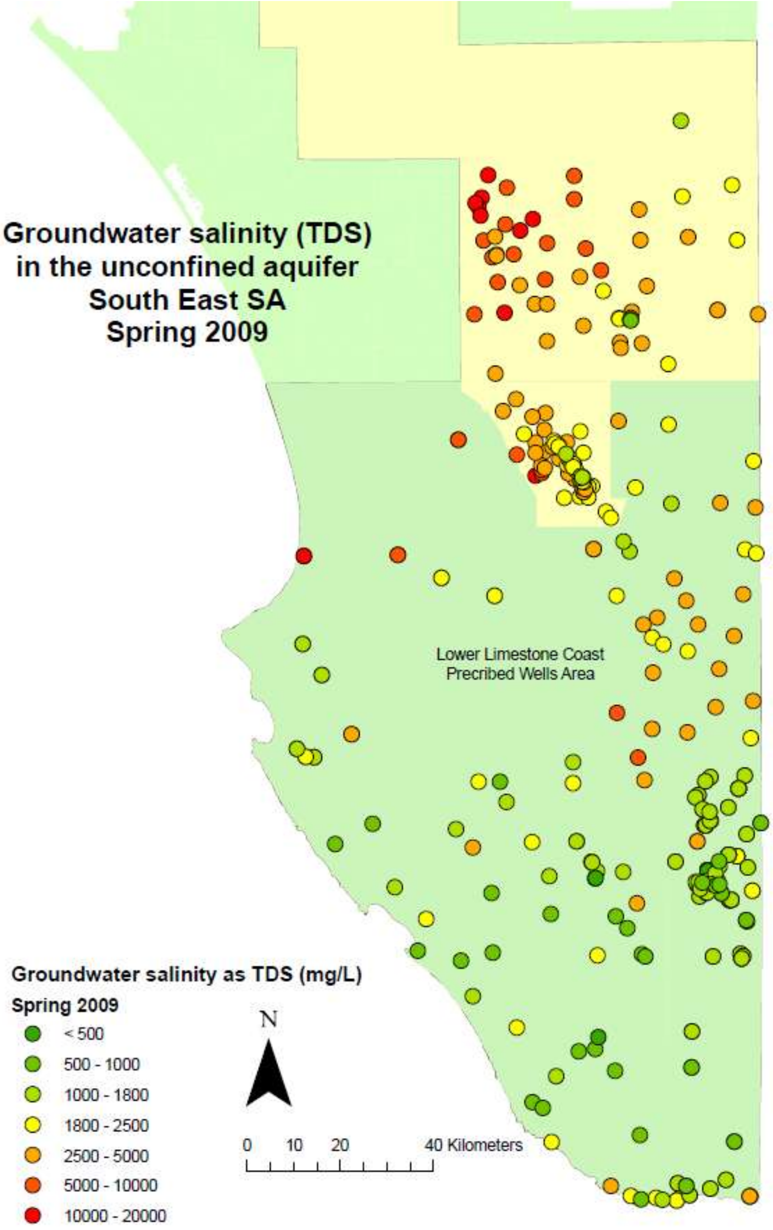

Figure 5.3 Unconfined aquifer salinity, Spring 2009

5.3.1.2 Confined aquifer

The underlying confined aquifer is dominated by lateral regional flow. Love et al. (1993) identify two possible areas where recharge to the confined aquifer is likely to occur. The first is in the north of the area, to the west of the Kanawinka Fault (between Naracoorte and Lucindale), where hydraulic data suggests there is downward leakage from the deeper part of the unconfined aquifer to the confined system. The other region corresponds to the area identified by Colville and Holmes (1972) around Nangwarry, where the unconfined and confined aquifers are close to the surface. The unconfined aquifer is characterised by a ‘sink’ in the water table in this region, whilst the confined aquifer is characterised by a groundwater mound. These features provide strong evidence for recharge to the confined aquifer in this region. Further work by Brown et al. (2001) in the Nangwarry area confirmed this, with recharge likely to be occurring via leakage through faults. Salinity levels in the confined aquifer range from ~600 mg/L to ~1900 mg/L (total dissolved solids).

Not as much is known about the confined aquifer compared to the unconfined aquifer, and allocations of groundwater from this aquifer have been based on modelling (Brown, 2000), rather than site specific recharge studies (as in the unconfined aquifer). Given this uncertainty, and taking into account the scope of this project, it is not necessary to construct a water balance for the confined aquifer.

5.4 SURFACE WATER

Approximately 660 km^2 of the South East is classified as being surface water. This includes wetlands, swamps, lakes and other features (Paydar et al., 2009). In many cases, these water bodies are discharge points for creeks and drains. Surface water flows into the region through a number of ephemeral creeks with catchments extending into Victoria. These include Morambro Creek, Naracoorte Creek, Mosquito Creek, Nalang Creek and Tatiara Creek. The mean annual flow into the region from these creeks is ~18GL (Paydar et al,. 2009). These creeks generally discharge into swamps and runaway holes, but may spill further into the western regions in flood years.

Given that most of the region has no natural outlet for surface water, a drainage system comprising more than 2000km of constructed drains has been constructed to channel surface water out of the region. The largest of these drains is Drain M which flows from Bool Lagoon near Naracoorte, and discharges to the sea near Beachport, with a mean annual flow of ~ 28 GL. Some of the drains are also constructed to intercept saline groundwater and remove it from the area. South of Mount Gambier there are a number of creeks and drains including Eight Mile Creek and Piccaninnie Ponds, which receive groundwater discharge directly through springs. These spring-fed creeks also discharge to the sea.

The extent of surface water groundwater interactions in the South East has not been quantified, however initial work estimates that there is a high potential for interaction in at least 45% of the regions wetlands (Sheldon, 2009).

5.5 METHODOLOGY

5.5.1 WATER BALANCE

As outlined above, little information exists to construct a reliable water balance for the confined aquifer. However, sufficient data exists to construct one for the unconfined aquifer, which is the most utilised of the two aquifers. Sufficient data also exists to describe the surface water processes as part of this balance (even though the degree of interaction between surface water and groundwater has not been quantified). Figure 5.4 conceptualises and Table 5.1 summarises this information.

It is important to note that this water balance does not encompass the entire South East NRM Region, but only those areas where resources are prescribed and data is available (see Figure 5.5). Also worth noting is that this water balance differs from previous water balances such as that presented by Paydar et al (2009) in its emphasis on groundwater. For example, Paydar et al (2009) considered the ‘control volume’ for their water balance to be the un-saturated zone (the area between the ground surface on the watertable), and hence groundwater extraction was considered an input, as it contributed water to the un-saturated zone. In this water balance however, the control volume is designated as the unconfined aquifer system, as well as overlying surface water processes (given their acknowledged interaction with groundwater). Because of this, the water balance looks somewhat different. For example, Paydar et al. (2009) included rainfall and evapotranspiration over the entire land surface in their estimates, however these have not been included in this water balance. Rather groundwater recharge is included, because recharge estimates account for evapotranspiration of rainfall from the land surface. Rainfall on and evaporation from surface water bodies is included though, as areas covered by surface water are not included in the spatial up-scaling of recharge rates (Brown et al., 2006).

In Figure 5.3, two processes are shown as unknowns:

1. Lateral groundwater inflow/outflow
2. Inter-aquifer leakage

While estimates of lateral groundwater inflow exist (Bradley et al. 1995), lateral outflow and off-shore or submarine groundwater discharge has not been quantified. Given the discrepancy that would be induced by including lateral inflow and not outflow, both have been left out of the water balance. Likewise, inter-aquifer leakage has not been quantified, and therefore has been left out of the balance. It should be noted however that this process may be an important source of recharge to the confined aquifer in some areas (eg. leakage through faults in the Nangwarry area).

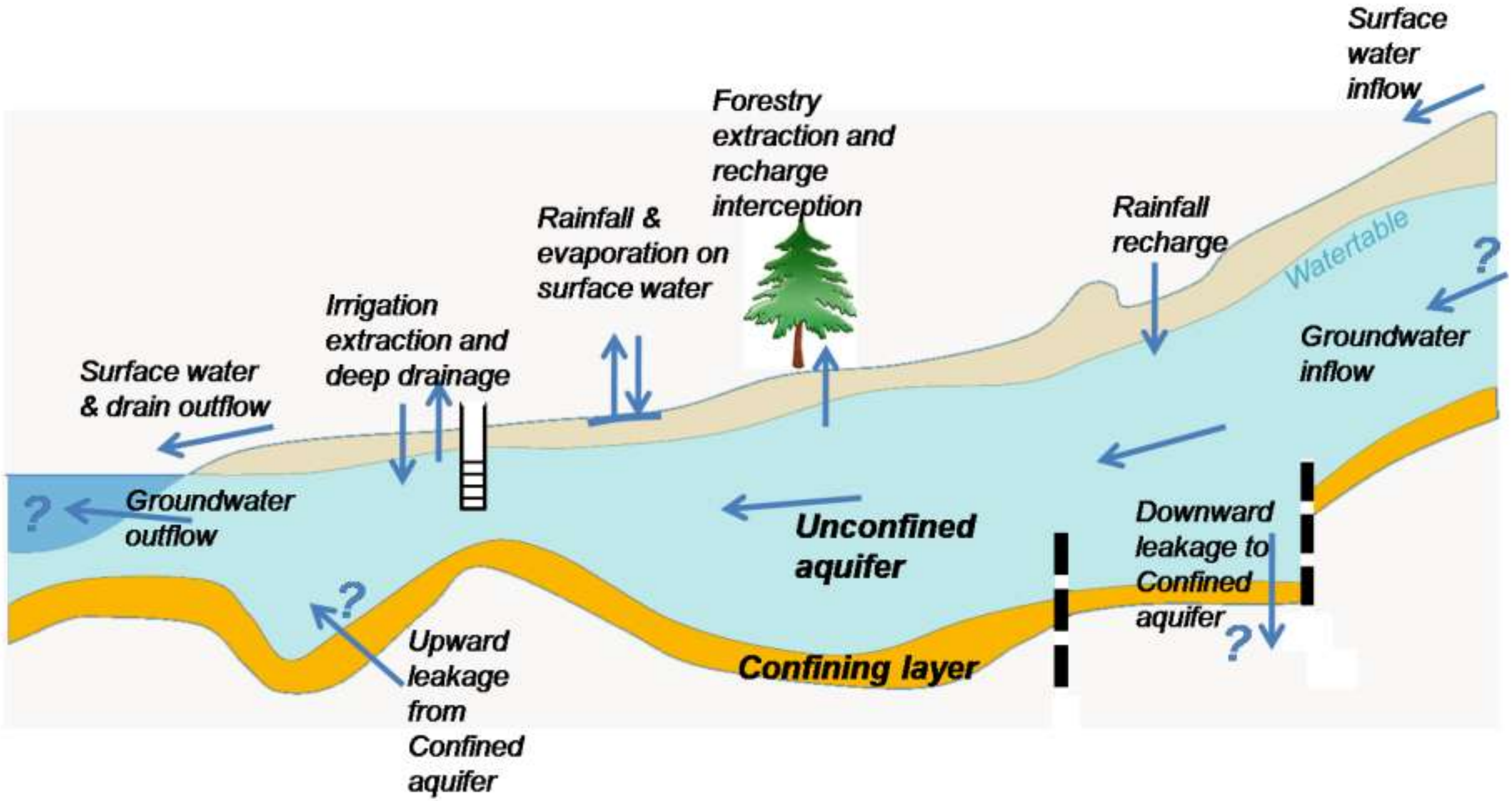

Figure 5.4 Conceptualisation of key processes in the water balance for the Unconfined aquifer and surface water features in the South East

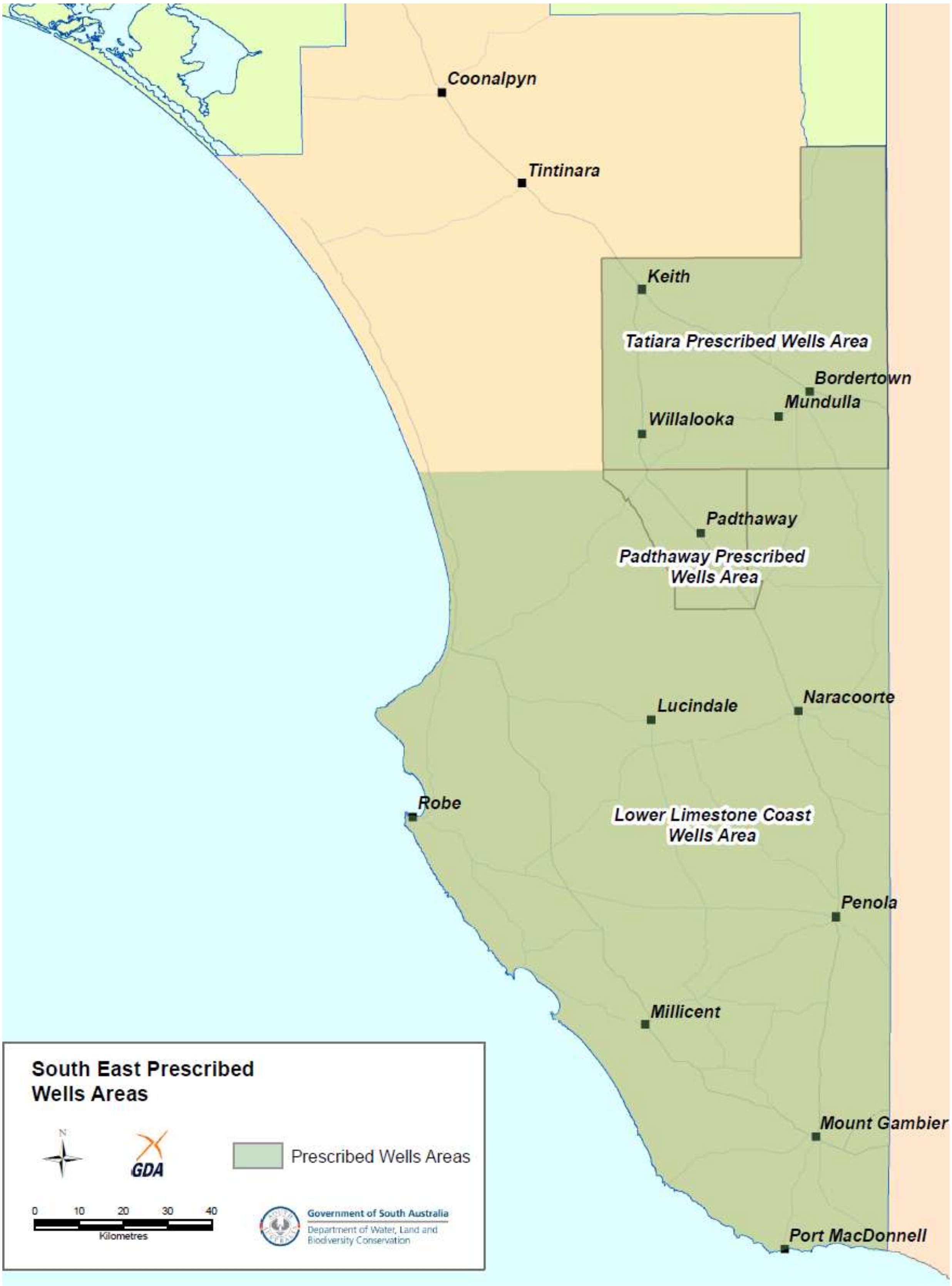

Figure 5.5 Prescribed Wells Areas in the South East that the water balance applies to

Table 5.1 Processes quantified in the water balance, their sources, and the assumptions made in their inclusion

	Process	Source	Comments
Inflows	Recharge	Brown et al (2006)	Estimated from a combination of methods including water-table fluctuations and hydrochemistry. Represents long-term average recharge, and doesn't account for temporal differences (ie. reduced recharge in low rainfall years).
	Surface water inflows	Paydar et al (2009)	Based on mean annual total flow from Mosquito Creek, Naracoorte Creek, Morambro Creek, Nalang Creek and Tatiara Creek. Doesn't account for temporal differences (ie. low rainfall years)
	Drainage from flood irrigation	Latcham et al (2007)	Estimates in Latcham et al (2007) are based on full-use of groundwater allocations. The figure reported here has been scaled back based on Hodge's (2009) estimate of groundwater use vs. allocation.
	Rainfall on surface water bodies	Paydar et al (2009)	Estimate based on area covered by surface water and long term average rainfall for the region reported in Paydar et al (2009). Rainfall on other land types is not included, as recharge estimates take into account rainfall and evapotranspiration from other land uses.
Outflows	Groundwater extraction for pumping	Hodge (2009)	Some of this data comes from metered (ie. measured) use, while some is estimated based on the area of land irrigated and theoretical crop water requirements. The estimates present a limitation, however with more metered data in the future this will improve.
	Stock and domestic use	Latcham et al (2007)	Estimate, stock and domestic use is not metered, however it is assumed to be a relatively small component of the water balance in much of the South East, and therefore not as important as other processes.
	Evaporation from surface water bodies	Paydar et al (2009)	Evapotranspiration from other land uses is not included, as the inclusion of groundwater recharge as an input instead of rainfall essentially accounts for this (ie. evapotranspiration of rainfall prior to recharge is included in the estimates of recharge).
	Discharge from groundwater springs	Paydar et al (2009)	Discharge from groundwater-fed springs on the coastline south of Mount Gambier (eg. Ewens Ponds, Piccaninnie Ponds). Numbers are based on long term averages and sub-marine groundwater discharge is not accounted for.
	Discharge from surface water drains	Paydar et al (2009)	Discharge from surface water drains in the western regions. This is a long term average and doesn't account for temporal differences.
	Interception of recharge by plantation forestry	DWLBC (2010)	Based on area of land covered by plantation forestry, and assuming 83% of recharge is intercepted under softwoof plantations, and 78% under hardwood plantations.
	Direct extraction from plantation forestry	DWLBC (2010)	Based on the proposed management accounting assumption that forestry does not extract groundwater >6m below the ground surface. Groundwater levels from June 2004 are used.

5.6 RESULTS

Table 5.2 gives the water balance for the Prescribed Wells Areas in the South East region shown in Figure 5.5. Given that the data used to populate the water balance are derived from estimates, sensitivity bounds of ±20% are given. As can be seen, the water balance shows a net gain in water, which does not reflect the declining groundwater level trend in the region. For the entire South East region, the difference between inputs and outputs is <10% of either total inputs or total outputs. Given that the uncertainty in inputs or outputs is at least 20%, the difference can be considered to be within the limits of uncertainty. More specific reasons for the difference between input and outputs are discussed in the following section of the report.

Table 5.2 Water balance for the South East of South Australia

	Process	**80% Volume (GL)**	**100% Volume (GL)**	**120% Volume (GL)**
Inflows	Recharge	1,102	1,378	1,653
	Surface water inflows	14	18	22
	Drainage from flood irrigation	26	32	38
	Rainfall on surface water bodies	318	397	476
	Total inflows =	**1,460**	**1,825**	**2,189**
Outflows	Groundwater extraction for pumping	332	415	498
	Stock and domestic use	15	19	23
	Evaporation from surface water bodies	617	771	925
	Discharge from groundwater springs	78	97	116
	Discharge from surface water drains	85	106	127
	Interception of recharge by plantation forestry	159	199	238
	Direct extraction from plantation forestry	85	106	127
	Total outflows =	**1,371**	**1,713**	**2,054**
Balance	**Inflows – outflows =**	**89**	**112**	**135**

Table 5.3 gives a separate water balance for the Lower Limestone Coast Prescribed Wells Area (shown in Figure 5.4). As with the water balance for the entire region, a gain in water is shown. Again, this difference is within the limits of uncertainty.

Table 5.3 Water balance for the Lower Limestone Coast Prescribed Wells Area

	Process	80% Volume (GL)	100% Volume (GL)	120% Volume (GL)
Inflows	Recharge	1,004	1,256	1,507
	Surface water inflows	14	15	18
	Drainage from flood irrigation	18	23	28
	Rainfall on surface water bodies	247	309	371
	Total inflows =	**1,283**	**1,603**	**1,924**
Outflows	Groundwater extraction for pumping	214	268	322
	Stock and domestic use	13	17	20
	Evaporation from surface water bodies	481	601	721
	Discharge from groundwater springs	78	97	116
	Discharge from surface water drains	79	99	119
	Interception of recharge by plantation forestry	159	199	238
	Direct extraction from plantation forestry	85	106	127
	Total outflows =	**1,109**	**1,387**	**1,663**
Balance	**Inflows – outflows =**	**174**	**216**	**261**

5.7 DISCUSSION

The water balances presented in Tables 5.2 and 5.3 Show an overall positive change in water storage in the region. This does not reflect recent trends in groundwater level in the unconfined aquifer across the entire region, and there are a number of reasons for this. Inputs from recharge are based on estimates that reflect long term averages of groundwater recharge, and don't account for year to year variation in rainfall and recharge. Therefore, the recharge volume cited here is likely to be an overestimate, given the groundwater trends that are currently being observed. Recharge estimates used previously to those given in Brown et al. (2006) are lower, and result in a deficit in the water balance if used. Smerdon (2009) acknowledged this in a review of the Lower Limestone Coast Water Allocation Plan, and suggested that recharge values be updated regularly to reflect climate conditions. Given this temporal variation, Smerdon (2009) also recommended taking a precautionary approach to allocating groundwater based on recharge estimates. Currently in the South East, up to 90% of the estimated recharge volume is allocated, however Smerdon (2009) suggests this percentage should be 'significantly lower.' This is considered a valid recommendation, given that currently groundwater use from the unconfined aquifer is <50% of that allocated, and adverse trends are still being observed.

Furthermore, the regional approach taken in developing the water balance neglects to highlight specific management areas that are considered to be over-allocated (eg. the Coles and Short management areas as shown in Latcham et al., 2007). A more detailed analysis of groundwater availability in the context of water quality (eg. salinity) is not included, but should be taken into account when considering groundwater availability.

Other limitations in the water balance relate to groundwater extraction. While metered groundwater extraction will provide more accurate estimates of groundwater extraction in the future, the currently used estimates of groundwater extraction may influence the accuracy of the water balance. The degree of surface water – groundwater interaction is also poorly understood, as is the role of lateral groundwater through-flow in sustaining water levels throughout the region.

Addressing these knowledge gaps would involve examining temporal changes in the water balance across the entire region. This would be best achieved with a numerical groundwater model for the region. Currently, groundwater models in the South East have been developed based around specific issues (eg. Padthaway, Bakers Range and Coles-Short area, Tatiara), but these have already provided useful information regarding the conceptualisation of groundwater recharge and extraction for pumping (ie. over-estimates in recharge and under-estimates in extraction). The development of a model for the South East, or a suite of models, along with on-going monitoring and meter reading on extraction wells, would help refine estimates of recharge and extraction, and allow for assessment of their temporal differences. It would also improve our understanding of the importance of lateral groundwater through-flow, and how changes in the water table in one area may affect the groundwater resources in other areas.

5.8 CONCLUSIONS AND RECOMMENDATIONS

A brief review of the key water processes in the South East of South Australia has been conducted. The review has placed an emphasis on groundwater processes, given their regional importance. A water balance for the South East has been constructed based on available data. It has shown that:

- The water balance displays a net gain in water storage
- This does not reflect current trends (groundwater level decline in much of the region)
- The main reason for this relates to the data being used reflecting long term averages, rather than more recent trends
- A precautionary approach of allocating less than 90% of estimated recharge be considered in the future development of groundwater policy

It is recommended that this water balance be used as a guide for conceptualising key processes, and as a preliminary assessment of the water resources of the South East. More detailed modelling will be required in the future to help reduce uncertainty in quantifying key processes.

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